Cenozoic Exhumation of the Southern British Isles*

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Abstract

Outcropping rocks across southern Britain were exhumed from up to 2.5 km depth during Cenozoic times. This has been widely attributed to Paleocene regional uplift resulting from igneous underplating related to the Iceland mantle plume. Our compilation of paleothermal and compaction data reveal spatial and temporal patterns of exhumation showing little correspondence with the postulated influence of underplating, instead being dominated by kilometer-scale variations across Cenozoic compressional structures, which in several basins are demonstrably of Neogene age. We propose that crustal compression, due to plate boundary forces transmitted into the plate interior, was the major cause of Cenozoic uplift in southern Britain, witnessing a high strength crust in western Europe.

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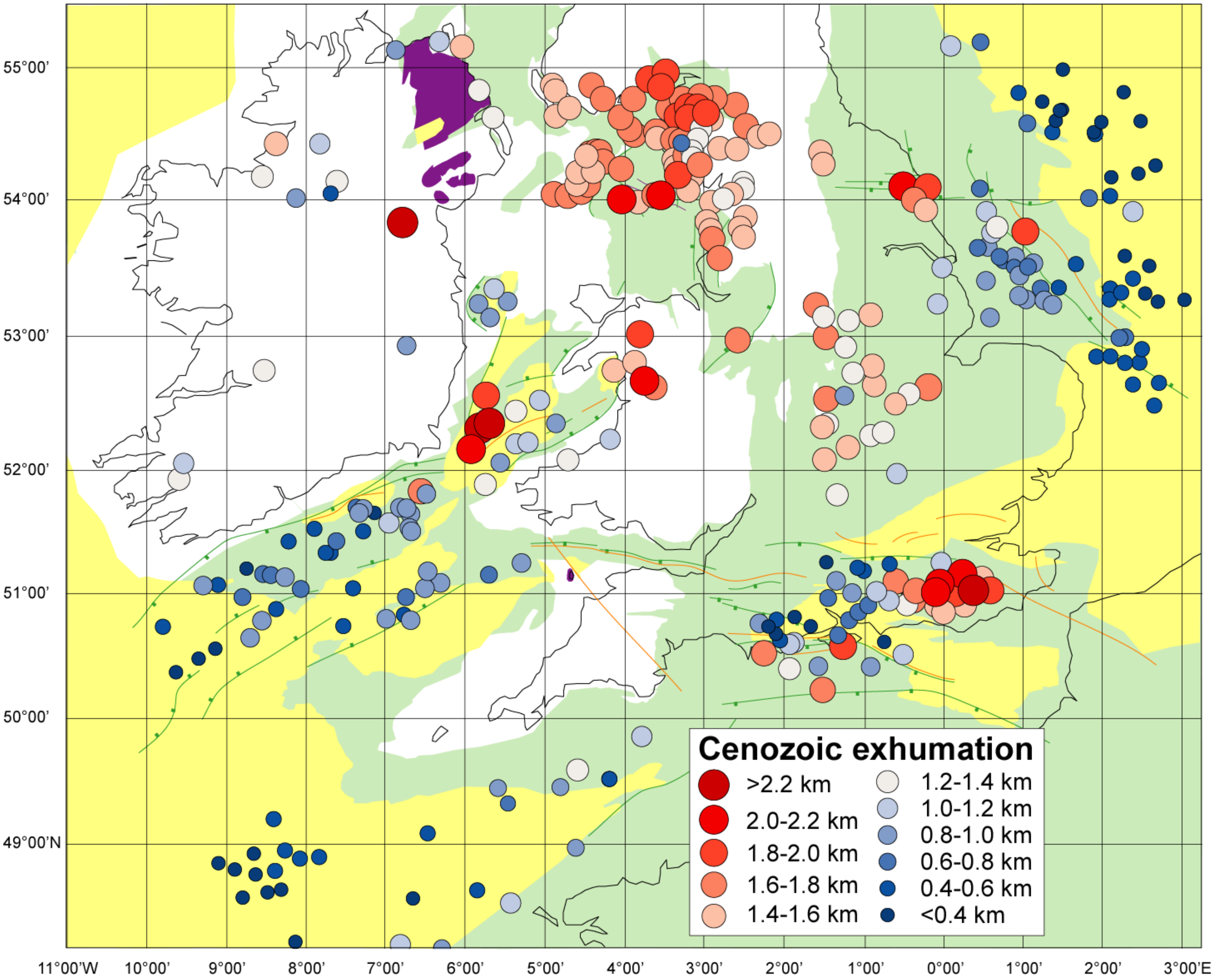
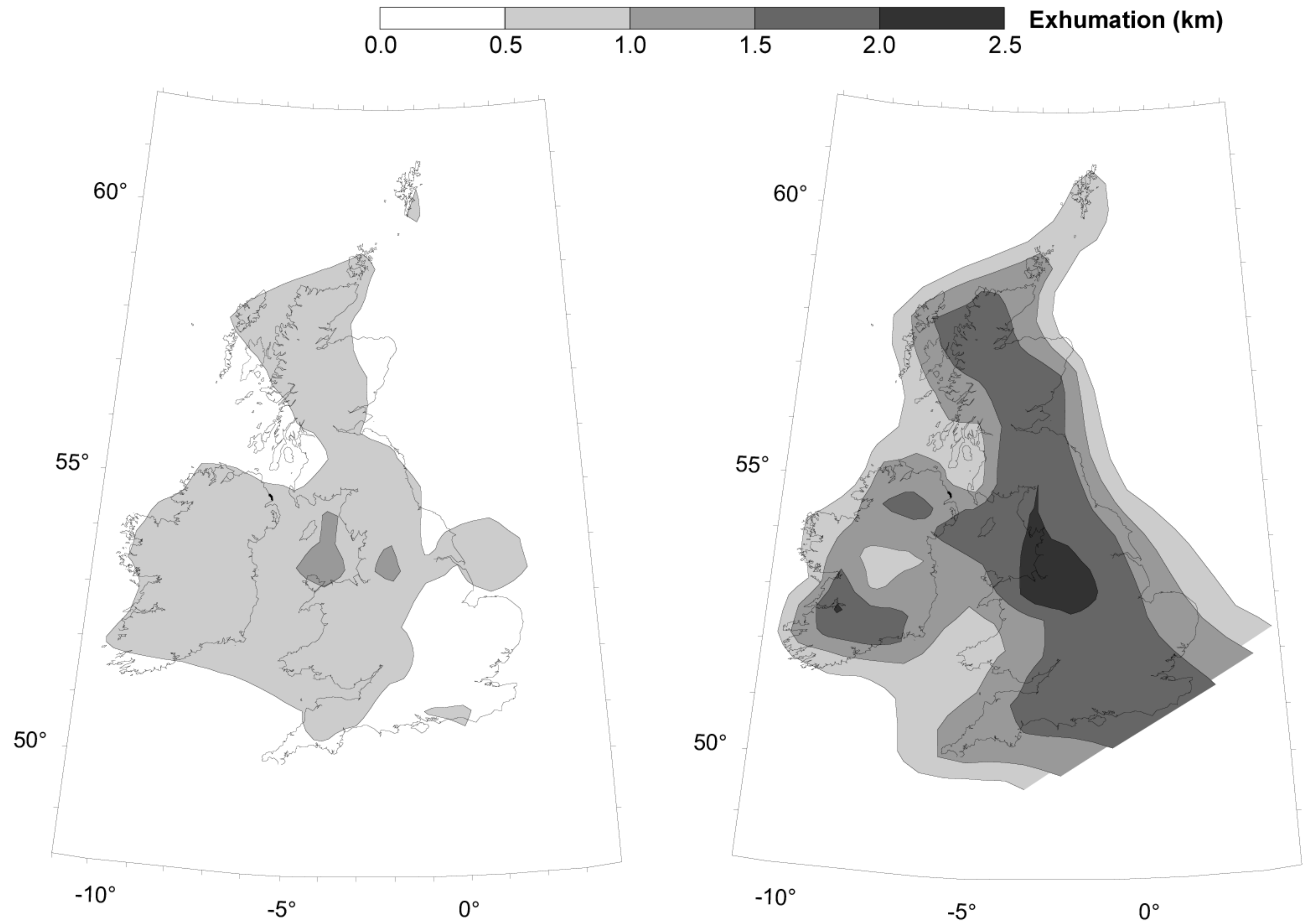
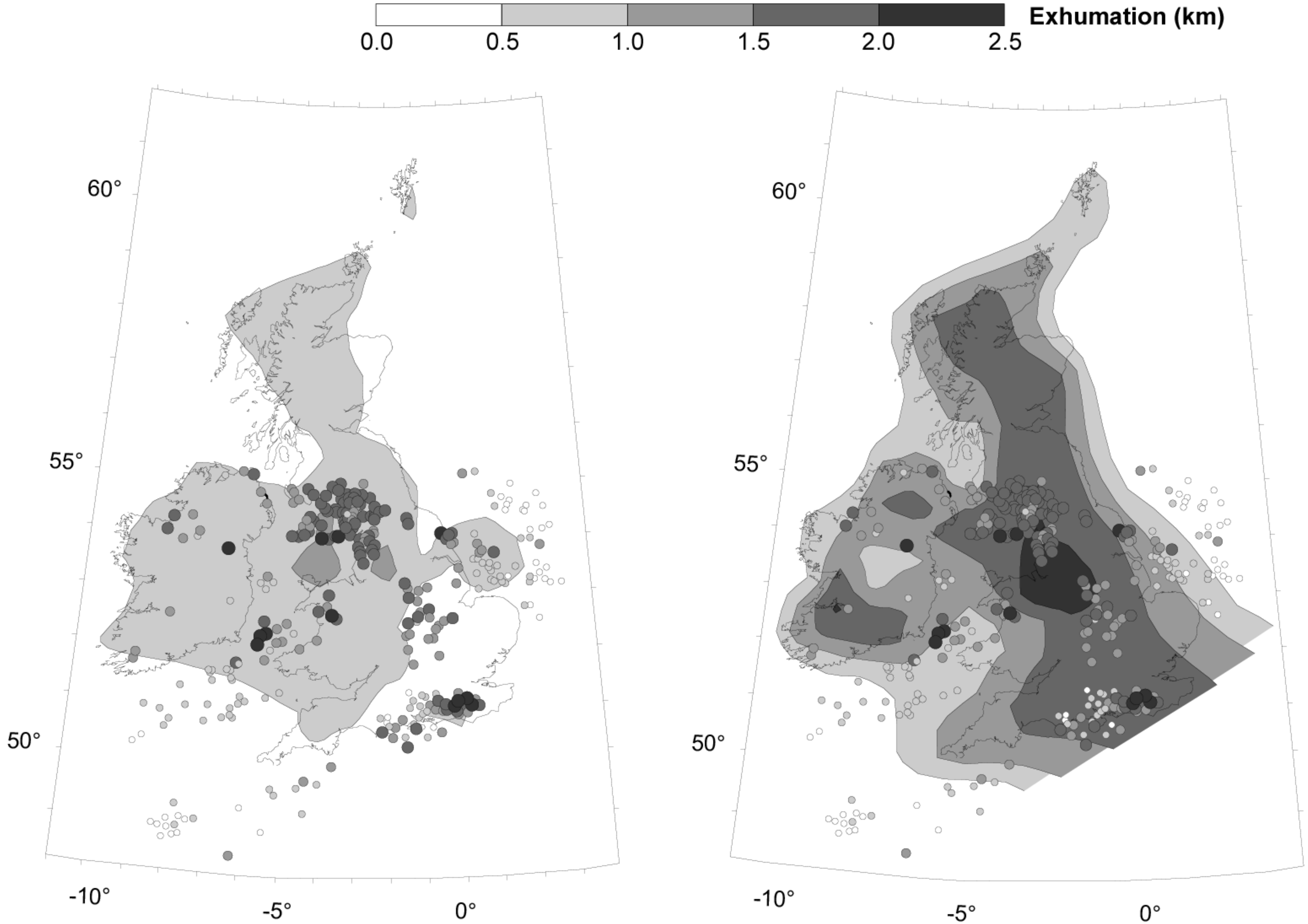
- Presently outcropping rocks in southern British Isles have been more deeply buried by up to 2.5 km of section removed during Cenozoic exhumation
- Exhumation has been primarily explained in terms of either igneous underplating related to Iceland mantle plume during early Palaeogene or compression of crust by plate boundary forces
- We have complied 329 estimates of exhumation using AFTA, vitrinite reflectance and sedimentary rock compaction methods
- Our results demonstrate major short-wavelength variations in exhumation over recognized Cenozoic compressional structures and multiple phases of exhumation
- We argue that crustal compression was the major cause of Cenozoic exhumation across the southern British Isles
- The short-wavelength signal due to crustal compression is superimposed on more regional exhumation which is mainly Neogene in age


Cenozoic exhumation
>2.2 km
2.0-2.2 km
1.8-2.0 km
1.6-1.8 km
1.4-1.6 km
1.2-1.4 km
1.0-1.2 km
0.8-1.0 km
0.6-0.8 km
0.4-0.6 km
<0.4 km
55°00'
54°00'
53°00'
52°00'
51°00'
50°00'
49°00'N
11°00'W
10°00'
9°00'
8°00'
7°00'
6°00'
5°00'
4°00'
3°00'
2°00'
1°00'
0°00'
1°00'
2°00'
3°00'E



Modified after Jones *et al.* 2002



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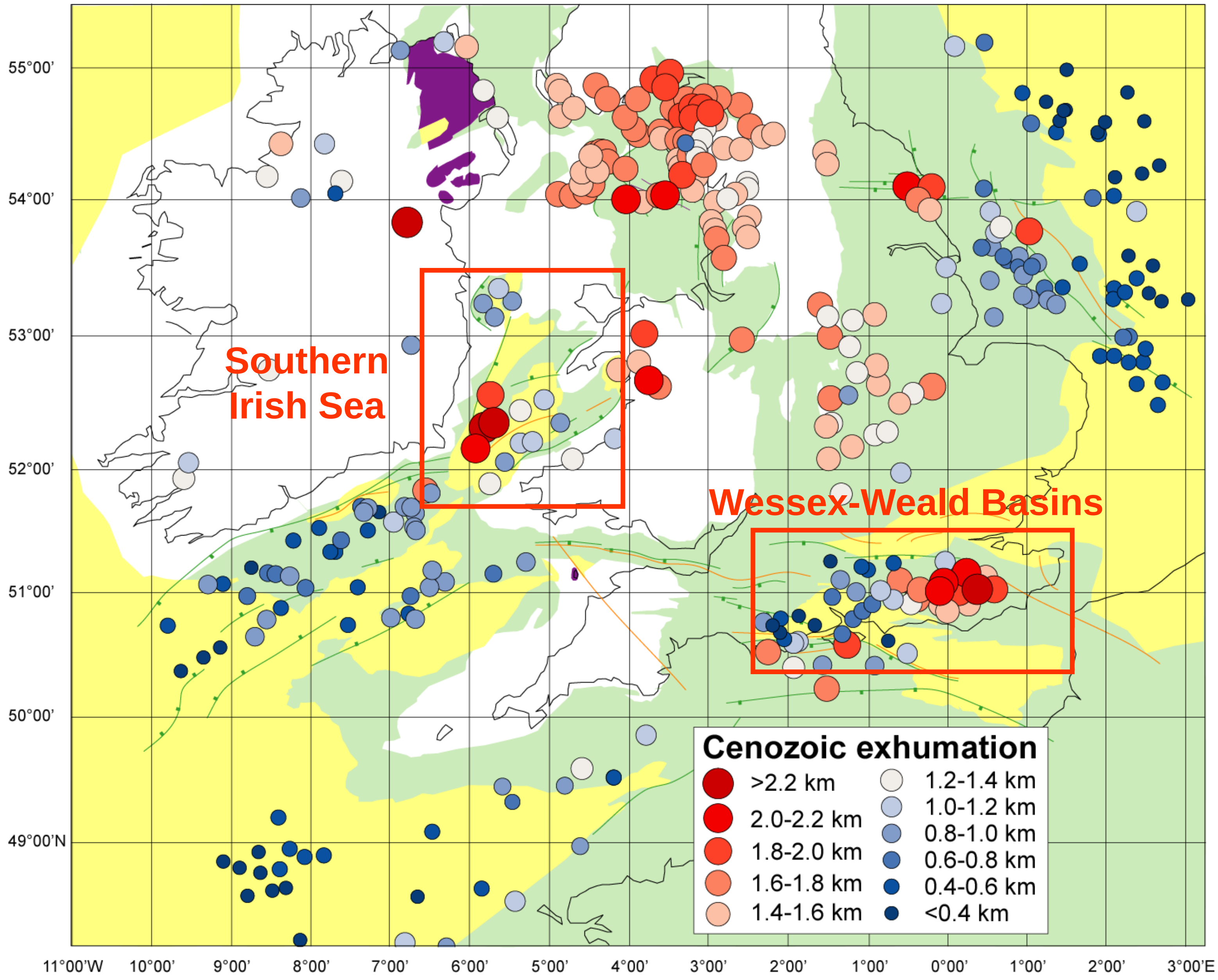
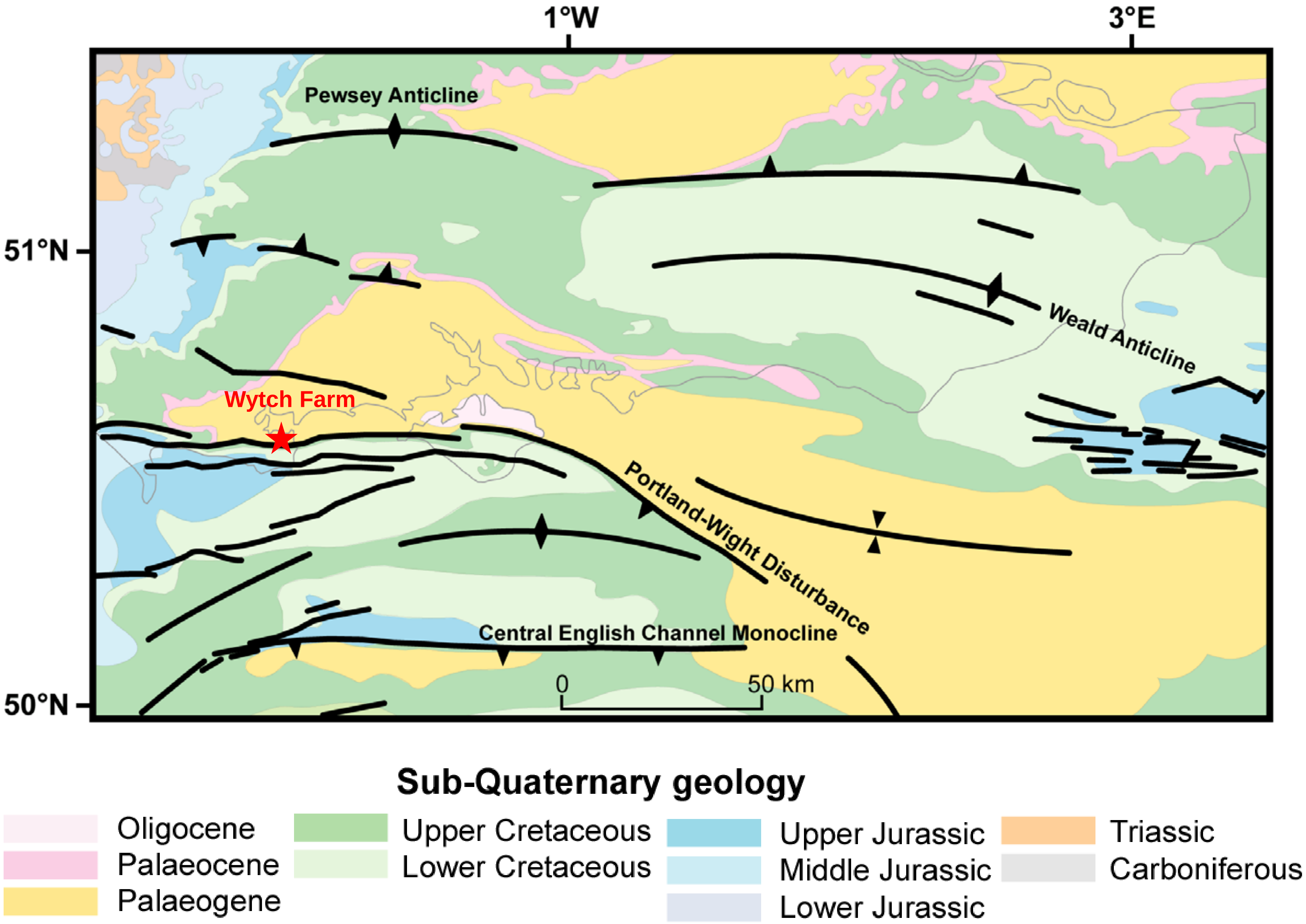
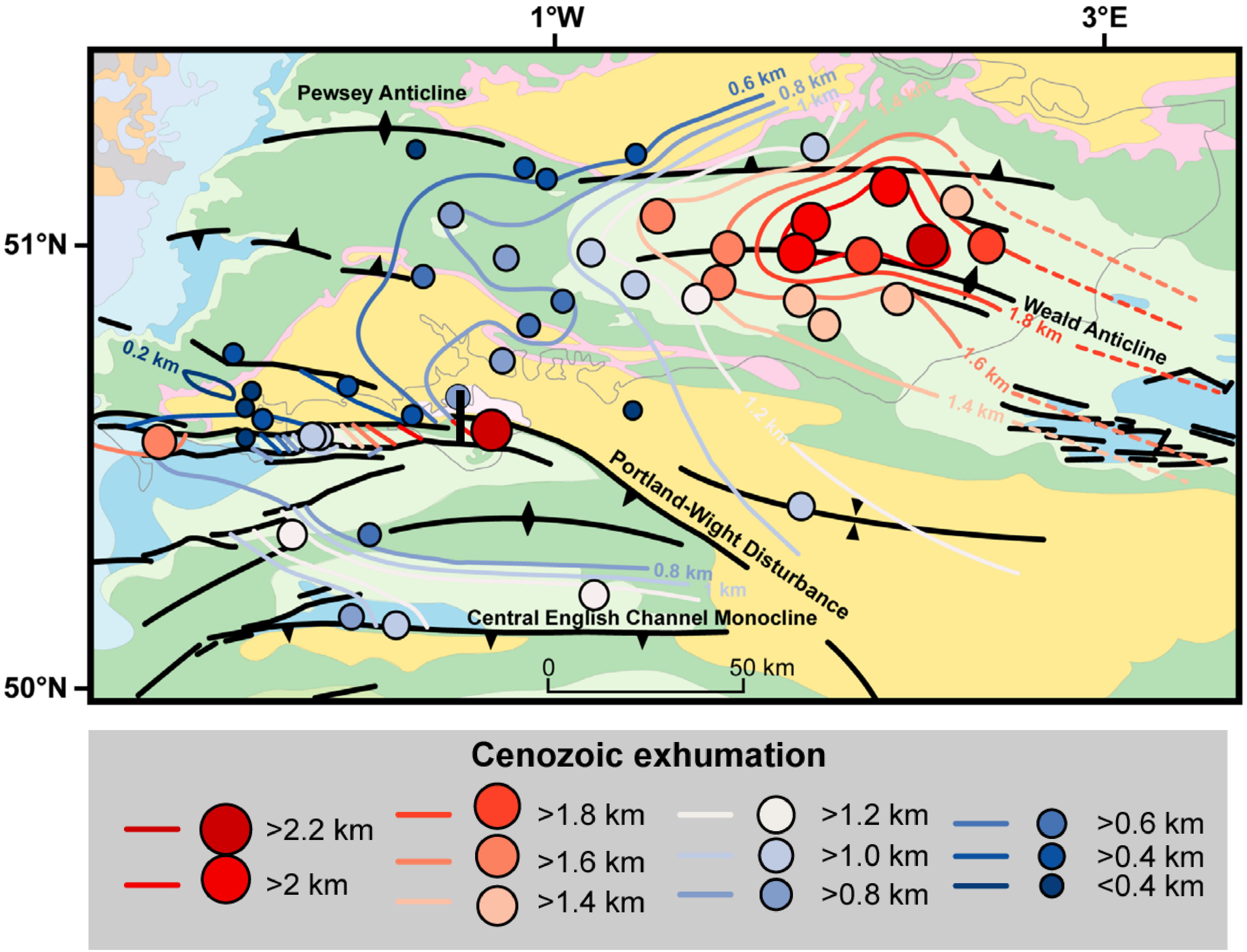

Southern Irish Sea
Wessex-Weald Basins
Cenozoic exhumation
>2.2 km
2.0-2.2 km
1.8-2.0 km
1.6-1.8 km
1.4-1.6 km
1.2-1.4 km
1.0-1.2 km
0.8-1.0 km
0.6-0.8 km
0.4-0.6 km
<0.4 km
55°00'
54°00'
53°00'
52°00'
51°00'
50°00'
49°00'N
11°00'W
10°00'
9°00'
8°00'
7°00'
6°00'
5°00'
4°00'
3°00'
2°00'
1°00'
0°00'
1°00'
2°00'
3°00'E

Wessex-Weald Basins

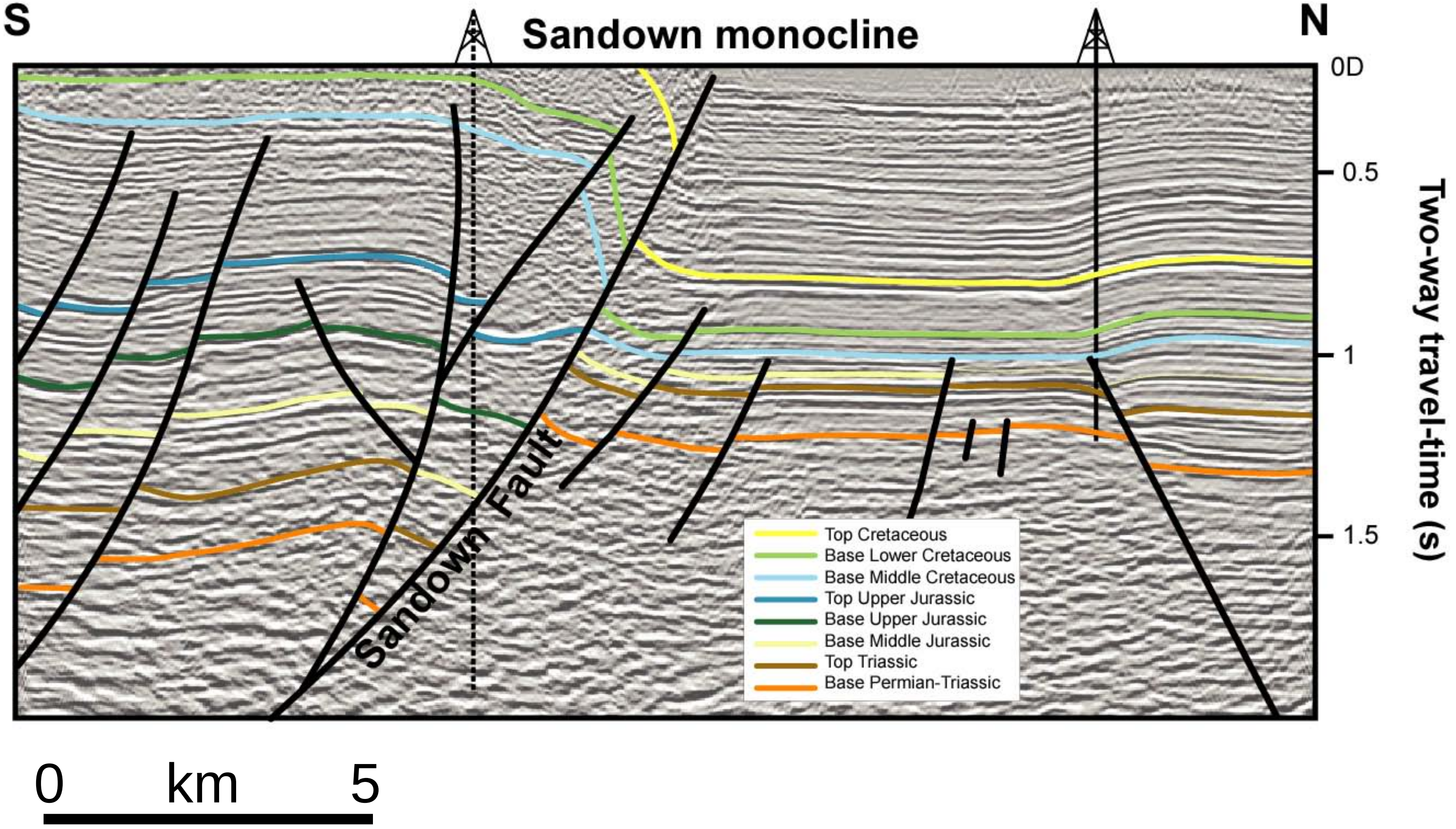
- Located beyond the limit of recognized plume activity (no Palaeogene igneous rocks)
- Exhumation estimated from sonic velocity of Jurassic Oxford Clay Formation and AFTA data (Butler & Pullan 1990; Bray *et al.* 1998; Law 1998)
- Exhumation began in mid-late Eocene and culminated in Neogene and is localized over major compressional structures
- 470 million barrels of oil are reservoired in the Wytch Farm oil field – Europe’s largest onshore oil field


1°W
3°E
51°N
50°N
Pewsey Anticline
Weald Anticline
Wytch Farm
Portland-Wight Disturbance
Central English Channel Monocline
0
50 km
Sub-Quaternary geology
Oligocene
Palaeocene
Palaeogene
Upper Cretaceous
Lower Cretaceous
Upper Jurassic
Middle Jurassic
Lower Jurassic
Triassic
Carboniferous


1°W
3°E
51°N
50°N
Pewsey Anticline
0.6 km
0.8 km
1 km
1.4 km
0.2 km
1.8 km
1.6 km
1.4 km
1.2 km
Weald Anticline
Portland-Wight Disturbance
0.8 km
1 km
Central English Channel Monocline
0
50 km
Cenozoic exhumation
>2.2 km
>2 km
>1.8 km
>1.6 km
>1.4 km
>1.2 km
>1.0 km
>0.8 km
>0.6 km
>0.4 km
<0.4 km

Arreton-2 borehole (projected)
Exhumation = 1.84 km

Sandhills-1 borehole
Exhumation = 0.75 km

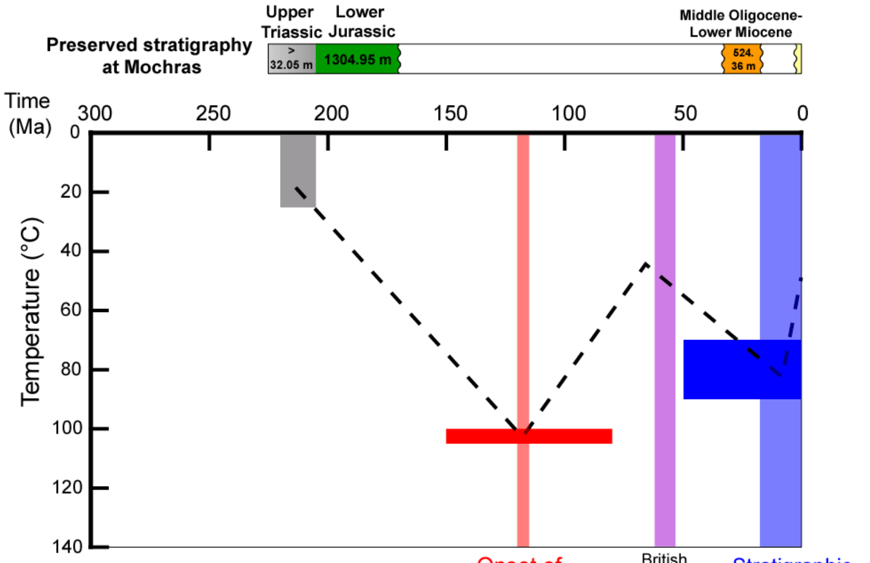


Seismic data courtesy of Lynx Information Systems

Southern Irish Sea

- Located near the postulated focus of underplating related exhumation; should reveal evidence for substantial Palaeocene exhumation if controlled by underplating
- Over 1 km of Palaeogene-Neogene sediments preserved in these basins, allowing effects of Neogene exhumation to be separated from those of earlier events
- AFTA data from Mochras borehole provide no evidence for early Palaeogene cooling (Holford *et al.* 2005 JGSL)
- Oligocene-Miocene section at Mochras is overcompacted, witnessing ~1.5 km of Neogene exhumation (Holford *et al.* 2005 JGSL)

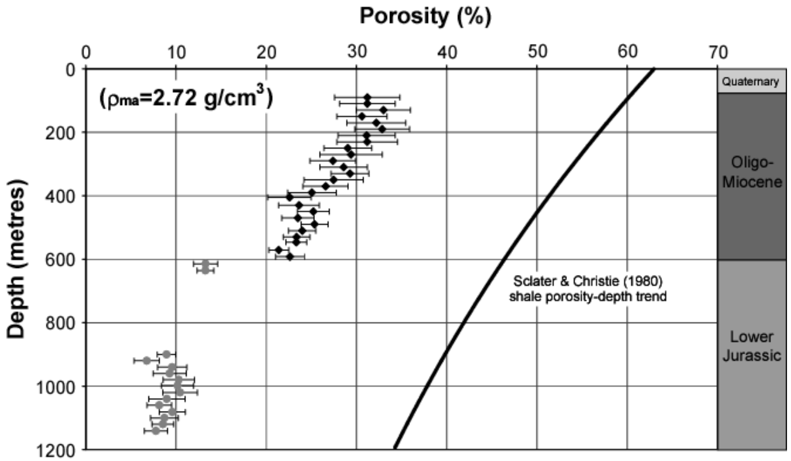
Mochras borehole



Onset of cooling from regional AFTA studies **120-115 Ma**

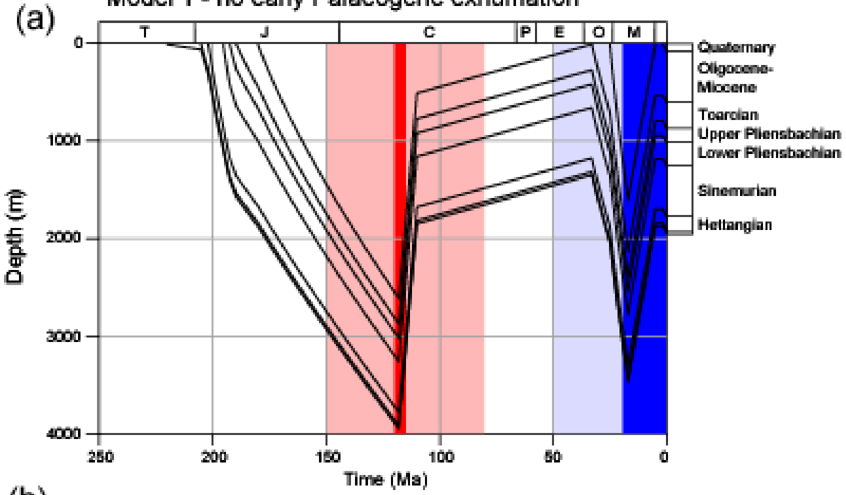
British Cenozoic Igneous Province magmatism **~62-53 Ma**

Stratigraphic constraints suggest cooling began **<20 Ma**

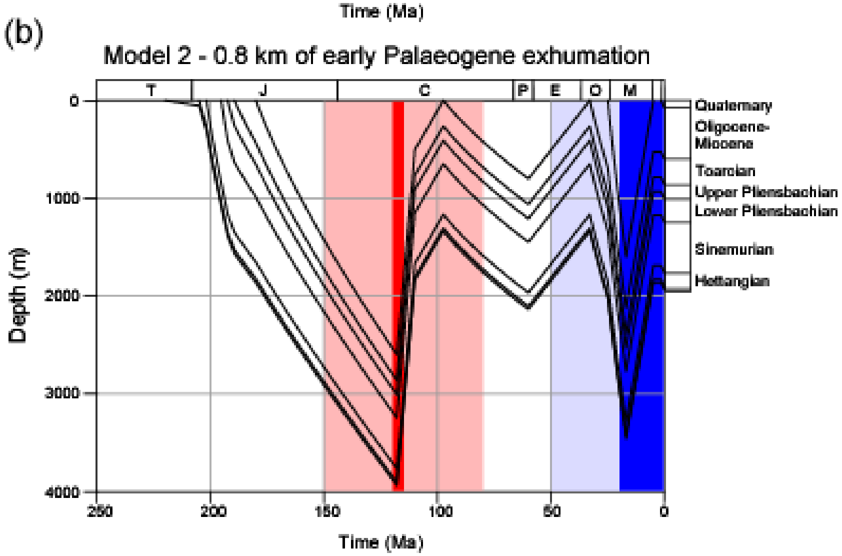


Neogene exhumation		**Early Cretaceous exhumation**	
Apparent exhumation (EA)		*Apparent exhumation (EA)*	
Mean:	**1.32 km**	Mean:	**2.75 km**
SD:	**0.13 km**	SD:	**0.25 km**
Total exhumation (ET) = **1.39 km**		*Total exhumation (ET)* = **3.35 km**	

Model 1 - no early Palaeogene exhumation



Model 2 - 0.8 km of early Palaeogene exhumation



Holford *et al.* 2005 JGSL

Southern Irish Sea

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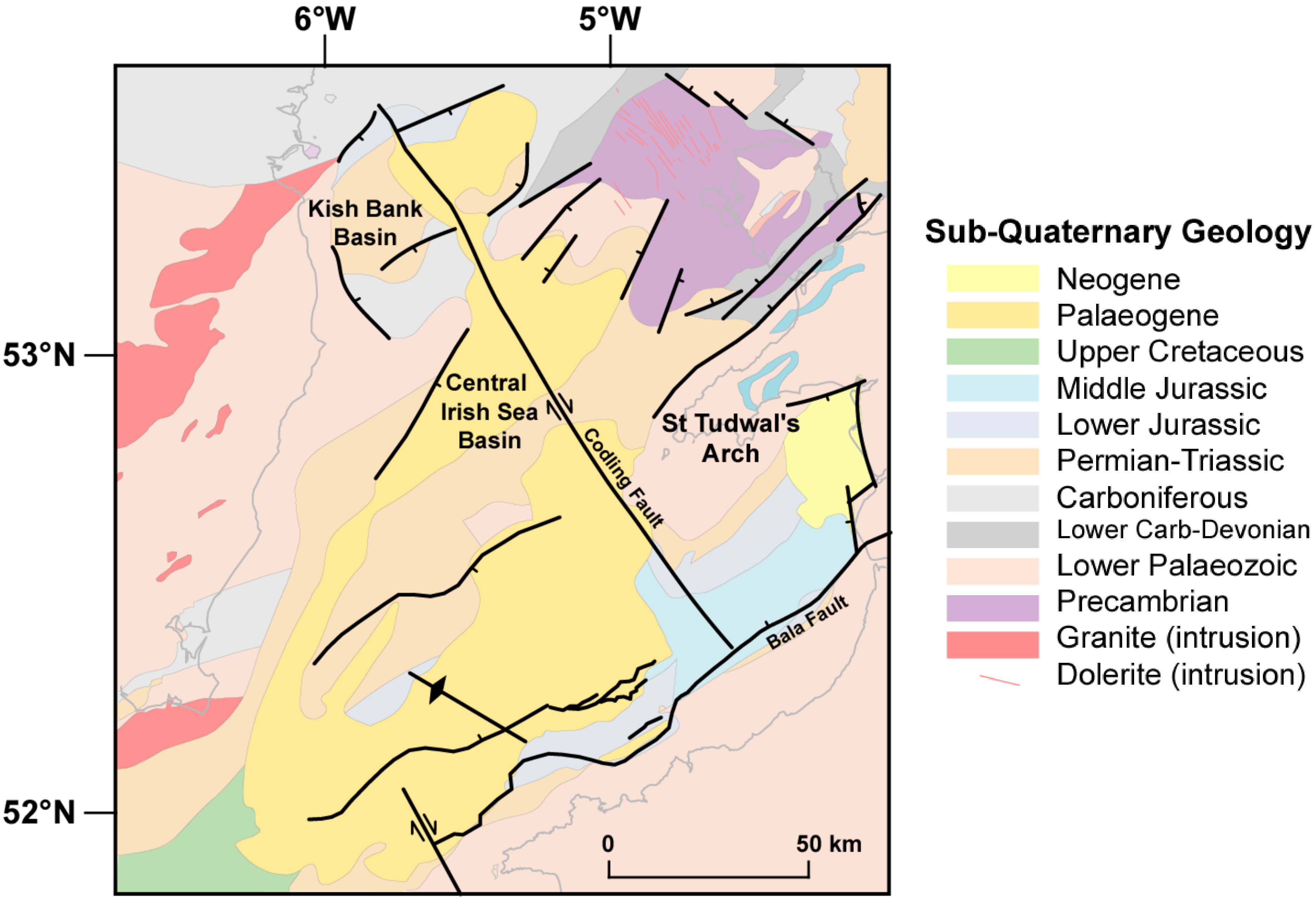
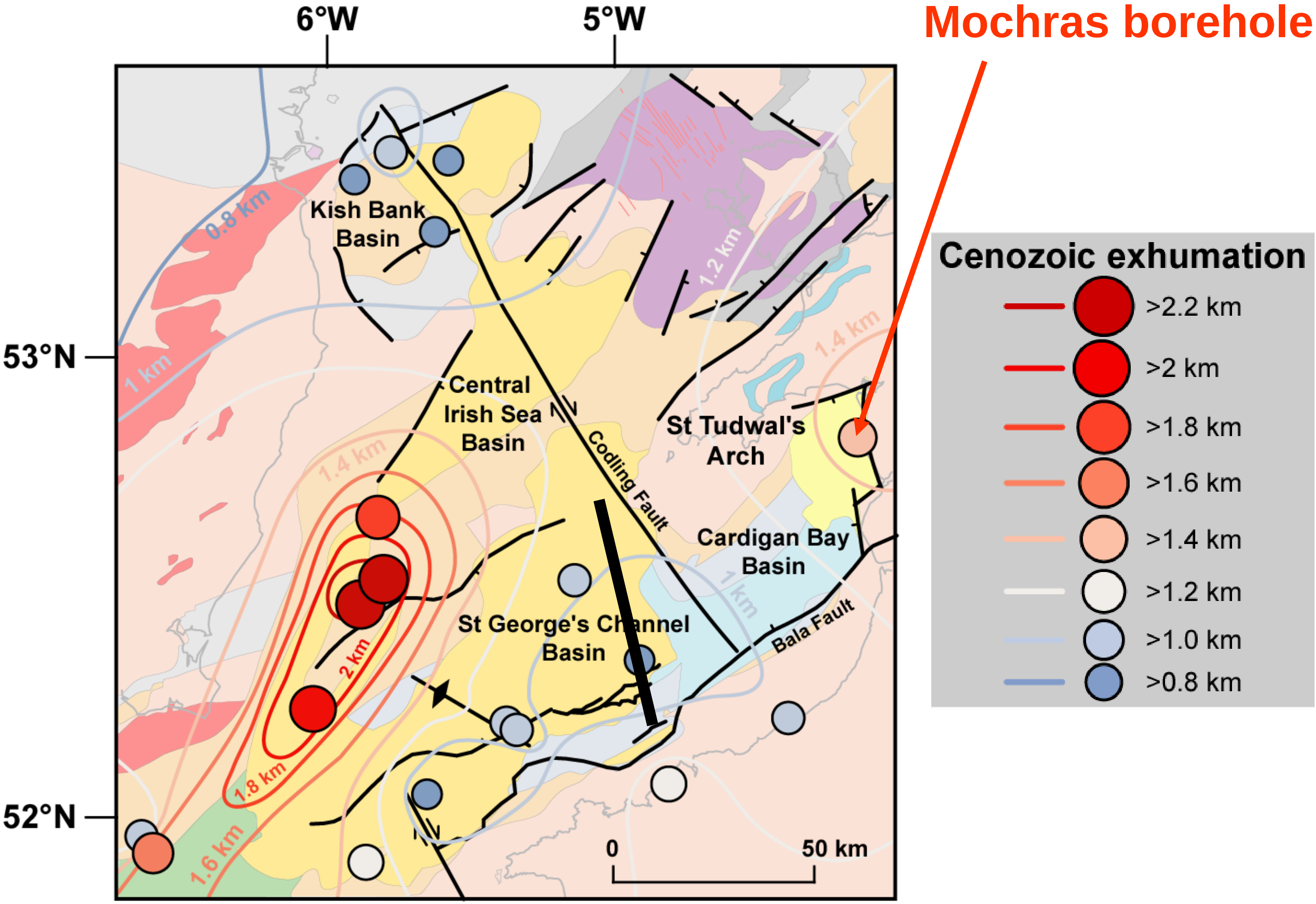
- Palaeogene-Neogene sequence of St George’s Channel Basin shows significant dip demonstrating major post-Palaeogene deformation and exhumation
- Timing and style of exhumation is therefore inconsistent with early Palaeogene underplating

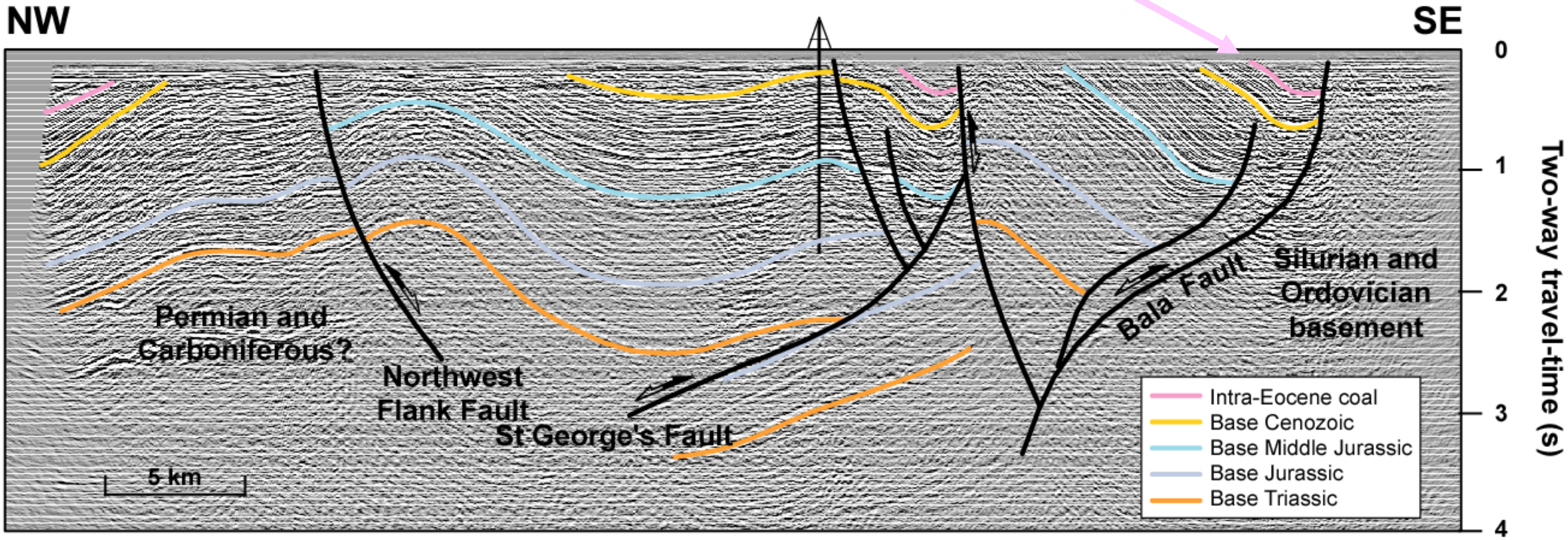

6°W
5°W
53°N
52°N
Kish Bank Basin
Central Irish Sea Basin
St Tudwal's Arch
Codling Fault
Bala Fault
0
50 km
Sub-Quaternary Geology
Neogene
Palaeogene
Upper Cretaceous
Middle Jurassic
Lower Jurassic
Permian-Triassic
Carboniferous
Lower Carb-Devonian
Lower Palaeozoic
Precambrian
Granite (intrusion)
Dolerite (intrusion)



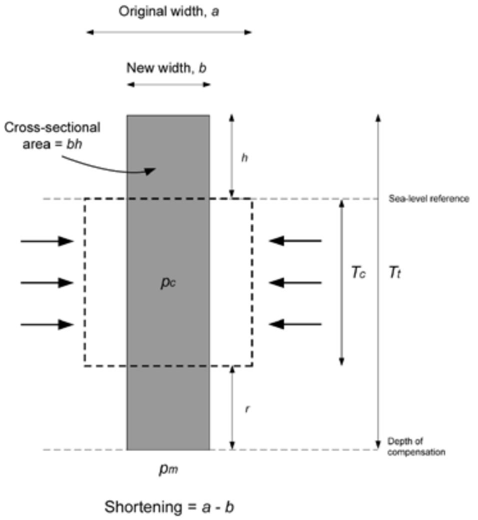
Mochras borehole

Tilting and truncation of intra-Eocene marker witnesses a Neogene phase of compressional deformation

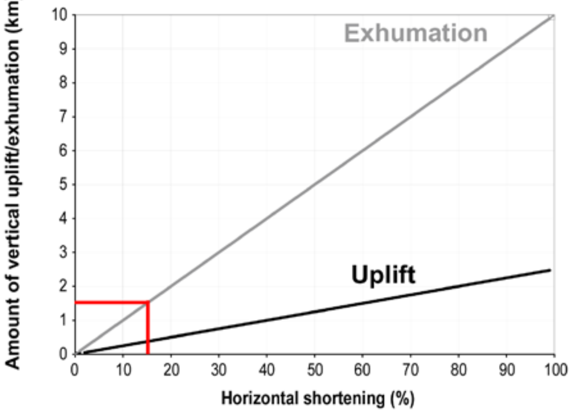
107/16-1
Exhumation = >0.8 km



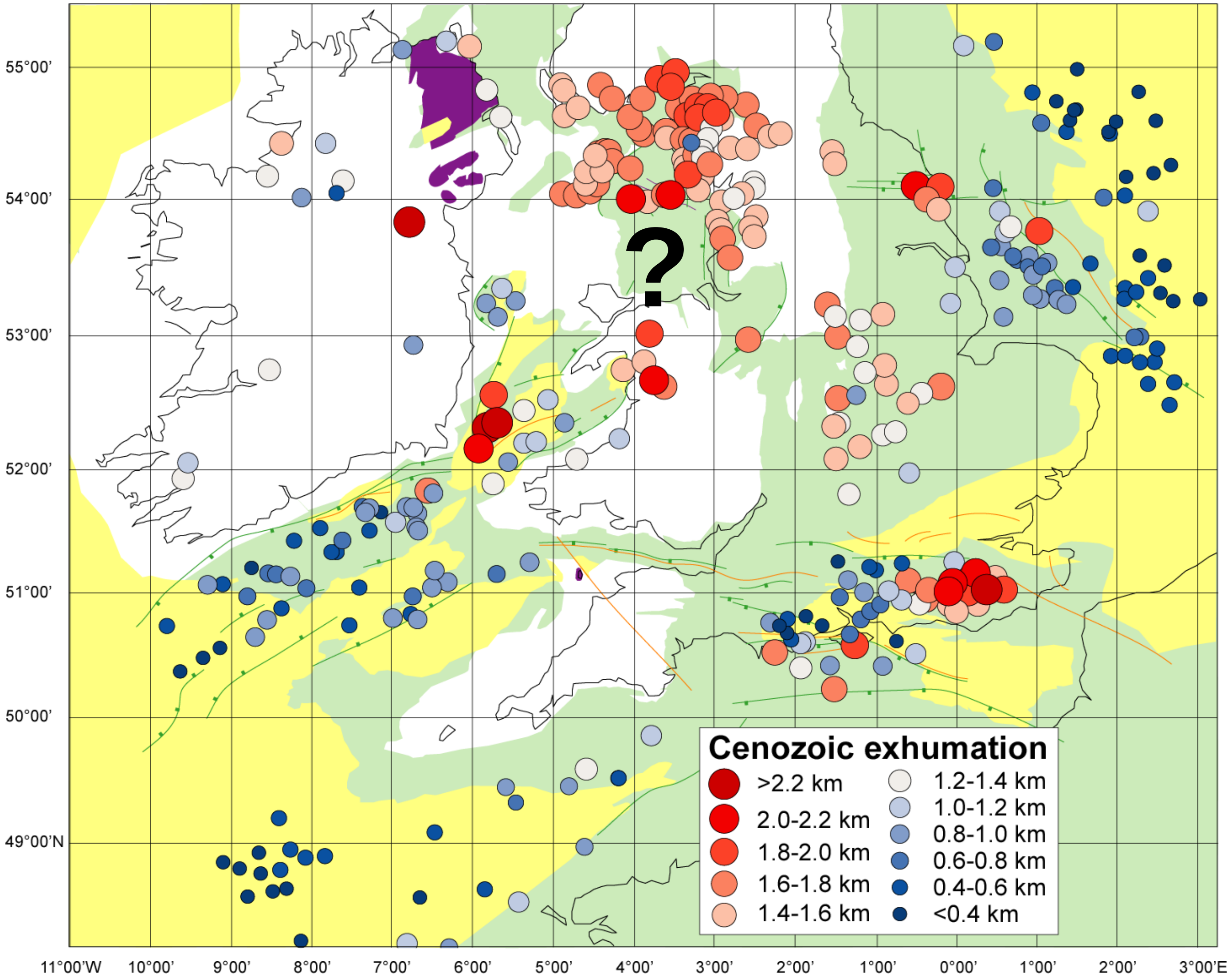
Line-length restoration of Base Middle Jurassic horizon indicates ~15% shortening



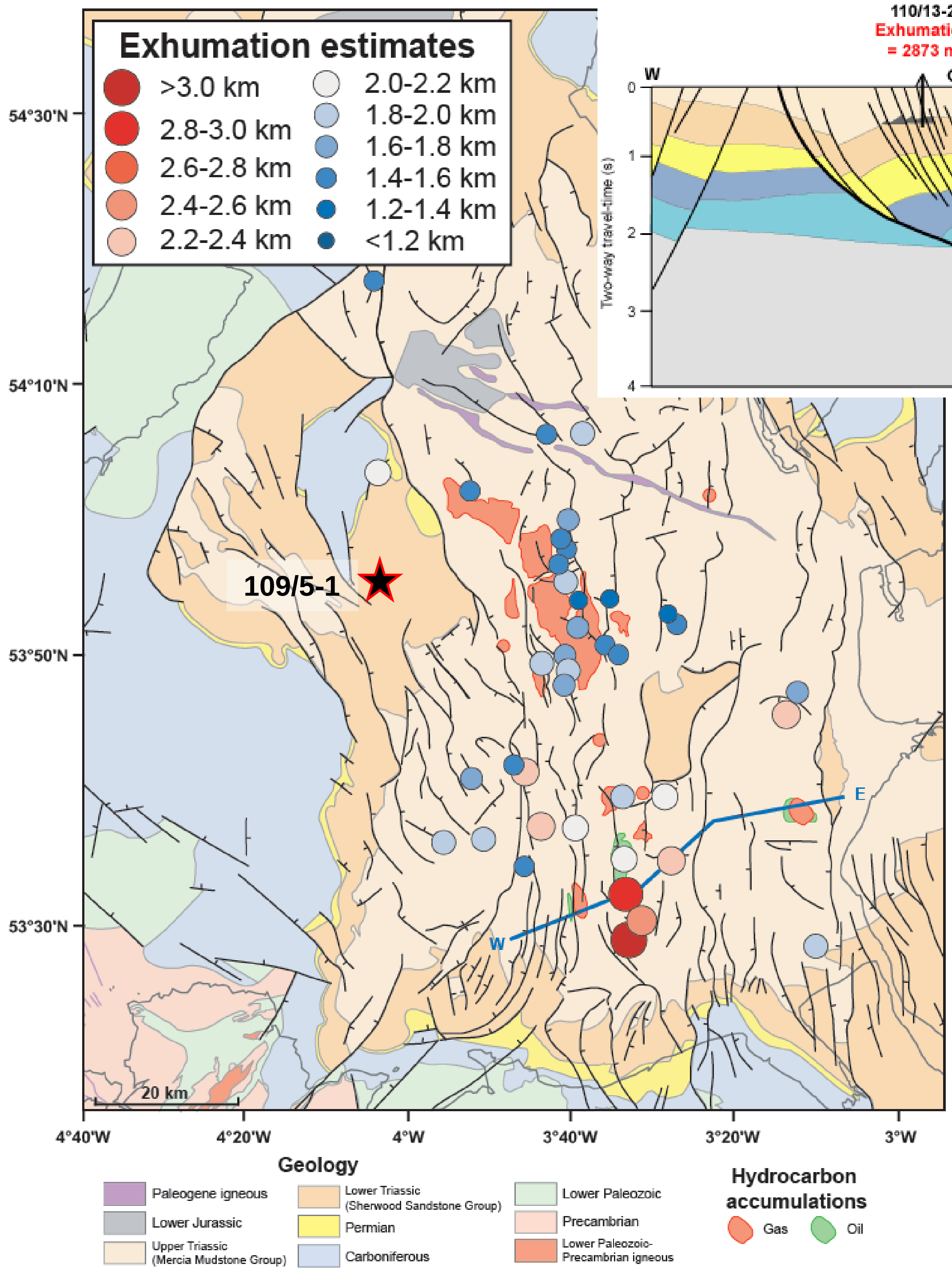
Relationship between shortening, uplift and exhumation (under conditions of Airy isostasy)

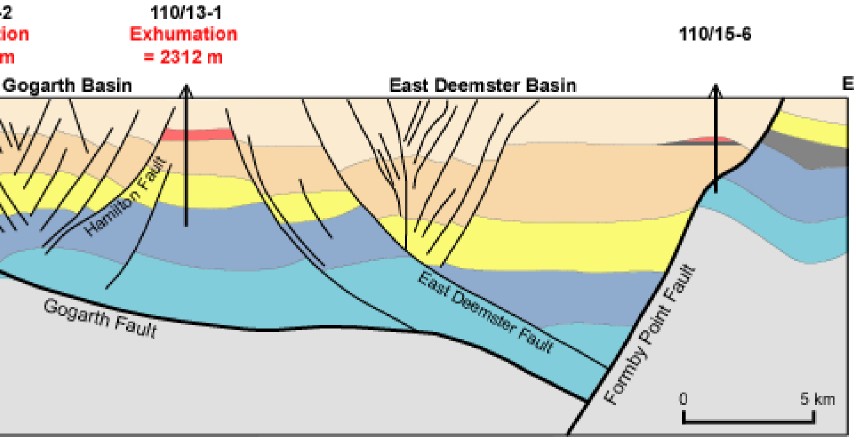


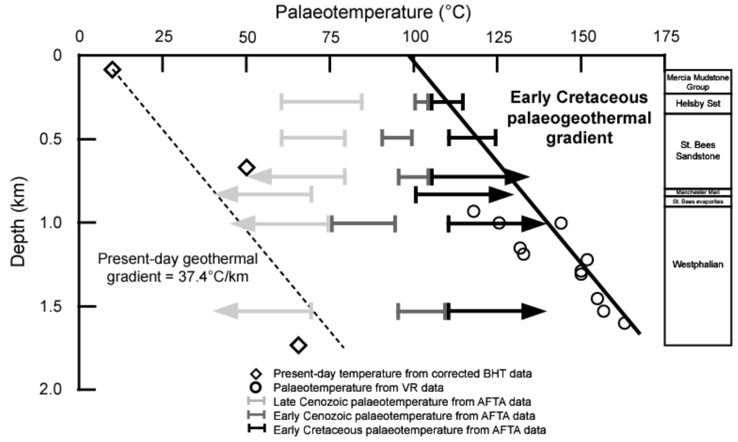
What about the East Irish Sea Basin?

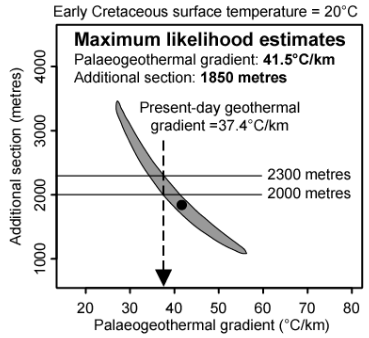


Exploration well 109/5-1

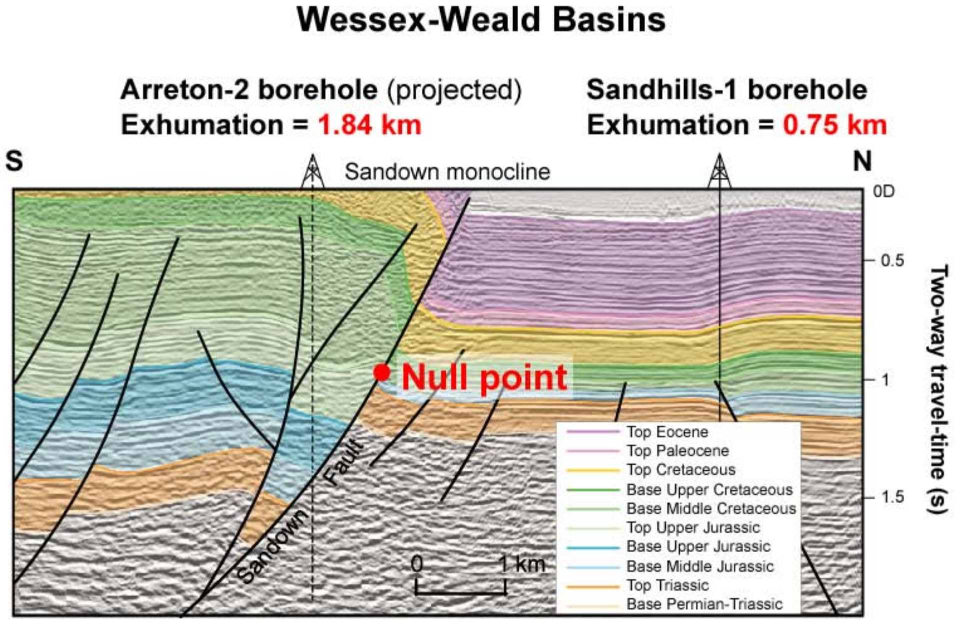


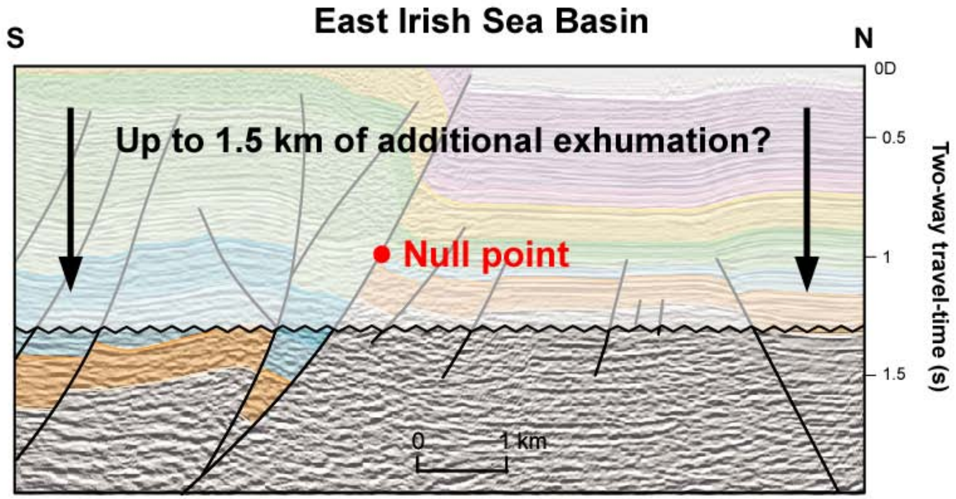




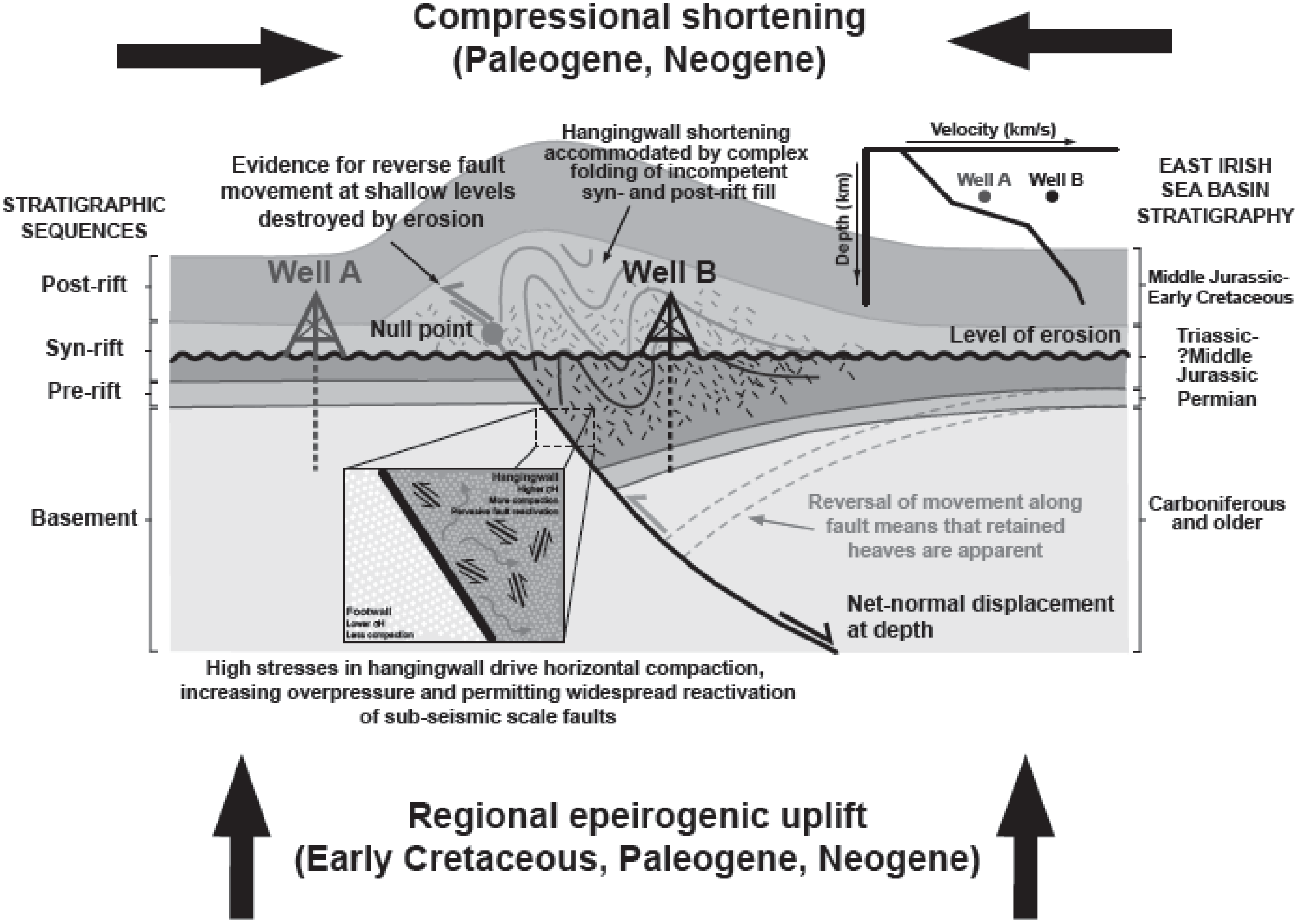


The cryptic signature of sedimentary basin inversion





- The EISB has been deeply eroded (up to 3.3 km of post-Upper Triassic strata removed)
- Some evidence for crustal shortening has been lost because erosion has cut below the **null point**
- There is only evidence for the earlier phase of extension
- Less deeply eroded basins (e.g. Wessex Weald) contain abundant evidence for shortening because, unlike the EISB, the postrift successions have only been partially removed


Compressional shortening
(Paleogene, Neogene)
STRATIGRAPHIC SEQUENCES
Post-rift
Syn-rift
Pre-rift
Basement
Evidence for reverse fault movement at shallow levels destroyed by erosion
Hangingwall shortening accommodated by complex folding of incompetent syn- and post-rift fill
Velocity (km/s)
Depth (km)
Well A
Well B
EAST IRISH SEA BASIN STRATIGRAPHY
Middle Jurassic-Early Cretaceous
Triassic-?Middle Jurassic
Permian
Carboniferous and older
Well A
Well B
Null point
Level of erosion
Hangingwall
Higher σH
More compaction
Reverse fault reactivation
Footwall
Lower σH
Less compaction
Reversal of movement along fault means that retained heaves are apparent
Net-normal displacement at depth
High stresses in hangingwall drive horizontal compaction, increasing overpressure and permitting widespread reactivation of sub-seismic scale faults
Regional epeirogenic uplift
(Early Cretaceous, Paleogene, Neogene)

Correlation of exhumation with Atlantic Margin unconformities and plate boundary deformation

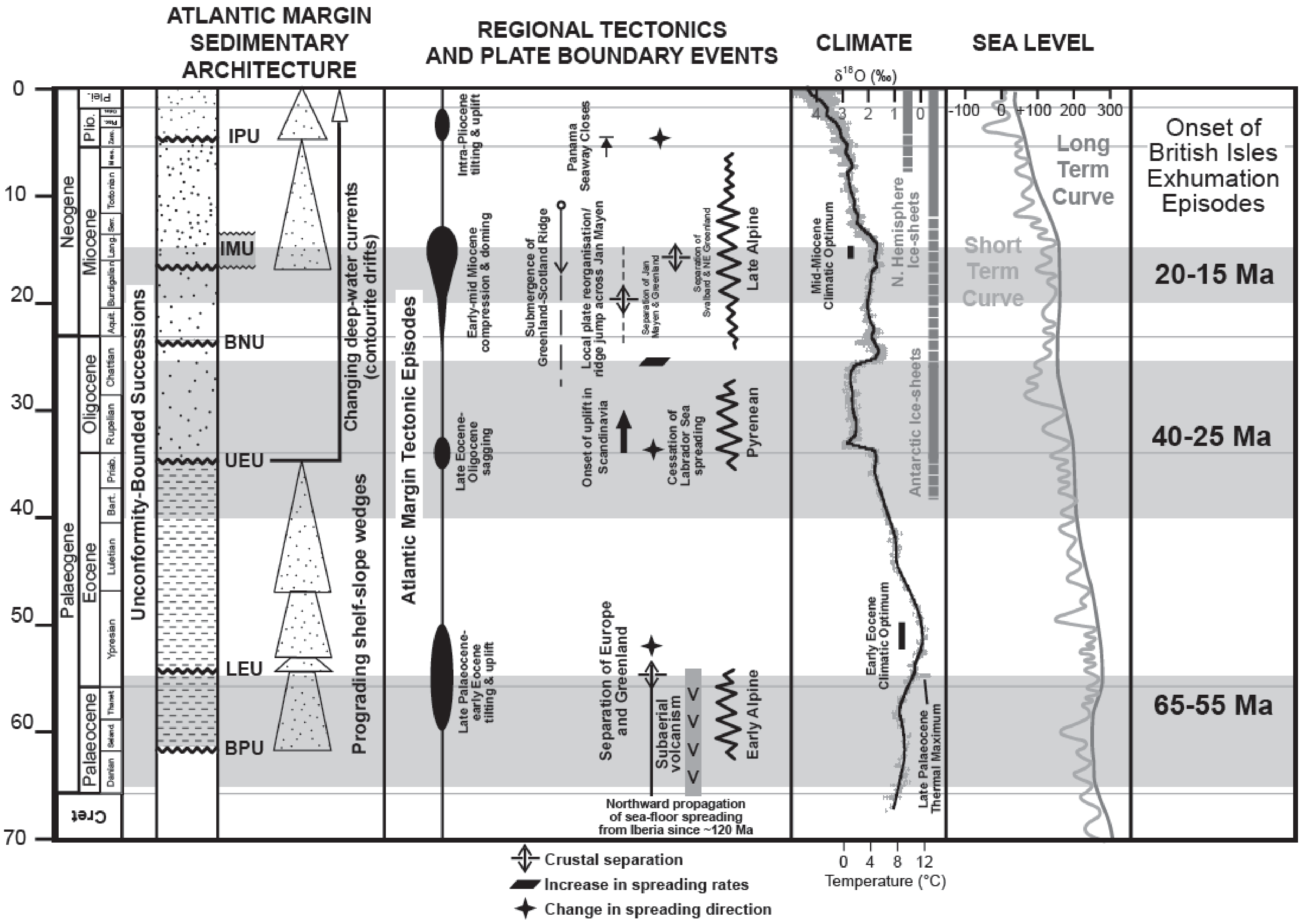
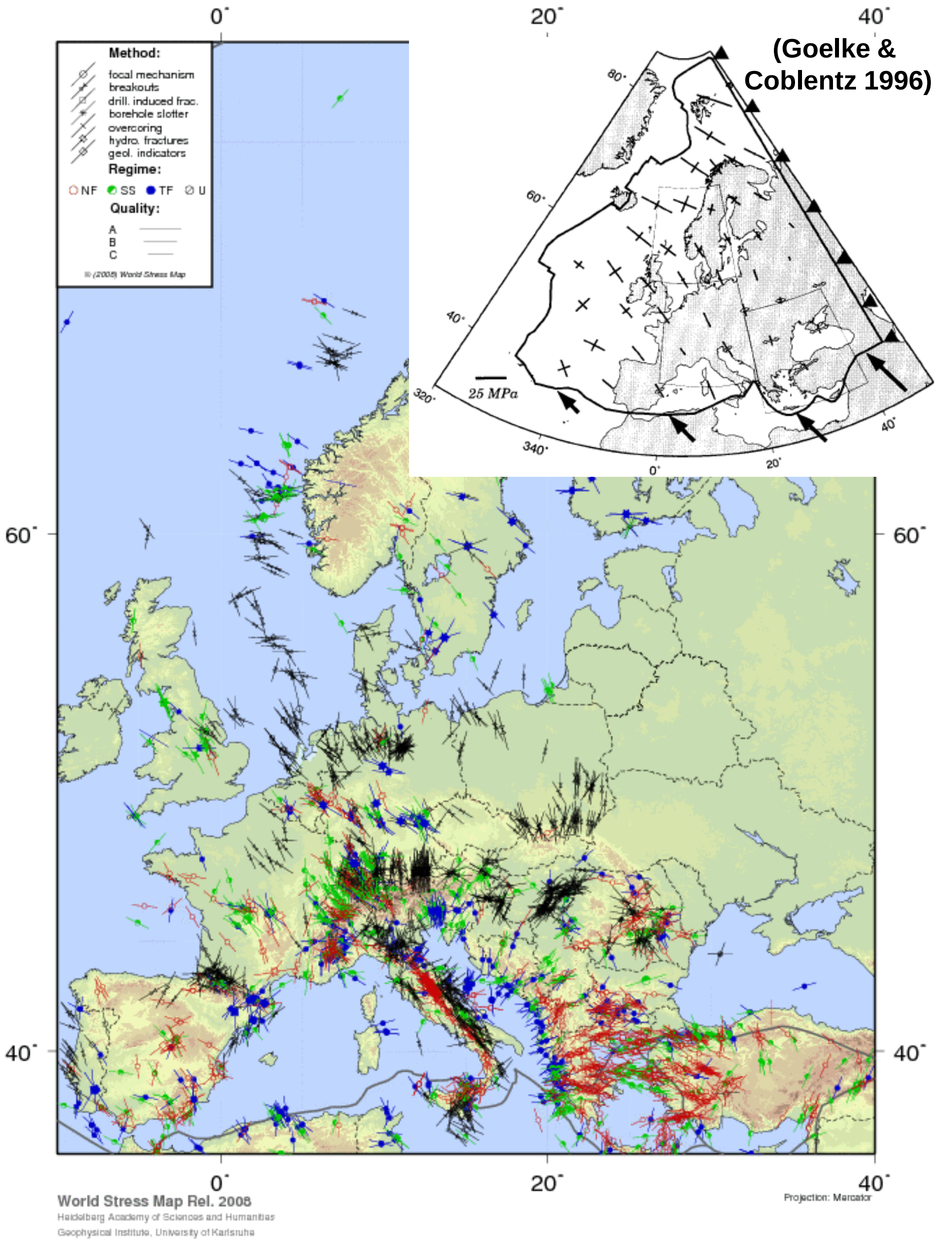


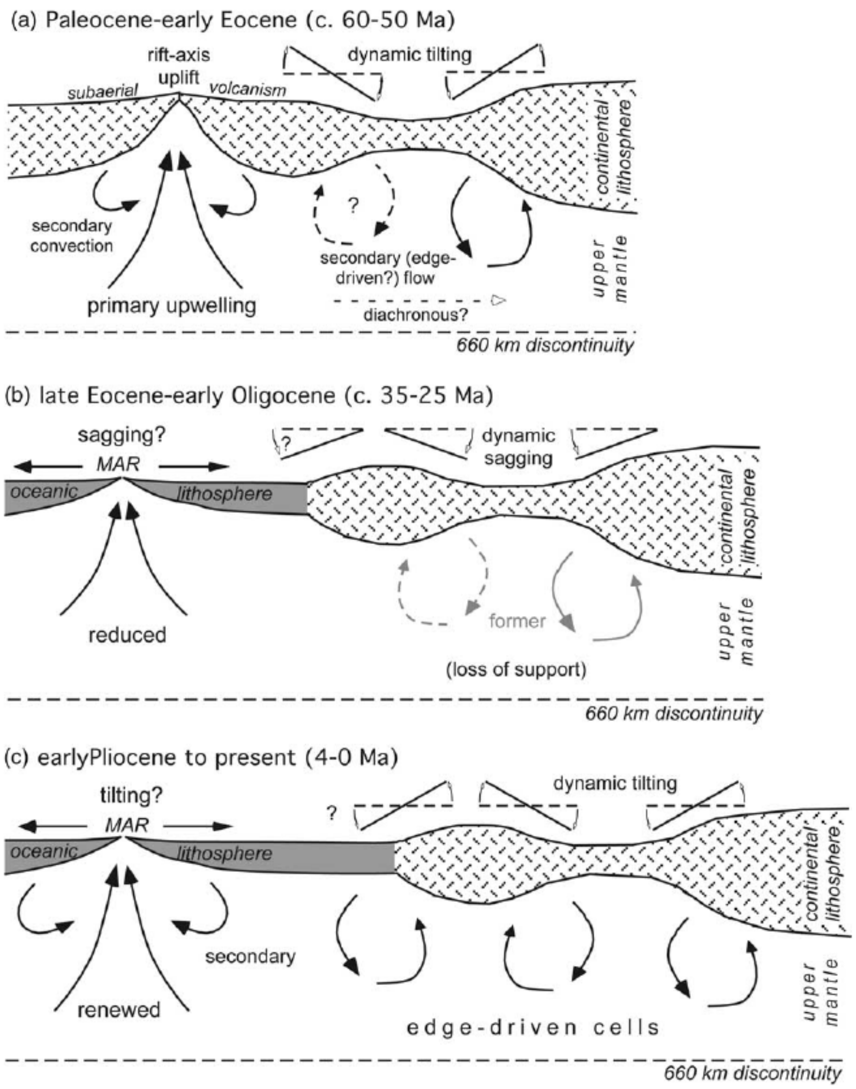
Plate boundary forces



(Goelke & Coblentz 1996)

(World Stress Map 2008)

Evolving patterns of mantle convection



(Praeg et al. 2005)

Conclusions

- Our data demonstrate major short-wavelength variations in exhumation (i.e. ~1 km variation over ~10 km distance) and multiple phases of exhumation
- In many regions timing of exhumation post-dates timing of plume activity, with Neogene exhumation especially significant
- Cenozoic compressional structures increasingly recognized in northern Britain and along the Atlantic Margin
- Neither the distribution nor chronology of exhumation supports underplating as the major cause of exhumation
- Crustal compression due to plate boundary stresses originating from mid-Atlantic ridge spreading and Alpine collision transmitted ~1000 km into the plate interior was the major cause of Cenozoic exhumation
- Short-wavelength exhumation is superimposed on regional exhumation of primarily Neogene age – this may be related to lithospheric shortening, mantle convection, but not the Iceland mantle plume

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- Lynx Information Systems
- Seismic Micro-Technology

Selected References

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