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Depth-dependent Stretching on the Lofoten, Vøring and Møre Rifted Margins: Implications for Subsidence and Hydrocarbon Maturation

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Reverse and forward structural-and-stratigraphic modelling show that depth-dependent stretching occurs on the outer part of the Norwegian rifted margin. Subsidence analysis shows substantial thinning of the continental lithosphere within ~ 100 – 150 km of the COB, while the upper crust shows no significant faulting and extension at breakup or immediately preceding breakup in the Palaeocene. For the Lofoten Margin β stretching-factors approaching infinity are required at ~ 54 Ma west of the Utrøst Ridge to restore Top Basalt and the Top Tåre to presumed sub-aerial depositional environments. Breakup age β stretching-factors are predicted to rapidly reduce towards the east of the Utrøst Ridge.

For the Vøring margin, south of the Bivrøst Transform and Lineament System, β stretching-factors of ~ 1.8 to 2.5 are needed to restore Top Basalt and Top Tåre to sea level (see Roberts et al 1997 also). Again no similar magnitude of extension by faulting is observed in the upper crust. These observations can be continued southwards into the northern Møre Basin. For the mid-Lofoten margin an additional Eocene crustal thinning event younger than 54 Ma is required to explain observed subsidence. The absence of significant Palaeocene extension on the Lofoten and Vøring margins, and the additional Eocene subsidence and faulting, implies that depth-dependent stretching of the Norwegian rifted margin occurred during early sea-floor spreading rather than during pre-breakup intra-continental rifting.

Depth-dependent stretching has been observed at other rifted continental margins including the Galicia, Goban Spur, NW Australian and South China Sea rifted margins (Driscoll & Karner 1998, Davis & Kusznir 2002). Stretching estimates, independently determined from upper crustal faulting, whole crustal thinning and post-rift lithosphere thermal subsidence, show that extension increases with depth within ~ 100 – 150 km of the COB such that upper-crustal extension is significantly smaller than whole-crustal or whole-lithosphere extension. Depth-dependent stretching cannot be explained by sub-seismic resolution faulting, aseismic extension, second generation faulting or lithosphere simple shear. Paradoxically all rifted margins appear to be "upper plate" in terms of detachment models (Driscoll and Karner, 1998). Depth dependent stretching may have a similar causal mechanism to that responsible for observed mantle exhumation on the Iberian rifted margin (Pickup et al 1996). Exhumation of continental mantle at rifted margins is independently supported by wide-angle seismology, direct sampling, geochemical analysis, magnetic anomalies, and orogenically exhumed rifted margins (Whitmarsh et al 2001). Finite-element models of early sea-floor spreading predict depth-dependent stretching and the exhumation of continental mantle (Davis & Kusznir 2002), which is pulled from beneath the adjacent continental crust and exposed at the surface. Depth dependent stretching and mantle exhumation at rifted margins may be inevitable consequences of early sea-floor spreading rather than pre-breakup rifting, and occur symmetrically on both conjugate margins so explaining the "upper plate" detachment paradox identified by Driscoll & Karner (1998).

Temperature and maturation modelling shows that the inclusion of depth-dependent stretching has an important effect on temperature and %VR evolution in depth and time. Failure to include the large β factors for the lower crust and lithospheric mantle (below the unstretched upper crust) leads to a serious under prediction of temperature and %VR. While the effect of emplacing thick sills or of magmatic underplating at continental breakup has an important effect on modelled temperature and %VR, their effects are small by comparison with the effects of depth-dependent stretching.

Palaeobathymetric restorations using flexural backstripping and reverse post-rift thermal-subsidence modelling (Roberts et al 1998), and which include depth-dependent stretching, predict shallow palaeo-water depths of less than 200 m at Palaeocene times for the pre-break up Lofoten and Vøring margins. Palaeocene palaeo-bathymetries are predicted by reverse post-rift modelling to shallow westwards and becoming emergent in the extreme west of the modelled profiles.

References

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