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Crustal architecture and evolution of conjugate margins off Mid-Norway and Greenland

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Studies of conjugate rifted continental margins are essential for a better understanding of the fundamental processes responsible for the break-up and separation of lithospheric plates. In particular, rifting, break-up and associated magmatism provide initial conditions for sea floor spreading and influence the thermal regime and vertical movements of the sedimentary basins on volcanic passive margins.

The passive continental margin off Norway, and its conjugate off East Greenland, is part of a region which has experienced several post-Caledonian episodes of lithospheric extension. We recognize Late Paleozoic-Early Mesozoic, Late Jurassic-Early Cretaceous, mid-Cretaceous (Aptian/Albian-Cenomanian) and Late Cretaceous-Paleocene rift structures, and a shift in the central rift zone with time. The latest episode culminated in crustal break-up and accretion of oceanic crust, accompanied by large-scale igneous activity, near the Paleocene-Eocene transition.

Off Norway, the volcanic margin between Jan Mayen and Greenland-Senja fracture zones is globally one of the best explored and studied both by academia and industry. The large existing geophysical and geological database comprises a regional grid of deep wide-angle seismic data (OBS and ESP), deep and conventional multichannel seismic (MCS) reflection profiles, potential field data, heat flow, and scientific and commercial boreholes. Mapping of crustal structure is difficult in large areas using MCS data, due to the presence of large amounts of early Eocene extrusives and intrusives. Wide-angle seismic data are therefore important for mapping the thickness and extent of sills in the sediments, the top of the crystalline crust, a high-velocity body in the lower crust, as well as Moho. An integrated analysis of the data reveal important vertical and lateral variations in crustal structure and composition resulting from a complex history of rifting prior to and during the last Late Cretaceous-Early Tertiary rift episode leading to break-up and volcanic margin formation.

There is a well-defined along-strike margin segmentation and the various segments are characterized by distinct crustal properties, structural and magmatic styles, and post-opening history of vertical motion. The present margin segmentation is mainly related to Late Jurassic-Early Cretaceous transfer zones which have pre-determined the location of early opening fracture zones. However, many indicators point towards a much longer history of structural inheritance, extending back to pre-Mesozoic times.

Off Greenland, deep seismic data only exist from the fjords and on the outer margin south of 76°N, whereas regional MCS and potential field data exist on most of the margin. Only one scientific borehole has been drilled on this margin segment. The poor data coverage is mainly due to ice conditions, as most years the offshore areas are blocked by sea-ice all year round. Interpretation of the data shows striking differences in crustal structure north and south of Kong Oscar Fjord (KOF). North of KOF, which is conjugate to the southern Vøring margin on the Norwegian side, the seismic data reveal a gradual eastward crustal thinning across Caledonian, Devonian, Mesozoic and Tertiary structural provinces. A lower crustal high-velocity body has been related to magmatic underplating during emplacement of Tertiary flood basalts in East Greenland.

The earliest Eocene continental break-up and onset of sea floor spreading in the Norwegian-Greenland Sea was preceded by a rift episode which was probably initiated in the middle Campanian. Along the rifted margin off mid-Norway the evolution comprises an early rift phase (~81-65 Ma) characterized by large-scale normal faulting, varying structural styles and along-margin segmentation; and a late rift phase (~65-55 Ma) with continued extension, regional uplift, intrusive igneous activity and subsequent erosion. Rift structures characterized by low-angle detachment faulting within thick Cretaceous strata are observed along some of the rifted margin segments. A change in mode of rifting from brittle to more ductile extensional deformation in the late rift phase is interpreted as the combined effects of changing rift rheology due to plume arrival, focussing of extension toward the initial plate boundary and the fact that most of the brittle deformation may be hidden beneath the lavas erupted during break-up. The rifting ended with break-up at ~55 Ma accompanied by massive, but gradually waning extrusive igneous activity over the next 3 m.y.

A significant along-margin change in style and volume of the early Eocene break-up magmatism occurs across the Bivrost Fracture Zone/Lineament at the transition between the Vøring and the Lofoten-Vesterålen margin provinces. The two areas also reveal striking differences in structural development and post-opening vertical motion history. In particular, the Vøring margin is characterised by: (1) The Vøring marginal high bounded landward by the Vøring Escarpment; (2) thick and prominent wedges of seaward dipping reflectors present on the marginal high; (3) break-up lavas, the inner flow complex terminating a short distance landward of the Vøring Escarpment; (4) widespread sill intrusions in the Vøring Basin; (5) a thick 7+ km/s lower crustal body associated with magmatic underplating. In contrast, the Lofoten-Vesterålen margin is characterized by: (1) absence of a typical marginal high bounded landward by a major escarpment; (2) small and shallow seaward dipping reflector seismic images without the typical wedge-like pattern observed on the Vøring margin; (3) break-up lavas covering almost the entire continental slope and terminating near the shelf edge; (4) considerably reduced amount of sill intrusions; and (5) decrease in the thickness and volume of the 7+ km/s lower crustal body.

The refined pre-A22 sea floor spreading anomalies and fracture zones, and the continent-ocean boundary (COB) off Norway and Greenland provide geometrical and azimuthal constraints on plate tectonic reconstructions (Fig. 1). The reconstructions yield an unstable plate boundary with several short-lived transforms between opening and A23 (~51 Ma) time and require a pole of rotation which produces more northerly relative motion vectors than previously. The transforms are spatially linked to transfer zones that govern the margin segmentation, implying structural inheritance. Furthermore, our well-constrained reconstructions place the COB on the Greenland shelf ~65-90 km off the coastline just north of West Jan Mayen Fracture Zone (Fig. 1), and they also account for the azimuthal differences between the conjugate Greenland and Senja fracture zones, providing a geometrical model in which the Greenland submarine ridge is a continental sliver.

Following break-up, the subsiding mid-Norwegian margin experienced modest sedimentation until the late Pliocene when huge wedges of glacial sediments prograded westward, constituting at least one half of the post-opening sediment volume.

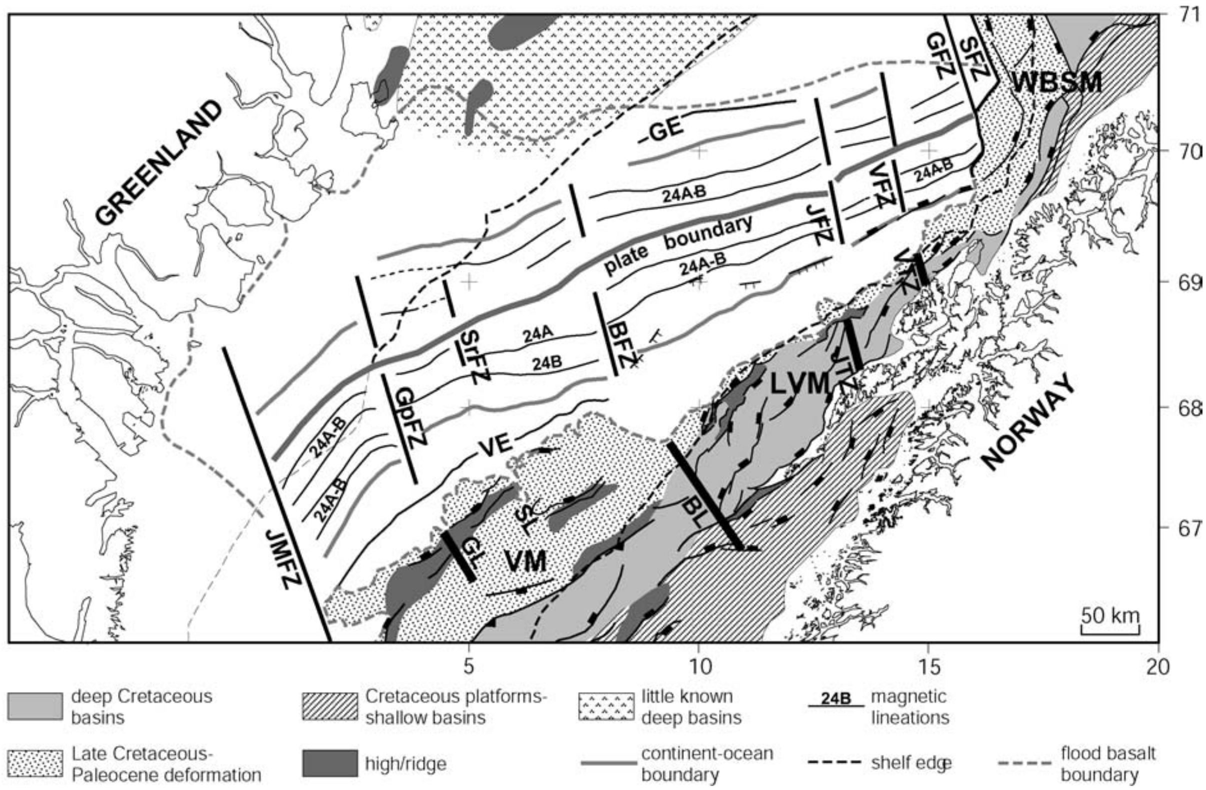

Fig. 1. Plate reconstruction to Chron 23n.2n, ~51 Ma. VM, LVM, WBSM, Vøring, Lofoten-Vesterålen and West Barents Sea margins, respectively; VE, GE, Vøring and Greenland escarpments, respectively; GL, SL, BL, Gleipne, Surt and Bivrost lineaments, respectively; JTZ, VTZ, Jennegga and Vesterålen transfer zones, respectively; JMFZ, GpFZ, SrFZ, BFZ, JFZ, VFZ, SFZ, GFZ, Jan Mayen, Gleipne, Surt, Bivrost, Jennegga, Vesterålen, Senja and Greenland fracture zones, respectively.