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Rift evolution and structural style in the Orphan Basin: results from regional structural restorations and crustal area balancing

Adam J. Cawood[1], David A. Ferrill[1], Alan P. Morris[1], David Norris[2], David McCallum[2], Erin Gillis[2], and Kevin J. Smart[1]

[1]Southwest Research Institute, San Antonio, Texas, USA (adam.cawood@swri.org)
[2]Oil and Gas Corporation of Newfoundland and Labrador, St John's, Canada

The Orphan Basin on the eastern edge of the Newfoundland continental margin formed as a Mesozoic rift basin prior to continental breakup associated with the opening of the North Atlantic. Few exploration wells exist in the basin, and until recently regional interpretations have been based on sparse seismic data coverage - because of this the structural evolution of the Orphan Basin has historically not been well understood. Key uncertainties include the timing and amount of rift-related extension, dominant extension directions, and the structural styles that accommodated progressive rift development in the basin.

Interpretation of newly acquired modern broadband seismic data and structural restoration of three regional, WNW-ESE oriented cross-sections across the Orphan Basin and Flemish Cap provide new insights into rift evolution and structural style in the area. Our results show that major extension in the basin occurred between 167 Ma and 135 Ma, with most extension occurring prior to 151 Ma. We show that extension after 135 Ma largely occurred east of Flemish Cap due to a shift in the locus of rifting from the Orphan Basin to east of Flemish Cap. We find no evidence for discrete rifting events in the Orphan Basin, as has been suggested by other authors. Kinematic restoration and associated heave measurements for the Orphan Basin show that extension was both widespread and relatively evenly distributed across the basin from Middle-Late Jurassic to Early Cretaceous.

We provide evidence for more widespread deposition of Jurassic strata throughout the Orphan Basin than previously interpreted, and show that Jurassic deposition was controlled by the occurrence and displacement of crustal-scale extensional detachment faults. Structure in the three regional cross sections is dominated by large-scale, shallowly dipping extensional detachment faults. These faults mainly dip to the northwest and control the geometry and position of extensional basins – grabens and half-grabens – which occur at a range of scales. Stacked detachment surfaces, hyperextension, and attenuation of the crust are observed in central and eastern parts of the Orphan Basin. Zones of extreme crustal attenuation (to ca. 3.7 km) are interpreted to be coincident with large-displacement (up to 60 km) low-angle detachments. Results from crustal area balancing suggest that up to 41% of extension is not recognized through structural seismic interpretation, which we attribute to subseismic-scale ductile and brittle

deformation, and uncertainties in the identification of detachment surfaces or complex structural configurations (e.g., overprinting of early extensional deformation).

Rifting style in the central, northern, and eastern parts of the Orphan Basin is dominated by low-angle detachment faulting with maximum extension perpendicular to the incipient rift axis. In contrast, structural geometries in the southwestern part of the basin are suggestive of transtensional deformation, and interplay of normal and strike-slip faulting. Results from map-based interpretation show that strike-slip faults within this transtensional zone are associated with displacement transfer between half-grabens of opposing polarity, rather than regional strike-slip displacement. These structures are interpreted as contemporaneous and kinematically linked to displacement along low-angle detachment surfaces elsewhere, and are not attributed to distinct episodes of oblique extension.