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Diachronous Growth of Normal Fault Systems in Multiphase Rift Basins: Structural Evolution of the East Shetland Basin, Northern North Sea

Johan S. Claringbould (1), Rebecca E. Bell (1), Christopher A-L. Jackson (1), Robert L. Gawthorpe (2), and Tore Odinsen (3)

(1) Basins Research Group (BRG), Department of Earth Science and Engineering, Imperial College London, SW7 2BP, UK, (2) Department of Earth Science, University of Bergen, Allégaten 41, 5007 Bergen, Norway, (3) Statoil ASA, Sandslihaugen 30, 5254 Sandsli, Norway

Our ability to determine the structural evolution and interaction of fault systems (kinematically linked group of faults that are in the km to 10s of km scale) within a rift basin is typically limited by the spatial extent and temporal resolution of the available data and methods used. Physical and numerical models provide predictions on how fault systems nucleate, grow and interact, but these models need to be tested with natural examples. Although field studies and individual 3D seismic surveys can provide a detailed structural evolution of individual fault systems, they are often spatially limited and cannot be used examine the interaction of fault systems throughout the entire basin. In contrast, regional subsurface studies, commonly conducted on widely spaced 2D seismic surveys, are able to capture the general structural evolution of a rift basin, but lack the spatial and temporal detail. Moreover, these studies typically describe the structural evolution of rifts as comprising multiple discrete tectonic stages (i.e. pre-, syn- and post-rift). This simplified approach does not, however, consider that the timing of activity can be strongly diachronous along and between faults that form part of a kinematically linked system within a rift basin.

This study focuses on the East Shetland Basin (ESB), a multiphase rift basin located on the western margin of the North Viking Graben, northern North Sea. Most previous studies suggest the basin evolved in response to two discrete phases of extension in the Permian-Triassic and Middle-Late Jurassic, with the overall geometry of the latter rift to be the result of selective reactivation of faults associated with the former rift. Gradually eastwards thickening intra-rift strata (deposited between two rift phases) that form wedges between and within fault blocks have led to two strongly contrasting tectonic interpretations: (i) Early-Middle Jurassic differential thermal subsidence after Permian-Triassic rifting; or (ii) Triassic syn-rift activity on west-dipping faults.

Our analysis of regional 2D and basin-wide 3D 'mega-merge' seismic reflection data calibrated by wells allow us to re-evaluate the pre-Triassic-to-Cretaceous structural evolution of the ESB. Our results suggest that pre-Triassic extension was accommodated by diachronous growth of NW-SE-to-NE-SW-striking faults that dipped either to the east or the west. In the NW of the ESB, Triassic syn-rift deposits are observed along large (>20 km long), NE-SW-striking faults. Elsewhere in the basin, post-rift deposits gradually thicken eastward, suggesting differential Triassic post-rift thermal subsidence with its axis to the east of the ESB. Subsequent Early-to-Middle Jurassic deposits thicken eastward across large N-S striking faults, suggesting syn-depositional fault growth.

Our observations suggest that, rather than forming in response to discrete periods of extension separated by periods of tectonic quiescence, the ESB witnessed diachronous fault system evolution with faults showing polyphase activity, cross-cutting relationships, and protracted growth from the pre-Triassic to Middle-Late Jurassic. The results of this work reveal the complex structural evolution of rifts, highlight the power of 3D mega-merge seismic reflection data, and demonstrate that the conventional rift package nomenclature of pre-, syn-, and post-rift is difficult to apply at the basin-scale.