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Integrating Reflection Seismic, Gravity and Magnetic Data to Reveal the Structure of Crystalline Basement: Implications for Understanding Rift Development

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Numerous rifts form above crystalline basement containing pervasive faults and shear zones. However, the compositional and mechanical heterogeneity within crystalline basement and the geometry and kinematics of discrete and pervasive basement fabrics are poorly understood. Furthermore, the interpretation of intra-crustal structures beneath sedimentary basins is often complicated by limitations in the depth of conventional seismic imaging, the commonly acoustically transparent nature of basement, limited well penetrations, and complex overprinting of multiple tectonic events. Yet, a detailed knowledge of the structural and lithological complexity of crystalline basement rocks is crucial to improve our understanding of how rifts evolve. Potential field methods are a powerful but perhaps underutilised regional tool that can decrease interpretational uncertainty based solely on seismic reflection data.

We use petrophysical data, high-resolution 3D reflection seismic volumes, gridded gravity and magnetic data, and 2D gravity and magnetic modelling to constrain the structure of crystalline basement offshore western Norway. Intra-basement structures are well-imaged on seismic data due to relatively shallow burial of the basement beneath a thin (<3.5 km) sedimentary cover. Variations in basement composition were interpreted from detailed seismic facies analysis and mapping of discrete intra-basement reflections. A variety of data filtering and isolation techniques were applied to the original gravity and magnetic data in order to enhance small-scale field variations, to accentuate formation boundaries and discrete linear trends, and to isolate shallow and deep crustal anomalies. In addition, 2D gravity and magnetic data modelling was used to verify the seismic interpretation and to further constrain the configuration of the upper and lower crust.

Our analysis shows that the basement offshore western Norway is predominantly composed of Caledonian allochthonous nappes overlying large-scale anticlines of Proterozoic rocks of the Western Gneiss Region. Major Devonian extensional brittle faults, detachments and shear zones transect those tectono-stratigraphic units. Results from structural analysis of enhanced gravity and magnetic data indicate the presence of distinct intra-basement bodies and structural lineaments at different scales and depth levels which correlate with our seismic data interpretation and can be linked to their onshore counterparts exposed on mainland Norway. 2D forward models of gravity and magnetic data further support our interpretation and quantitatively constrain variations in magnetic and density properties of principal basement units.

We conclude that: i) enhanced gravity and magnetic data are a powerful tool to constrain the geometry of individual intra-basement bodies and to detect structural lineaments not imaged in seismic data; ii) insights from this study can be used to evaluate the role of pre-existing basement structures on the evolution of rift basins; and iii) the integration of a range of geophysical datasets is crucial to improve our understanding of the deep subsurface.