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Do pre-existing basement structures influence the geometry and growth of normal faults and rifts?

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Rifts often evolve on a template of crystalline basement that may contain strong lithological and mechanical heterogeneities related to complex pre-rift tectonic histories. Numerous studies argue that reactivation of such pre-existing structures can influence the geometry and evolution of normal faults and rift physiography. However, in many cases: (i) it is unclear where, if at all, structures at the rift margin continue along-strike below the rift axis; and (ii) the precise geometric and kinematic relationship between pre-existing structures and newly formed normal faults is not well understood. These uncertainties reflect the fact that: (i) potential field data are typically of low-resolution, and thus cannot resolve the detailed morphology of shallow fault networks; (ii) field data cannot provide an accurate 3D image of intra-basement structures and the overlying rift; and (iii) seismic reflection data typically do not image deeply buried intra-basement structures. Understanding the kinematic as well as geometric relationship between intra-basement structures and rift-related fault networks is important for understanding plate motions and for undertaking stress inversions, given that paleo-extension directions (and sigma 3) are, in many rifted provinces, typically thought to lie normal to the dominant fault strike.

We here tackle these problems using subsurface data from the Taranaki Basin, offshore New Zealand, and the northern North Sea, offshore west Norway. Our data provide excellent imaging of shallowly buried intra-basement structures, as well as cover-hosted normal faults and their associated pre- and syn-growth strata. We identify a range of intra-basement structures, both extensional and contractional,, and a range of geometric and kinematic interactions between intra-basement structures and cover normal faults. For example, some of the normal faults are physically connected to intra-basement structures oriented oblique to the regional extension direction. It is notable that, even in cases, intra-basement structures were apparently not extensionally reactivated during the later rift phase. Displacement maxima on cover faults occur at

100-200 m above the crystalline basement-cover interface, suggesting the former did not form due to simple extensional reactivation and upward propagation of pre-existing structures; rather, ‘passive’ basement structures somehow perturbed the regional stress field, leading to the development of normal faults whose strikes mimic those of the underlying pre-existing basement structures. Cover normal faults can also display a range of complex geometries related to the linkage of numerous, originally separate slip surfaces, and upward-bifurcation of strongly segmented fault systems. We also show that the timing of physical linkage between basement and cover structures can be recorded in the geometry of related growth strata, which document the switch from non-rotational to rotational faulting.

Our analyses show that km-scale, intra-basement structures can control the nucleation and development of newly formed, rift-related normal faults, most likely due to a local perturbation of the regional stress field. Because of this, simply inverting fault strike for causal extension direction may be incorrect, especially in provinces where pre-existing, intra-basement structures occur. We also show that a detailed kinematic analysis is key to deciphering the temporal as well as the geometric relationships between structures developed at multiple structural levels.