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The 3D structure and growth of dykes and dyke-induced normal faults

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Dyke intrusion can accommodate extension during continental rifting through to seafloor spreading. To track dykes in active rifts, seismicity and ground deformation data is used to detect faults driven by dyke intrusion. It has particularly been recorded that graben-bounding normal faults develop above dykes that open as the host rock extends. Such dyke-induced normal faults have been observed along active continental rifts and oceanic spreading centres, as well as on volcanoes in various tectonic settings and on other planets. Because the location, structure, and displacement of dyke-induced normal faults reflect the volume, position, and dynamics of dykes, understanding how normal faults grow above and relate to dyke emplacement is fundamental to: (1) determining the role of dykes in continental break-up; (2) identifying dyke-induced faults and dykes along volcanic rifted margins, where they have yet to be observed, thus allowing their impact on ancient breakup events, margin evolution, and petroleum system development to be evaluated; (3) enabling extraction of more accurate dyke properties from monitored dyke-induced fault events, thereby improving eruption forecasting; and (4) deciphering the evolution of other planets. Over the last 40 years, numerous modelling approaches have been employed to assess how faults grow above dykes. Four hypotheses emanating from these models suggest faults either grow downwards from the surface, upwards from the dyke tip, a combination of both, or that they initiate between and grow towards the dyke tip and surface. Whereas final fault geometry is similar across these hypotheses, their growth patterns predict unique fault displacement trends. However, we cannot rigorously test these hypotheses due to a lack of sufficient 3D field exposures or geophysical images that detail dyke-induced fault structure. Furthermore, most models are 2D and only examine vertical fault growth, without considering how faults grow laterally, interact with each other, or respond to different dyke propagation directions and far-field stress conditions. The applicability of the different hypotheses to natural examples therefore remains contentious, compromising how we infer dyke properties from dyke-induced faults. We have identified a suite of dykes and dyke-induced faults, which extend for >100 km, in 3D seismic reflection data from offshore NW Australia. These data present a unique opportunity to quantify fault displacement patterns and thereby test hypotheses concerning fault growth above dykes. Associated with the dykes and dyke-induced faults are a series of pit chain craters, similar to structure observed in modern rifts and on other planetary bodies, allowing us to examine their 3D morphology. Overall, our work will provide new insights into the identification and growth of dykes and dyke-induced normal faults, revealing how they contribute to continental rifting and breakup.