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Diachronous fault array growth within continental rift basins: Quantitative analyses from the East Shetland Basin, northern North Sea

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The evolution of rift basins has been the subject of many studies, however, these studies have been mainly restricted to investigating the geometry of rift-related fault arrays. The relative timing of development of individual faults that make up the fault array is not yet well constrained. First-order tectono-stratigraphic models for rifts predict that normal faults develop broadly synchronously throughout the basin during a temporally distinct 'syn-rift' episode. However, largely due to the mechanical interaction between adjacent structures, distinctly diachronous activity is known to occur on the scale of individual fault segments and systems. Our limited understanding of how individual segments and systems contribute to array-scale strain largely reflects the limited dimension and resolution of the data available and methods applied. Here we utilize a regional extensive subsurface dataset comprising multiple 3D seismic MegaSurveys (10,000 km2), long (>75km) 2D seismic profiles, and exploration wells, to investigate the evolution of the fault array in the East Shetland Basin, North Viking Graben, northern North Sea. Previous studies propose this basin formed in response to multiphase rifting during two temporally distinct extensional phases in the Permian-Triassic and Middle-to-Late Jurassic, separated by a period of tectonic quiescence and thermal subsidence in the Early Jurassic. We document the timing of growth of individual structures within the rift-related fault array across the East Shetland Basin, constraining the progressive migration of strain from pre-Triassic-to-Late Jurassic. The methods used include (i) qualitative isochron map analysis, (ii) quantitative syn-kinematic deposit thickness difference across fault & expansion index calculations, and (iii) along fault throw-depth & backstripped displacement-length analyses. In contrast to established models, we demonstrate that the initiation, growth, and cessation of individual fault segments and systems was strongly diachronous across the East Shetland Basin. Moreover, we document protracted fault activity throughout the pre-Triassic-to-Late Jurassic, challenging the notion that a basin-wide period of tectonic quiescence characterised the Early Jurassic. We argue that the diachronous development of individual fault segments and systems may have resulted from variable strain distribution throughout the rift basin over time. This is possibly a result of the narrowing underlying lithospheric thermal structure across the Northern North Sea during this time. The pre-Triassic-to-Late Jurassic diachronous development of individual faults across East Shetland Basin hampers the usage of first-order discrete tectonic stages (i.e. pre-, syn-, and post-rift) on the fault array scale. When describing the evolution of rift margin covering fault arrays, we suggest the usage of rift maxima and minima (i.e. higher and lower basin-wide fault activity) during a first-order syn-rift phase.