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Geometry and controls on the development of igneous sill-related forced folds: 2D seismic reflection case study from offshore Southern Australia

Christopher Jackson (1), Nick Schofield (2), Craig Magee (1), and Bogdan Golenkov (1)

(1) Basins Research Group (BRG), Department of Earth Science and Engineering, Imperial College, London, SW7 2BP, UK, (2) School of Geosciences, University of Aberdeen, Meston Building Old, Aberdeen, AB24 3UE, UK

Emplacement of magma in the shallow subsurface can result in the development of dome-shaped folds at the Earth's surface. These so-called 'forced folds' have been described in the field and in subsurface datasets, although the exact geometry of the folds and the nature of their relationship to underlying sills remains unclear and, in some cases, controversial. As a result, the utility of these features in tracking the subsurface movement of magma, and predicting the potential size and location of potentially hazardous volcanic eruptions, is uncertain. Here we use high-quality, 2D seismic reflection and borehole data from the Ceduna sub-basin, offshore southern Australia to describe the structure and infer the evolution of igneous sill-related forced folds in the Bight Basin Igneous Complex (BBIC). We mapped 33 igneous sills, which were emplaced 200-1500 m below the palaeo-seabed in an Upper Cretaceous, coal-bearing, predominantly coastal-plain succession. The intrusions, which are expressed as packages of high-amplitude reflections, are 32-250 m thick and 7-19 km in diameter. They are overlain by dome-shaped folds, which are up to 17 km wide and display up to 210 m of relief. The edges of these folds coincide with the margins of the underlying sills and the folds display the greatest relief where the underlying sills are thickest; the folds are therefore interpreted as forced folds that formed in response to emplacement of magma in the shallow subsurface. The folds are onlapped by Lutetian (middle Eocene) strata, indicating they formed and the intrusions were emplaced during the latest Ypresian (c. 48 Ma). We demonstrate that fold amplitude is typically less than sill thickness even for sills with very large diameter-to-depth ratios, suggesting that pure elastic bending (forced folding) of the overburden is not the only process accommodating magma emplacement, and that supra-sill compaction may be important even at relatively shallow depths. Based on the observation that the sills intruded a shallowly-buried succession, the discrepancy between fold amplitude and sill thickness may reflect loss of host rock volume by fluidisation and pore fluid expulsion from poorly-lithified, water-rich beds. This study indicates that host rock composition, emplacement depth and deformation mechanisms are important controls on the style of deformation that occurs during intrusive igneous activity, and that forced fold amplitude may not always reflect the thickness of an underlying igneous intrusion. In addition, the results of this study suggest that physical and numerical models need to model more complex host rock stratigraphies and rheologies if they wish to capture the full range of deformation mechanisms that occur during magma emplacement in the Earth's shallow subsurface.