THREE DIMENSIONAL ANALOGUE MODELLING OF EXTENSIONAL FAULT SYSTEMS AND THEIR APPLICATIONS TO THE BARROW-DAMPIER SUB-BASIN, WESTERN AUSTRALIA

By

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DEDICATION

In memory of my beloved father
Haji Fazal Elahi Minhas

STATEMENT OF AUTHENTICITY

To the best of my knowledge and belief, the thesis contains no material which has been accepted for the award of any other degree or diploma in any University and the thesis contains no material previously published or written by another person, except where due reference is made in the text of the thesis.

If accepted for the award of the degree and, if applicable, I consent to the thesis being made available for photocopying and loan.

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ABSTRACT

Scaled models of tectonic structures are often used to show allowable geometries and to illustrate the effects of progressive deformation. Analogue modelling is a tried and proven technique for simulating extensional fault structures and can imitate the style of structures imaged by seismic reflections. Sandbox models were constructed to simulate extensional structures above simple listric, ramp-flat-ramp and complex detachment morphologies. Only one modelling style was used in this thesis, that of a fixed footwall with a non-stretching plastic film attached to the movingwall of the box which separates the footwall from the hangingwall along the detachment surface. These models cannot simulate thermal, isostatic, compactional and confining pressure effects. Dry quartz sand with a grain size of approximately 300μm was used as a modelling material in 2D experiments, sand mixed with plaster and a PVA compound in 3D experiments and coarse granular $NaHCO_3$ was used in Computerised Tomography experiments.

Previous extensional sandbox models were unable to demonstrate structural patterns where pre-existing faults with a range of orientations became incorporated in the extension. A new 3D technique has been devised to simulate extensional structures developed in regions where the sediments have been subject to more than one period of extension, each with a different orientation. 3D models were stabilised and physically cut Both 2D and 3D models were made as, both, forward models and as reconstructions of field examples based on seismic interpretation. The forward models investigated hangingwall deformation and fault patterns in areas where a listric extensional fault is modified by the presence of an existing fault at an angle to the current detachment. The field examples involved constructing models of the detachment surface from depth converted seismic sections and deforming them to check the accuracy of the initial interpretation. Computerised Tomography (CT) technique has also been used to simulate progressive deformation.

2D experiments are repetitions of sandbox models described in the literature but present some new results. These experiments demonstrate sequential fault evolution and illustrate fault reactivation and nucleation during progressive stages of deformation. The tracing of particle motion during extensional deformation provides constraints on the validity of graphical depth-to-detachment and fault reconstruction techniques. Modified Chevron Construction and Inclined Shear Construction, which imply movement parallel to the detachment or inclined shear planes are considered likely to be accurate, whereas, my analysis shows that even those are inadequate. A geometric interpretation of particle paths has been suggested. A wide variety of detachment morphologies and their combinations were constructed in the 3D model box. 3D modelling allows edge effects to be avoided or specifically included and allows for more complex detachment surfaces to be modelled. The building of a side ramp into a 3D model can simulate the presence of faults that pre-date the active extensional features. These models allow the recognition of fault patterns in plan view, as the active faults approached pre-existing faults. These models show relative distribution of pre-rift and syn-rift sediments in extensional regimes. The models constructed with an end ramp incorporating a side ramp show a rotational block and a crestal collapse block parallel to each ramp with a third graben developed above the intersection of the two detachment ramps. These experiments show that the hangingwall geometries are mainly controlled by main active detachment, although, the side ramp has a strong influence on the hangingwall structure. Computerised Tomography is a non-destructive technique for the analysis of internal fault geometries of analogue models. Materials with low X-ray attenuation are the most appropriate for tomography. Various low density materials were tested which have similar mechanical properties to sand and coarse granular $NaHCO_3$ was selected as the most appropriate material. It provided results on the relative compaction and dilation of a sedimentary sequence in extensional sedimentary basins. The main areas chosen to model field examples are from the North West Shelf, Western Australia. The Barrow and Dampier Sub-basins provided three examples to be modelled into a scaled model box. Specific 2D and 3D models constrained by seismic interpretation and depth conversion, confirmed the existence of the Mermaid Fault as a ramp-flat-ramp detachment.

There was a major period of extension on the detachment during the Permian with movement diminishing through the Triassic. The modelling makes it clear that the substantial unconformity developed between the Late Permian and Early Triassic involved considerable uplift of the area to the west of Arabella-1. 3D modelling of the Beagle Sub-basin suggests that the Cossigny Fault was an early, deep seated fault that acted as a side ramp to later extension. 3D modelling also shows that the sedimentation history in the Cossigny Trough should be the same as that in the Beagle Trough and Thouin Graben. Flinders Fault is a planar fault with hangingwall deformation where subsidence dominates over extension. This case study suggested that the model can be improved by continuous sloping the distal part of the detachment. 3D modelling of the Sholl Island Fault has confirmed that the hangingwall above low angle detachments deforms by rotation with little faulting and minimal development of a crestal collapse block. The comparison of modelling with seismic can only be achieved after depth conversion, so that the imaged structures are presented as true depth sections.

Sandbox modelling work done in this thesis conclude that the shape of an extensional detachment surface is the major control on the geometry of deformation of the hangingwall. General rules have been concluded for the development of faults in extensional hangingwall deformation controlled by the intersection and shape of the detachment. These rules only apply to cases where the detachment does not stretch. The shape of rollover anticline differs slightly when the side ramp is planar rather than listric and in the planar case the hangingwall deformation is mainly controlled by antithetic faults. Three prominent graben produce by extension diagonally away from two pre-existing side ramps, two of them parallel to each side ramp with a third graben at the intersection of detachments. A curved listric detachment produce a single graben parallel to the strike of the main detachment. Rotational extension produce a style of extensional deformation where a narrow crestal collapse block on the slow moving wall develops, this merges to form a wider crestal collapse block in the fast moving zone. Differential extension above a simple listric detachment creates an orthogonal transfer fault zone. A listric end ramp constructed at an angle of 220 degrees to the active detachment produce characteristic features, such as reduced subsidence above the "nose". This nose is a natural consequence of extension from a backward dipping detachment morphology, e.g., the change in orientation between the Barrow and Dampier Sub-basins.

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