ORIGIN AND STRUCTURE OF THE CEDUNA DELTA SYSTEM, OFFSHORE SOUTH AUSTRALIA

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Abstract

This thesis consists of five papers, each of which complements the regional understanding of the Ceduna Delta System, offshore South Australia. Deltas commonly form linked systems of extension, on the delta top, and compression, in the delta toe. This link is promoted by the presence of a detachment layer of more ductile sediments at the base of the delta, which mechanically decouples deltaic sediments from those beneath it. These systems are often explained using Critical Taper Wedge mechanics, which is commonly applied to understand the rock strength properties and the role of pore fluid pressure at the base of the wedge (within the detachment layer) and within the wedge, in these linked systems of extension and compression.

To better understand the effect of basal pore fluid pressure on delta—deepwater fold thrust belt systems, I present an in-depth application of Critical Taper Wedge mechanics to the data-rich deepwater Niger Delta Toe in West Africa, a modern day analogue for the ancient Ceduna Sub-basin (Paper 1). This application involved developing a new technique to measure key variables from seismic reflection data in the Niger Delta Toe and input them into a script to calculate the basal pore fluid pressure required to form the observed present-day geometries. With this new approach and increased understanding of the role of basal pore fluid pressure on delta wedge geometry it was possible to better understand how detachment variables control distribution of the lobes that comprise the Cretaceous-age Ceduna Delta. Regional structural mapping of the Ceduna Delta resulted in separation of the delta lobes based on tectonic style and also examining the linkages between the systems, explaining the unique stacking of the delta tops while each system maintained independent deepwater fold-thrust belts (Paper 2).

Furthermore, detailed 3D seismic reflection data is interpreted to investigate inversion structures and potential for fault reactivation in the basin (Paper 3). The boundary element method geomechanical code Poly3D© was used to investigate delta-top fault reactivation potential from a 3D seismic derived fault network along with the present day stress determined from petroleum wells. Results demonstrate a moderate to high probability for contemporary reactivation of faults under a strike-slip to strike-slip-normal fault stress regime (Paper 3).

In addition, detrital zircon analysis, apatite fission track analysis and zircon fission track analysis were undertaken to investigate the potential source(s) for the deltaic sediment input in the Ceduna Delta system (Paper 4). Over 1500 detrital zircon and apatite grains were analysed from petroleum wells and outcrop samples located onshore and offshore South Australia. The results indicate approximately 1-2 km of Late Cretaceous uplift/exhumation of the proximal arcuate shaped South Australian southern margin provided the source for the Santonian-Maastrichtian delta lobe, mainly from erosion of existing Permian-Cenomanian sedimentary cover. Finally, the last paper presented in this thesis (Paper 5) ties in new 2D reflection seismic data that was not available when Paper 2 was written, to further examine the geometry of the deepwater fold-thrust belts and the hydrocarbon potential of the Ceduna Sub-basin.

Table of Contents

Papers

Paper 1: MacDonald, J.D., Healy, D., King, R., and Backé, G., (*in review*): Mapping basal pore fluid pressure variations in the Niger Delta toe with a critical taper wedge model. *Marine and Petroleum Geology.*

Paper 2: MacDonald, J.D., King, R., Hillis, R.R., and Backé, G., (2010): Structural style of the White Pointer and Hammerhead Delta—Deepwater Fold-Thrust Belts, Bight Basin, Australia. *The Australian Association of Petroleum Production and Exploration Journal,* v 50, 487-510.

Paper 3: MacDonald, J.D., Backé, G., King, R., Holford, S., and Hillis, R.R., (2012): Geomechanical modelling of fault reactivation in the Ceduna Sub-basin, Bight Basin, Australia, *in*: Healy, D., Butler, R. W. H., Shipton, Z. K. & Sibson, R. H. (eds) 2012. Faulting, Fracturing and Igneous Intrusion in the Earth's Crust. *Geological Society, London, Special Publications*, 367, 71–89.

Paper 4: MacDonald, J.D., Holford, S., Green, P.F., Duddy, I., King, R., and Backé, G., (2013): Detrital Zircon Data Reveal the Origin of Australia's Largest Delta System. *Journal of the Geological Society, London.*

Paper 5: MacDonald, J.D., Holford, S., and King, R., (*in press*): Structure and Prospectivity of the Ceduna Delta—Deepwater Fold-Thrust Belt Systems, Bight Basin, Australia, *in*: Rosen, N.C., (ed) 2012. New understanding of the petroleum systems of the continental margins of the world. *GCSSEPM Foundation Bob F. Perkins Research Conference, v 32.*

Declaration

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4/4/2013

Justin Dedric MacDonald — Date

Statement of Authors' Contributions

The research summarized in the papers that constitute this thesis was undertaken within the 'S^3' research group (Stress, Seismic and Structure; formally the stress group) at the Australian School of Petroleum (ASP), with industry collaborators (Geotrack International Pty Ltd; Paul Green & Ian Duddy) and with an external co-supervisor at the University of Aberdeen (Dave Healy). The ASP 'S^3'group comprises several PhD students, research staff and lecturers who collaborate across a broad range of stress, tectonic, thermochronological, geochronological and structural/geomechanical related issues. Hence, all the papers presented are co-authored and detailed statements of relative contribution are summarised below and endorsed by the co-authors.

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