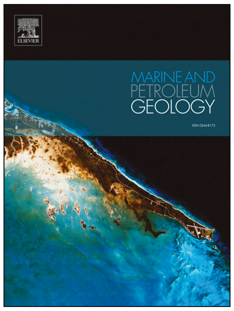

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Coupling a frictional-cohesive cover and a viscous substrate in a discrete element model: first results of application to thick- and thin-skinned extensional tectonics.

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Abstract

Mechanical stratigraphy is now recognised as a fundamental control on the development of geological structures in the upper crust at a variety of different scales. This is perhaps never more apparent than when salt is part of the crustal section being deformed. The interaction of a ductile salt substratum and a brittle sedimentary cover is complex, but an understanding of it is essential both from an economic and academic standpoint. Here, I present first results of a discrete element model which combines a viscous (linear Newtonian) substrate and a frictional-cohesive cover. The modelling approach is firstly presented and experimental scaling to appropriate geological timescales discussed. The approach is then applied to 3 experiments simulating extensional deformation, two of which are thick-skinned and one is thin-skinned. Strain rates in all experiments are c. 10^{15} s^{-1}. The complex manner in which salt flows in the substrate and faults develop in the cover are illustrated and their linkage/evolution examined. Movement of the viscous substrate is the result of both Couette-type and Poiseuille-type flows and combinations thereof, whilst deformation in the cover takes the form of discrete, dilational faults which are not directly linked, or only soft-linked, to any sub-salt basement faults. Cover faults typically lose displacement towards, and tip out at, the cover-substrate interface. In addition, in models with a basement fault, the fault itself presents a growing and important no-slip boundary which significantly affects viscous flow. Implications for the timing/evolution of, and strain within, the resultant structures are discussed.

Introduction

Geological structures in sedimentary basins, or continental margins, are rarely simple and much of their complexity arises from the stratigraphic, and thus mechanical, heterogeneity of the crustal section being deformed. As a consequence of such mechanical heterogeneity, different sections of the sedimentary upper crust can deform in very different manners. This is particularly marked when salt is part of the stratigraphy (e.g., Stewart *et al*., 1996, 1997; Jackson and Lewis, 2016; Ge *et al*., 2016; Fig. 1a). This is because evaporite rocks, in particular salt, are much weaker than most other sediments. The viscosity of rock salt is subject to some debate but perhaps ranges between $1x10^{16}$ and $1x10^{18}$ Pa.s (Jackson and Talbot, 1986; Withjack and Callaway, 2000). It will vary additionally depending on mechanical layering within the sequence itself and laterally. Regardless of the precise value, this allows it to flow over geological timescales and deform into the complex structures observed both in the field and in seismic. The involvement of salt in deformation has been studied through many geological and geophysical observations (e.g., Wu *et al*., 1990; Demercian *et al*., 1993; Marton *et al*., 2000; Rowan *et al*., 2000; Tari *et al*., 2002; Cartwright *et al*., 2012; Jackson and Lewis, 2016; Fig. 1a), principally as the result of hydrocarbon exploration. Significant thicknesses of salt occur in many passive continental margins and rifts (e.g., the Gulf of Mexico, many West African marginal basins, the Brazilian margin, the Nova Scotian margin, the North Sea). Continental margins typically contain a seaward thinning sedimentary wedge which often includes thick salt units. Moreover, they are characterised by a region of landward extension and a region of seaward contraction; which may be attributed to failure of the sedimentary overburden that accompanies the flow of the underlying salt (e.g., Worrall and Snelson, 1989; Koyi, 1996; Ge *et al*., 1997; Rowan *et al*., 2000). In many rift basins, such as the North Sea, evaporite rocks, including halite and gypsum, form an important, thick part of the pre-rift stratigraphy and can influence the structural and stratigraphic evolution of the rift (e.g., Hodgson *et al*., 1992; Stewart *et al*., 1999; Alves *et al*., 2002; Hudec & Jackson, 2007; Marsh *et al*., 2010; Duffy *et al*., 2013; Lewis *et al*., 2013). The evaporite units may fully or partially decouple the sub-salt deformation from that in supra-salt strata, giving rise to markedly different structural styles above and below the evaporite unit (Stewart *et al*., 1996, 1997; Withjack & Callaway, 2000; Richardson *et al*., 2005; Duffy *et al*., 2013; Fig. 1a,b). Salt also provides a ductile detachment layer allowing thin-skinned deformation to develop in the supra-salt strata when tilting induces gravitational sliding (e.g., Stewart & Coward, 1995; Stewart, 2007).