Passive Margin Salt Tectonics: Effects of Margin Tilt, Sediment Progradation, and Regional Extension

Steven J. Ings*
Department of Earth Sciences, Dalhousie University, Halifax, NS, B3H 3J5
sings@dal.ca

and

Lykke Gemmer and Chris Beaumont
Department of Oceanography, Dalhousie University, Halifax, NS, B3H 4J1

ABSTRACT

Deformation of many passive continental margin sedimentary packages is dominated by salt tectonics (e.g., offshore west Africa, east Brazil, eastern Canada). In many cases, salt became mobilized at an early stage of basin formation. In cases where salt deposition was syn-rift or immediately post-rift (e.g., Scotian margin, offshore eastern Canada), early salt mobilization may have been initiated by a combination of tilting and regional extension of the margin. On the Scotian margin, salt tectonics has been long-lived; once salt was initially mobilized, it continued to deform well into the Tertiary. Sediment progradation and aggradation into the Scotian Basin was likely the primary control on long-lived salt tectonics on the Nova Scotian margin.

We analyze the driving mechanisms of passive margin salt tectonics using finite element numerical models of a viscous substratum (salt) overlain by a frictional-plastic overburden (sedimentary rocks), and present results of models incorporating margin tilting, regional extension, and sedimentation.

The numerical models show that sediment progradation combined with basinward tilt destabilizes the salt-overburden system more than progradation alone. A basinward margin tilt of 1 degree accelerates the evolution of the system, and thereby produces landward extensional structures and basinward contractional salt structures earlier in the model evolution than with progradation alone, resulting in the formation of long allochthonous salt sheets extending greater lateral distances than in equivalent models without tilt.

Understanding the destabilizing mechanisms of salt on passive continental margins is vital to understanding the history of salt structure formation. This research may lead to improved seismic interpretations and hydrocarbon maturation estimates of shelf and slope sediments, offshore Nova Scotia and elsewhere.

Introduction

On many passive margins, salt-related structures are the dominant features visible in seismic sections (e.g., Marton et al. 2000). The study of salt tectonics aids our understanding of passive margin development and is highly relevant to petroleum exploration. Alsop et al. (1996), for example, estimated that salt and related sedimentary deformation structures are responsible for trapping up to 60 % of the hydrocarbon reserves in the Middle East. Further, the thermal properties of salt affect the heat budget in the petroleum system, thereby influencing maturation and hydrocarbon generation. As petroleum exploration becomes increasingly focused on deepwater salt provinces (e.g., the Scotian slope), insight into the processes driving salt movement will be useful in constraining the timing of salt structure development and also the implications this has for sediment distribution patterns and hydrocarbon maturation.

Numerical Model

Results presented are based on 2-D finite element modeling experiments (Fullsack 1995). The numerical model uses velocity-based finite element calculations designed for large deformation creeping flows (i.e., fluid Stokes flows). As a result, the model is capable of calculating the large strains commonly associated with salt tectonics. Salt is modeled as a linear viscous material with a viscosity of 10^{18} Pa·s and sedimentary overburden is modeled as a frictional-plastic material with an internal angle of friction of 20°. The model is used to investigate the effects of margin tilt, regional extension, and sediment progradation in driving salt-related deformation. Fig. 1 illustrates the region of passive margins which we consider in the numerical model.

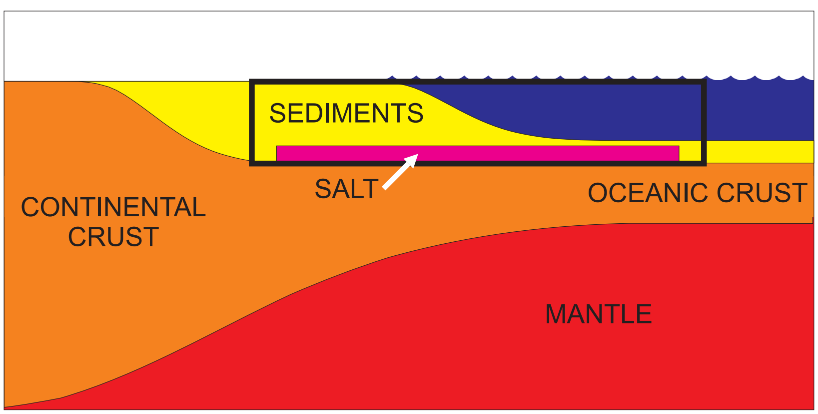

Fig. 1. Schematic diagram of a passive continental margin. Models in this paper are designed to investigate various salt tectonic processes of passive margins by considering the evolution of sedimentary overburden and salt in the region outlined in black.

Model Results

Fig. 2 is an example of a tilted margin model. In this model, a 600 km long model in which a 420 long, 1 km thick layer of salt (magenta) is overlain by an initially 0.5 km thick layer of sediments (yellow). As time progresses, sediments prograde into the model from the left (the landward end of the model) at a rate of 1 cm/yr. The prograding sediments have the same mechanical properties as the initial sedimentary overburden. The deposited sediment layers are coloured in order to visualize their deformation. Each layer represents 1 Myr of deposition. The model has a basinward tilt of 1°.

It is also necessary to consider the effects of sediment progradation combined with regional extension of the margin. The Scotian margin, for example, experienced at least two periods of extensional activity after salt deposition (Jackson and Vendeville 1994). Also during this time, multiple phases of progradation deposited thick successions of sediments onto the developing continental shelf (Wade and MacLean 1990). Modeling the effects of extension, combined with progradation, will aid in understanding whether or not extensional periods represent major periods of salt movement.

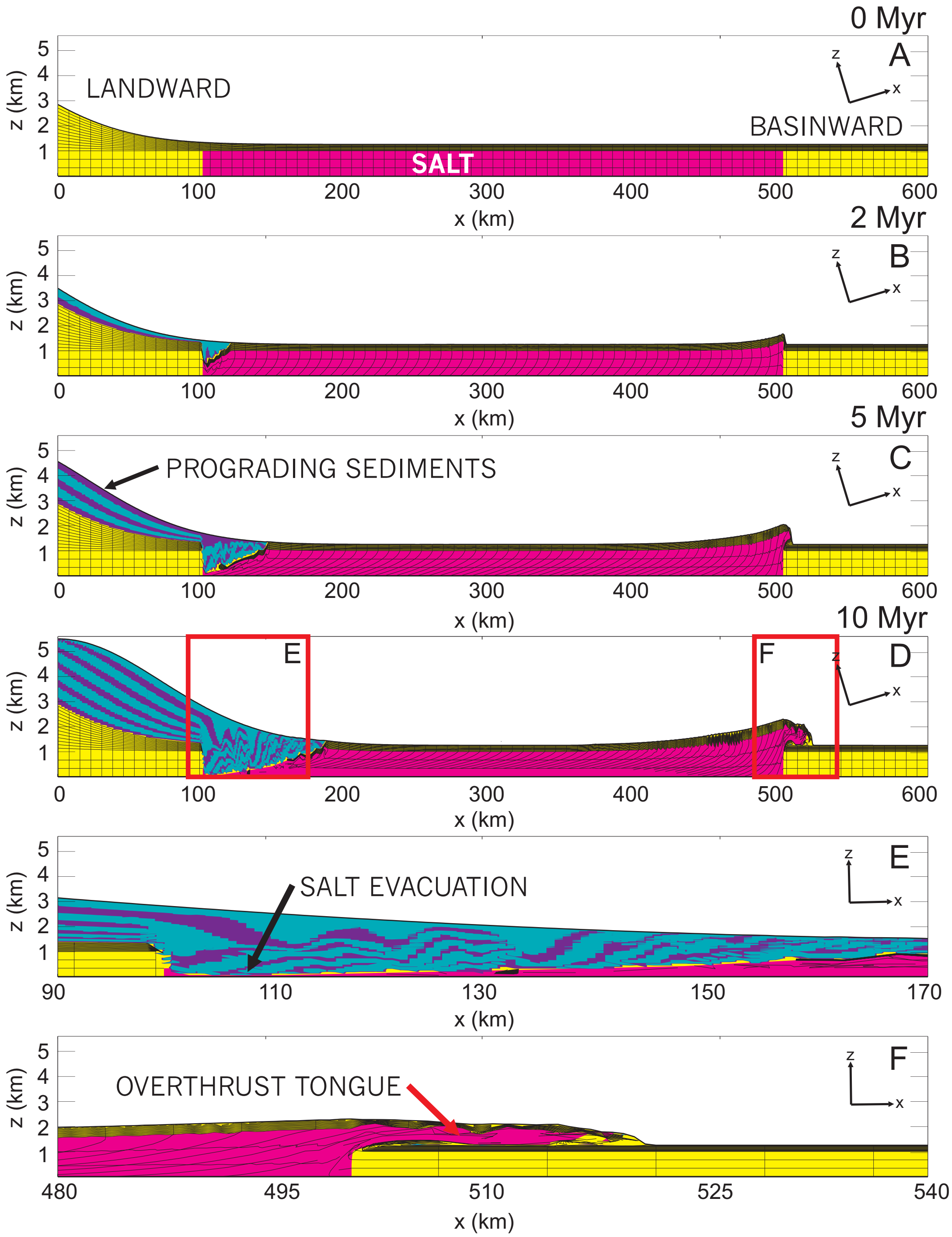

Fig. 2. Numerical model result of a tilted margin model; basinward margin tilt is 1°. Vertical exaggeration is ~ 17 in (A-D), ~1 in (E-F). The axes in the upper right indicate the orientation of the model relative to horizontal. Viscous salt (magenta) is overlain by frictional-plastic overburden (yellow). Sediments (blue and purple) prograde into the model at 1 cm/yr. (A) Initial model setup. (B-D) Evolution of the model from 2 to 10 Myr. (E) As the salt flows basinward, salt is evacuated from beneath the landward end. (F) Updip extension is accommodated by downdip contraction forming an allochthonous salt tongue as the salt overthrusts its depositional limit.

Ongoing Research

Fig. 3 illustrates the range of processes to be investigated in our models of passive margin salt tectonics. The methodology is to start with simple models and to increase the complexity of the model only as each individual processes is better understood. In the future, models incorporating isostasy will further the ideas of the tilted margin models presented in this paper. Such models may result in a reversal of the tilt of the salt layer as prograding sediments are isostatically balanced by basin subsidence. The current models do not consider the influence from seawater pressure in the submarine environment. This important effect influences the stability of the salt and its overburden and will also be included in future models.

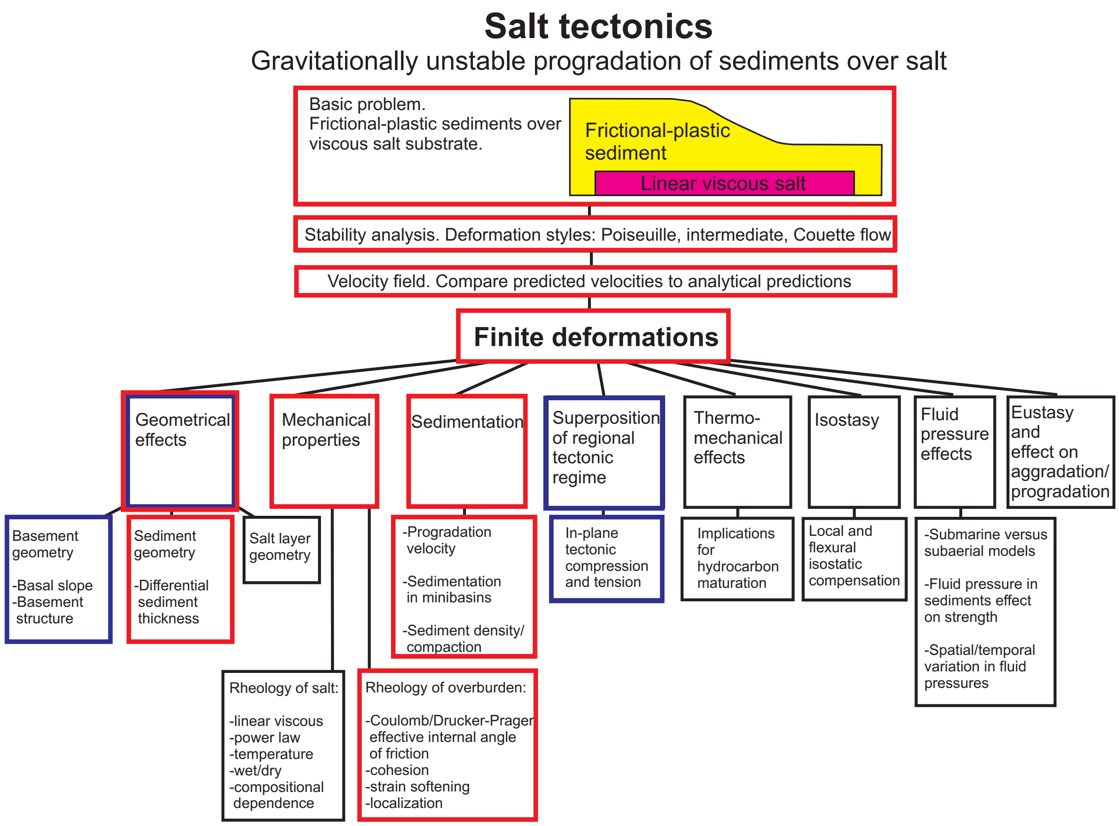

Fig. 3. Flowchart indicating our research plans relating to passive margin salt tectonics. Squares outlined in blue indicate the topics that are described in this paper. Squares outline in red indicate topics that are discussed in the paper: Gemmer, L., Ings, S., and Beaumont, C. 2003. Passive margin salt tectonics – dynamic modeling of sediment above a viscous salt layer; this volume.
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References

Alsop, G.I., Blundell, D.J., and Davison, I. (eds.) 1996. Salt Tectonics. Geological Society Special Publication 100, 310 pp.

Fullsack, P. 1995. An arbitrary lagrangian-eulerian formulation for creeping flows and its applications in tectonic models. Geophysical Journal International, 120: 1-23.

Gemmer, L., Ings, S., and Beaumont, C. Passive margin salt tectonics – dynamic modeling of sediment above a viscous salt layer. This volume.

Jackson, M.P.A., and Vendeville, B.C. 1994. Regional extension as a geologic trigger for diapirism. Geological society of America bulletin, 106: 53-73.

Marton, L.G., Tari, G.C., and Lehmann, C.T. 2000. Evolution of the Angolan passive margin, West Africa, with emphasis on post-salt structural styles. *In* Atlantic Rifts and Continental Margins, Geophysical Monograph 115. American Geophysical Union, p. 129-149.

Wade, J.A. and MacLean, B.C. 1990, The Geology of the southeastern margin of Canada, Chapter 5 in Geology of the Continental Margin of Eastern Canada, M.J. Keen and G.L. Williams (eds.); Geological Survey of Canada, Geology of Canada, no. 2, p. 167-238