Dynamical models of lithosphere extension, with reference to sedimentary basin formation

G.A. Houseman

Research School of Earth Sciences, Australian National University

The lithosphere extension model proposed by McKenzie (1978) has recently received increasing attention in tha analysis of basin tectonic and subsidence histories. It specifies a uniform horizontal extension, followed by thermal subsidence as the lithosphere returns to its original thermal equilibrium. This model or some variant of it has been applied by different authors to the Aegean Sea, the North Sea, the Bass Basin, and several other examples. The modelling to date is essentially kinematic, in that extension factors have been estimated without reference to the forces driving the tectonic activity. The work described here examines the stress state in the extending lithosphere in order to further develop the extensional model, and, possibly, to obtain useful constraints on the rheology of the lithosphere.

An extensional stress field in the lithosphere can result from localised elevation of the lithosphere by a hot rising thermal sheet or plume in the convecting mantle below. The lithosphere responds to an extensional deviatoric stress by normal faulting in the upper part of the crust and by ductile flow at greater depths. The model assumes that the strongest part of the lithosphere is the upper mantle, and uses the rheological laws for olivine summarised by Goetze (1978). For uplift of 1 km by a convective plume, the depth-averaged deviatoric extensional horizontal stress is around 16 MPa. The resulting strain rates depend strongly on the temperature in the upper part of the mantle.

Numerical models have been used to calculate the evolving temperature and stress fields in the extending lithosphere. The extension will be self limiting if the initial strain rate is sufficiently small, since cooling of the upper mantle associated with the thinning crust causes the ductile rheology to freeze (England, 1983). The subsidence histories for these theoretical extension models show several stages: (i) uplift (and possibly erosion), owing to plume formation; (ii) contemporaneous extension (active normal faulting), resulting in subsidence, owing to the thinned crust; (iii) thermal subsidence, owing to the cooling of the extended lithosphere; and (iv) further subsidence associated with the removal of the mantle plume.

References

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