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Analogue modelling of lithospheric-scale thinning and extension: Insights on magma-poor continental rifted margins

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The crustal-scale structure of rifted passive margins represents an issue of relevant academic and commercial hydrocarbon-industry interest, and has been extensively investigated in the last decade, using both geophysical prospecting and numerical and analogue modelling.

In spite of the efforts, some basic questions are still open to debate, mostly concerning the amount and mode of crustal and lithospheric thinning (e.g., Reston, 2009), and the possible depth- dependency of lithospheric stretching (e.g., Huismans and Beaumont, 2002). Although hampered by obvious limitations, sandbox analogue modelling has proven to be an effective way to investigate lithospheric-scale deformation, and particularly to visualize the 3D modelling evolution of modelling (Brun and Beslier, 1996; Callot et al., 2001, 2002; Michon and Merle, 2000, 2003).

This contribution presents the results of a set of lithospheric-scale sandbox modelling experiments aimed at investigating the relationship between brittle faulting and ductile thinning in the crust and mantle. Modelling has been performed in a sandbox using a 4-layers setup, with alternating layers of sand and silicone putty, representing the brittle and ductile rheology, respectively, of crust and mantle. The layer-cake has been set so as to float above a glucose solution, that represents the asthaenosphere, and the density of modelling materials has been appropriately scaled, in order to reproduce crustal and mantle rocks of a realistic lithospheric structure. Lateral anisotropy in the viscosity of the lower crust has been introduced in some 3D models.

The sandboxes used are made of plexiglass and have a width of ca. 30 cm and a length ranging from 40 to 50 cm. One of the short walls of the sandbox is pulled using a computer-controlled motor to impose extension at a velocity of 1 to 3 cm/hour; this wall is attached to two moving sidewalls that help pulling the sand/silicone layer-cake. Two end-member sets of models have been performed, based on the relative length of the two mobile sidewalls: a) the two sidewalls are of the same length and rifting is produced along a line parallel to the pulled wall, joining the tip of the sidewalls; and b) the two sidewalls have different lengths and, thus, an oblique rifting is produced. In the latter case, weak seeds in the brittle mantle are used to impose segmented boundaries. During extension loose sand has been poured at regular time intervals to simulate syn-rift sedimentation.

Laser scanning of the top surface has been performed at regular time intervals so as to monitor the surface faulting in the rift zone. At the end of extension (typically 12-20 cm), the models have been frozen and cut into vertical serial slices, so as to analyse the fault geometry in the volume unaffected by sidewall shearing, and to study the eventual 3D variations imposed in the model setup.

To a first order, the results show a pure shear affecting the ductile mantle lithosphere, in the initial stages, which is subsequently followed by a necking of the ductile lithospheric mantle and lower crust that join together, following the breakup of the brittle mantle. A simple shear deformation, typically dominated by one major extensional fault that soles out into the underlying ductile unit, characterizes the brittle upper layer. Typically, some degree of asymmetry in the fault system and in the sedimentary basin is observed in the brittle upper layer. Limited portions of weaker brittle mantle appear quite effective in localizing the main ductile mantle deformation, imposing the large-scale geometry of the rift system. Lateral heterogeneity in the viscosity of the lower crust affects the faulting of the overlying brittle layer, and may promote some degree of asymmetry in the rift fault patterns.

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