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Lithospheric and Crustal Thinning; Moretti, I. - Institut Français du Pétrole, B.P. 311, 92506 RUEIL MALMAISON CEDEX, France

In rift zones, both the crust and the lithosphere get thinner. The amplitude and the mechanism of these two thinning are different. The lithospheric thinning is a thermal phenomenon produced by an asthenospherical uprising under the rift zone. In some regions its amplitude can exceed 200 %. This is observed under the Baikal rift where the crust is directly underlain by the list mantellic asthenosphere (Zorin and Osokina, 1984). The presence of hot material under rift zones induces a large negative gravity anomaly (Ramberg and Morgan, 1984). A low seismic velocity zone linked to this thermal anomaly is also observed (Puzyrev et al., 1978). During the rifting, the magmatic chambers get progressively closer from the ground surface (Wendland and Morgan, 1982). Simultaneously, the Moho reflector is found at shallow depth under rift zones. This crustal thinning does not exceed 50 % (30 % in Suez, Makris et al., 1985; 25 % in East African Rift, Long, 1976; 30 % in Baikal rift, Puzyrev et al., 1978). Tectonic stresses and vertical movements result from the two competing effects of the lithospheric and crustal thinning. On the one hand, the deep thermal anomaly induces a large doming and is associated with extensive deviatoric stresses. On the other hand, the crustal thinning involves the formation of a central valley. This subsidence is increased by the sediment loading. The purpose of the paper is to quantify these two phenomena in order to explain the various morphologycal and thermal evolution of rift zones.

Geological records indicate that the rifting process can be fairly rapid, say 10 Ma. The time-scale has ruled out simple conductive mechanism based upon the effect of an asthenospheric thermal anomaly to explain the lithospheric thinning. Nevertheless, the propagation of a thermal perturbation across the whole lithosphere requires at least 50 Ma. Two mechanisms are thus postulated to respect the observed time scale: the first one considers a possible upward advection of hot material (Neugebauer, 1982; Turcotte and Emerman, 1983), the second one (Fleitout and Yuen, 1984) results from the ability of the thermal lithospheric structure to be destabilized on a short time scale by secondary convection. The model is based on a temperature- and pressure- dependent rheology; this yields a viscosity minimum at the base of the lithosphere and therefore favours a rapid convective thinning. The present paper adopts a similar approach; figure 1 depicts the general physical aspects of our model. The numerical code used to solve the thermo-mechanical equations (Anderson and Bridell, 1980) and the viscosity law are the same as those used by Fleitout et al. (1984). An initial thermal perturbation induces a convective flow; the resulting mass displacements and stresses affect the lithosphere and the gravity field. The stresses at the bottom of the crust are then used to quantify the vertical movements and the infered extensiv tectonic style.

The crustal behaviour in these extensional stress-field is very problematical. Seismic data point out a noconservation of the crustal mass during rifting (Chénet et al., 1982). The main phenomenon for crustal thinning may be different from the classical plastic flow commended by Mc Kenzie (1978). Mantellic dykes intrusions can also be envisaged at the base of the crust. These intrusions increases the mean density of the lower crust and changes this seismic velocity. We have tested these two extreme hypothesis.

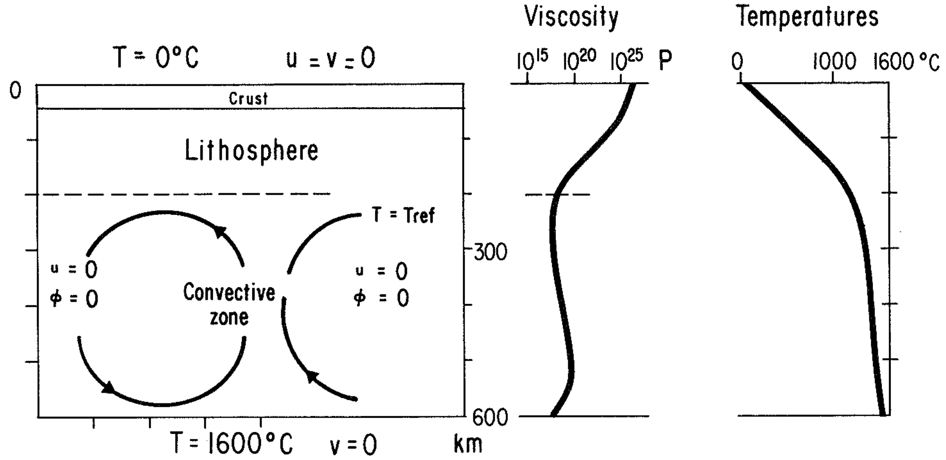

Fig. 1 : General hypothesis

Temperature boudary conditions are constant values at the surface and at the bottom of the box and lateral flow (φ) nul at the two side. u is the horizontal velocity and v the vertical velocity. The viscosity is gived by $\eta(T,z) = A \exp(Q/RT - Q/RT_r) \exp(z/B - Z^2/C)$

where z is the depth, Q the activation energy, R the gas constant and Tr is a reference temperature, A, B, C, are coefficents (Fleitout and Yuen, 1984).

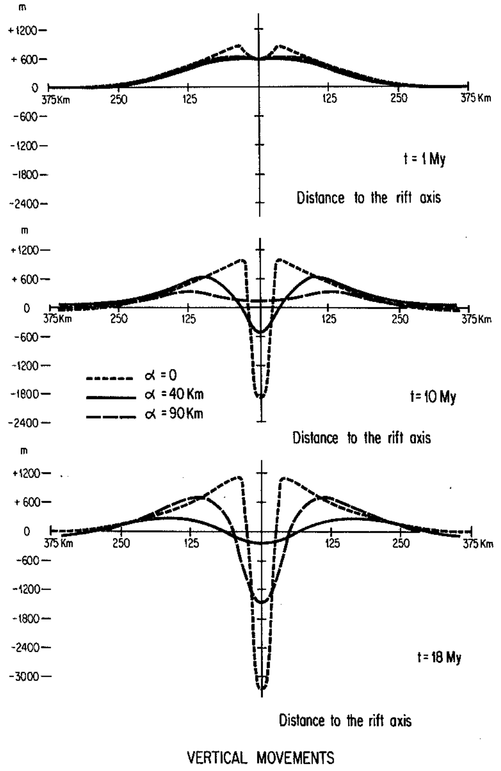

Fig. 2: vertical movements in meters function of the time. See other hypothesis in text. α is the flexural parameter.

As an example the figure 2 shows the topographic evolution for a crustal thinning of about 1 km/y with a velocity of the sedimentary loading of 0,125 mm/y in the 50 km.wide central valley without regional extension. Three crustal responses are assumed: a local and two regional distinct compensations (elastic behaviour with 40 and 90 km as flexural parameter). The possibility of a regional extensive stress is also envisaged. This induces an acceleration of both crustal and lithospheric thinnings. The displacement at the bottom of the crust and the heat flow variations at the surface are plotted on fig. 3; the horizontal velocity is constant (3 mm/y), the mass preservation is respected due to a mantle uprising.

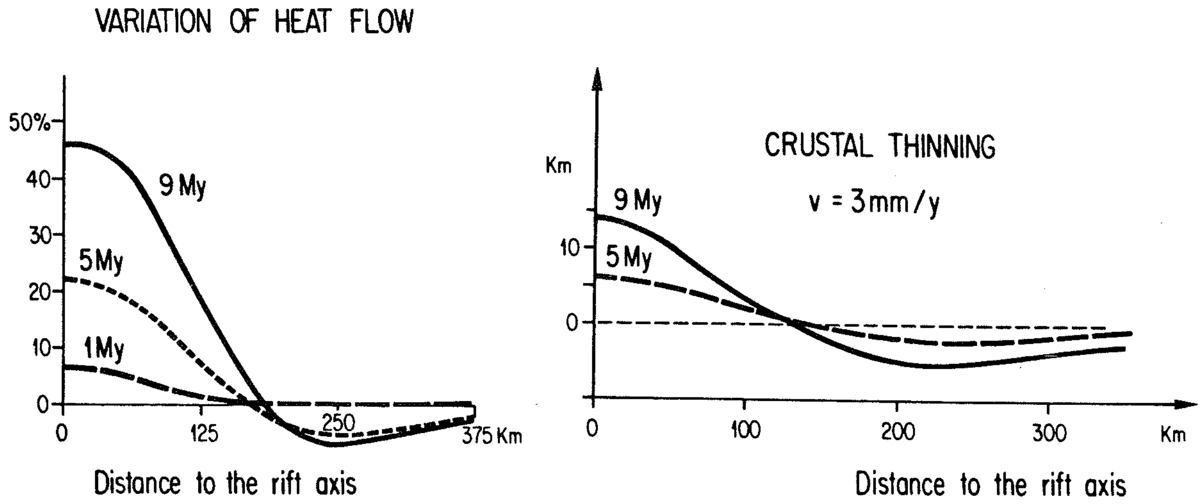

Fig. 3 : Heat flow variations and crustal thinning function of time. The horizontal fixed velocity is 3 mm/y. The mantle uprising induce a initial thermal anomaly of about 5 % in the central part.

In conclusion we show that many rift features and evolution patterns are best explained by these two scale processes. The mantle uprising first causes regional uplift. Too small crustal thinnings induce thermal doming whereas larger ones induce subsidence of the rift valley and uplift only on rift shoulders. When the crustal thinning stops, later, the whole region becomes uplifted; the potential subsidence of the already formed grabens in then only due to sediments loading.

Bibliography

Anderson, C., and Bridwell, R., 1980 - A finit element method for studying the transient non-linear thermal creep of geological structures. Intern. Journ. of numerical and analytical methods in geomechanics, 4, 255-276.

Chénet, P., Montadert, L., Gairaud, H., Roberts, D., 1982 - In Studies in continental margin geology, AAPG Mem. n°34, 703-715.

Fleitout, L., and Yuen, D., 1984 - Steady-state, secondary convection beneath lithospheric plates with temperature and pressure dependent viscosity, J.G.R., 89, 9227-9244.

Fleitout, L., Yuen, D., and Froidevaux, C., 1984 - Thermomechanical models of lithospheric deformation: application to the tectonics of western Europe. Thèse d'Etat, Université Paris Sud-Orsay.

Mc Kenzie, D., 1978 - Some remarks on the development of sedimentary basins, Earth Planet Sciences Letters, 40, 25-32.

Long, R., 1976 - The deep structure of the East African rift and its relation to Afar, in Afar between continental and oceanic rifting, Schweizebart.

Mareschal, J.C., 1983 - Mechanism of uplift preceding rifting, Tectonophysics, 94, 51-66.

Makris, J., Stofen, B., Vees, R., Allam, A., Maamoon, M., Shebata, W., 1985 - Deep seismic soundings in Egypt: Part II: crust and upper mantle of the Red Sea Coast. In press.

Neugebauer, H., 1983 - Mechanical aspects of continental rifting, Tectonophysics, 94, 91-108.

Puzyrev, N.N., Mandelbaum, M.M., Krylov, S.V., Mishenkin, B.P., Petrik, G.V. and Krupskaya, G.V., 1978 - Deep structure of the Baikal and other continental rift zones from seismic data, Tectonophysics, 45, 15-22.

Ramberg, I., and Morgan, P., 1984 - Physical characteristics and evolutionary trends of continental rifts. In press.

Tiercelin, J.J. and Favre, H., 1978 - Rates of sedimentation and vertical subsidence in neorifts and paleorifts, Tectonics and geophysics of continental rifts.

Turcotte, D., and Emerman, S., 1983 - Mechanisms of active and passive rifting, Tectonophysics, 94, 39-50.

Wendlandt, R., and Morgan, P., 1982 - Lithospheric thinning associated with rifting in East Africa, Nature, 298, n° 5876, 734-736.

Zorin, Y., and Osokina, S., 1984 - Model of the transient temperature field of the Baikal rift lithosphere, Tectonophysics, 103, 193-204.