AN ACTUALLY HOT TECTONIC MODEL FOR THE THARSIS HOTSPOT. D. Mège[1] and P. Masson[2], [1]Observatoire de Physique du Globe, URA 10 CNRS, Université Blaise-Pascal, 5 rue Kessler, 63038 Clermont-Ferrand, France, e-mail: daniel.mege@geol.u-psud.fr, [2]Laboratoire de Géologie Dynamique de la Terre et des Planètes, URA D1369 CNRS, Bâtiment 509, Université Paris-Sud, 91405 Orsay, France, e-mail: philippe.masson@geol.u-psud.fr.

SUMMARY

Comparison between the Tharsis province on Mars and hotspots on Earth shows that a simple model of aborted rifting in a crust weakened by a hotspot can account for most tectonic structures observed in this region.

INTRODUCTION

Although Tharsis has been considered as a hotspot for more than two decades, many recent tectonic models of Tharsis have neglected that Tharsis not only is a volcanically *loaded* region, but also was once a volcanically *active* region. Models based on elastic lithosphere loading ([1, 2]) have never completely satisfactorily accounted for the tectonic structures formed contemporaneously to volcanic activity [2, 3]. Evidence recently reported of probable existence of giant mafic dike swarms [4- 6] suggests a new model of Tharsis geodynamic evolution similar to plume tectonics models on Earth. Many details of the model can be found in a full paper [5].

THE MODEL

Early thermal uplift. Similar to hotspots on Earth, plume impingement at the base of the lithosphere close to the Noachian/Hesperian boundary creates thermal uplift (e.g., [7]), centred on Syria Planum. Compressive spreading stress at the boundary of the uplifted crust is responsible for compressional deformations circular about the dome [8], similar to inferred compressive belt around a 2.7-2.6 Gy Yilgarn hotspot [9]. Most ridges from the south Tharsis ridge belt [10] form.

Flood basalt eruption and dike swarm emplacement. During early Hesperian, flood basalt eruption occurs parallel to giant mafic dike swarm emplacement. Analogy is noted with large igneous provinces associated to terrestrial hotspots, such as the 1.67 Gy Coppermine River basalts and the Mackenzie dike swarm associated to the Mackenzie hotspot [11], and the 15.5-16.5 My Columbia River basalts, the Monument, Chief Joseph, and North Nevada rift dike swarms at the Yellowstone hotspot (ref. in [12]). The dike swarms, inferred from morphostructural arguments [5, 6], allow to infer the principal stress trajectories during emplacement [13]. Analysis of stress trajectories (figure 1, top) shows the existence of a regional tensile stress superimposed on hotspot-related stresses, which may originate from inflation/deflation events in magma chambers [14] as well as gravitational loading [15].

Wrinkle ridge formation. Wrinkle ridges [3] begin to form roughly concentric about the centre of the dome on the lava plateaus while flood lava eruption occurs, in response to thermal subsidence enhanced by isostatic subsidence (see [16]) induced by loading of the thermally-thinned brittle upper crust. Analogy is found with isostatic subsidence of the Columbia Plateau and Yakima ridge initiation concentric to the past location of the Yellowstone hotspot (see [17]). Similar structural characteristics are shared by the Tharsis wrinkle ridges and the Yakima fold belt [18]. Wrinkle ridge orientation is consistent with orientation of principal stresses resulting from dike geometry analysis on figure 1 (top), contrary to models considering Tharsis-related stress only [3]. Surface compression during dike swarm emplacement is made possible by transitory local change of principal stress magnitudes resulting from lava plateau subsidence.

Early narrow graben formation. Hesperian narrow grabens (radial and concentric about Syria Planum) formed in a stress field similar to that existing during dike swarm emplacement; location above dikes may be due to stress concentration at dikes due to their high Young's modulus, and to stress resulting from dike magma pressure [6].

Valles Marineris formation. Valles Marineris is parallel to the early radial grabens (figure 1, top) and should result from the same stress. Its formation is explained by crust weakening by the hotspot and rifting along favorably oriented crustal discontinuities, namely the dikes, very similar to models of rifting on Earth (e.g., [19]) also accounting for the Poseidon and North Nevada riftings at the Mackennzie and Yellowstone hotspots, respectively. Absence of plate tectonics allowed very limited extension only [20, 21], slowly proceeding up to Amazonian [22].

Recurrent magmatic activity. Recurrence of hotspot volcanic activity and dike swarm emplacement has been frequently observed on Earth (e.g. [23]), and is also featured on Mars at Tharsis after the Syria Planum events (figure 1, bottom). An Alba Patera-related swarm is identified [7, 24], and magmatic activity at both provinces are shown to be contemporaneous by analysis of stress field interactions [5].

Hotspot migration. Migration of magmatic activity from Syria Planum to Tharsis suggests relative plume/lithosphere motion. The Tharsis volcanic activity began with emplacement of flood lavas [25], but volcano morphology of the Tharsis Montes suggests that the latest lavas erupted should have been significantly more silicic, and denotes SW-NE migration of the last volcanic activity at the Tharsis Montes, similar to volcanic evolution at the Yellowstone hotspot from the McDermitt caldeira to the Yellowstone caldeira, via the Snake River plain. The 8 km-high permanent Tharsis rift line uplift is interpreted as due to a batholith similar to the thick Snake River batholith [7]. No wrinkle ridges appear to be associated to the Tharsis events, maybe because of lithosphere strengthening by previous magmatic activity.

Conversely, persistency of formation of extensional structures is explained by persistence of a remote extensional stress regime (box in figure 1, bottom).

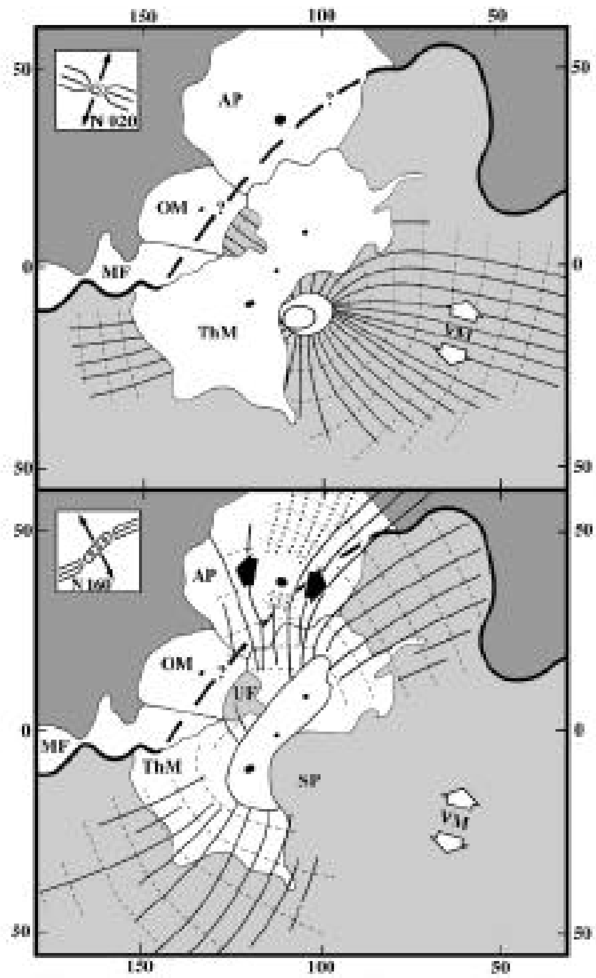

Figure 1 - Two-stage Tharsis tectonic model. White: deposits more recent than the stage considered; light grey: plateau materials; dark grey: plain materials; dashed lines: *s*3 trajectory; plain lines: horizontal principal stress trajectory perpendicular to *s*3; thin and heavy dotted lines: as dashed and plain lines; heavy line: dichotomy boundary; arrows: Valles Marineris and Alba Patera extension; AP: Alba Patera; MF: Medusae Fossae; OM: Olympus Mons; SP: Syria Planum; ThM: Tharsis Montes (caldeira located); VM: Valles Marineris. Arrows in boxes indicate regional (remote) *s*3 trajectory. 1° lat = 55 km.

CONCLUSION

One of the major differences between the model and terrestrial models is that much more melting is expected to have been produced by adiabatic decompression above the hotspot on Mars, due to lower gravity [5]. Permanent Valles Marineris uplift is attributed to underplating, resulting from generation of large volumes of magma even despite a very small extension [20, 26]. Similarly, large volumes of melt explains why thermal subsidence along the Tharsis Montes alignment did not produce a topographic depression similar to the Snake River plain at the Yellowstone hotspot.

The model proposed differs from previous tectonic models in the stress sources involved. Previous models have attempted to explain the tectonic structures by loading stress only, whereas the present model suggests that most extension is basically due to a persistent remote stress working in a hot and weakened lithosphere. Volcanic loading stress is however required, in addition to thermal subsidence, for producing the wrinkle ridges. Study of extensional hoop strain variation at various distances from the hotspot would help determine whether more stress is required near the volcanoes than at larger distances, which would denote a requirement for local stress in addition to the remote stress for explaining formation of the radial grabens.

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