DYNAMIC STRESS AT MARTIAN SURFACE IN THE MODEL OF ROTATION OF THE LITHOSPHERE.

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Introduction: The crustal dichotomy and the Tharsis volcanic province are dominant features at Martian surface. Both exogenic (giant impact) and endogenic (e.g., degree-1 convection) were proposed to explain the dichotomy. In a recent study Zhong [1] proposed a unified model for the Tharsis rise and the dichotomy. A lithospheric thickness variations of hemispherical pattern is assumed, consistent with the formation of the crustal dichotomy. Assuming the dichotomy is due to extensive melting, a melt residue cap of angular radius 90° and variable thickness (shallowing towards the edges) of stiff (i.e., devolatilized) material is imposed. A single upwelling forms below the center of the insulating cap. The interaction between the plume head and the thick melt residue results in motion of the entire lithosphere with respect to the plume, which continues until the plume is positioned below the edge of the melt residue cap. This model of rotation of the lithosphere (ROL) may explain the time–space patern of volcanism in the western hemisphere and the position of Tharsis province. In this study we investigate the pattern and evolution of the dynamic stress in the shallow lithosphere in the model of ROL, and the implications for surface tectonic features on Mars.

No melt residue: We first calculate the stress field for a reference model with no melt residue cap (corresponding to Model 1 in [1]). We solve three-dimensional incompressible mantle convection in spherical shell using CitcomS [2]. The temperature-dependent viscosity and weak asthenosphere result, after a transient period, in a degree-1 thermal structure dominated by a single upwelling, which remains stationery over time (Fig. 1a). The stress pattern at the surface of the lithosphere is characterized by a region of strong extension above the upwelling and a broad antipodal compressional domain. The extension is concentric around the plume, with the fault lines pointing radially from the plume center. This result is consistent with findings of Harder and Christensen [3] (in their model the degree-1 convective pattern arises from an endothermic phase transition in the deep mantle, rather than from T-dependent viscosity and weak asthenosphere as in our model).

Stress in model of ROL: We calculate the surface stress field for a model with a melt residue cap (Model 2 in [1]). The upwelling initially forms below the center of the melt residue cap (Fig. 1b). The interaction of the plume head with the melt residue cap subsequently drives rotation of the lithosphere with respect to the upwelling (Fig. 1c). This differential motion stops when the plume is located slightly past the cap boundary (Fig. 1d).

The stress pattern shown in Fig. 3 differs significantly

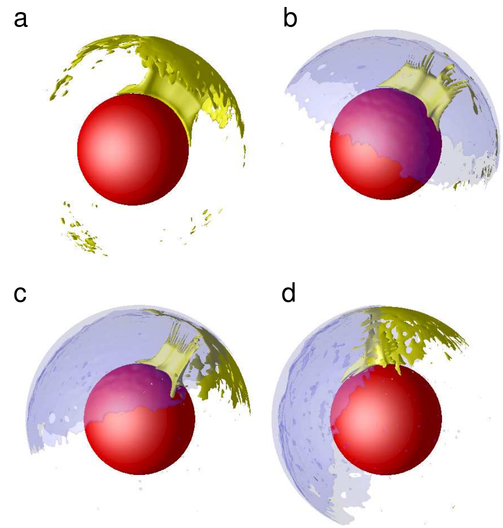

Figure 1: Thermal and melt residue structure. Core-mantle boundary shown in red, yellow isosurface shows dimensionless temperature at 0.07 above the horizontally averaged value, transparent blue tracks melt residue along -0.07 isosurface. Model 1 without melt residue (a); Model 2 at non-dimensional times 5.6×10^{-4} (b), 9.6×10^{-4} (c) and 1.8×10^{-3} (d).

from the reference Model 1 (Fig. 2). At non-dimensional time 5.6×10^{-4} (Fig. 3a) when the upwelling is still near the center of the melt residue cap, a localized zone of extension above the plume head is surrounded by a zone of weak compression, due to the negative buoyancy of the thick cold lithosphere. The extension stress pattern above the upwelling reflects the elongated (rather than circular) horizontal cross-section of the plume due to the lithospheric motion, which is approximately southward in the left hemispheres and northward in the right hemispheres in Fig. 3. Another region of significant extension arises along the trailing edge of the moving melt residue cap; the extension is perpendicular to the cap boundary. Broad region of compression arises in the downwelling-dominated hemisphere, similar in pattern to the one in Model 1.

At non-dimensional time 9.6×10^{-4} (Fig. 3b) when the cap has migrated about 2/3 its angular radius, a broad region of extension regime above the plume is a superposition of the extension due to upwelling (east-west extension along a narrow north-south oriented strike) and the extension due to lithospheric motion (north-south extension in a broad region along the east-west oriented cap boundary). At non-dimensional time 1.8×10^{-3} (Fig. 3c) the plume has stabilized slightly past the cap boundary.

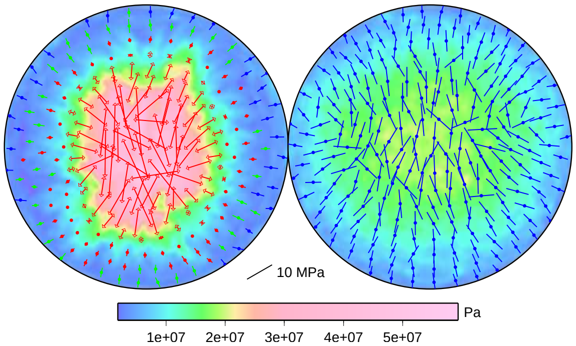

Figure 2: Stress field at the surface of the lithosphere in Model 1 (without melt residue cap). The upwelling is centered in the left hemispherical map. Stress magnitude (square root of second invariant of deviatoric stress) shown in color, and the maximum horizontal compressive stress shown as bars following the convention of the World Stress Map (http://www.world-stress-map.org/). Bars with arrowheads indicate extension, no arrows compression. Red bars indicate normal faulting regime, green strike-slip, and blue thrust faulting.

The extensional stress field above the upwelling regains some of its radial shape as in Model 1, although it is being distorted on southern side by the compressive field in the nearby cold cap.

Implications for surface tectonic features: The most significant prediction of the stress analysis is the elongated region of extension along the melt residue cap boundary at its downwind side. The extension is perpendicular to the cap boundary and persists throughout the entire $\sim 90°$ rotation of lithosphere relative to the upwelling. Even after the relative motion stops the extension is maintained along the cap boundary. This could result in large strain accumulation and rift opening. We predict persistent extensional regime in martian western hemisphere along the dichotomy boundary, possibly rifting with the fault zone parallel to the dichotomy boundary. This offers and intriguing explanation of Valles Marineris formation. Near the dichotomy boundary in the eastern hemisphere our model preditcs compressive dynamics stress state, although with lower stress level than in the west. This is in accordance with some observations of thrust faulting in that region [4].

Our analysis only predicts dynamic stresses for a crust-free planet. Further refinement (e.g., evaluation of strain accumulation, incorporation of crustal signal to the surface stress modeling) is necessary. However, the constraint of surface stress/strain field is a useful prediction for testing the model of ROL for single-plate planets.

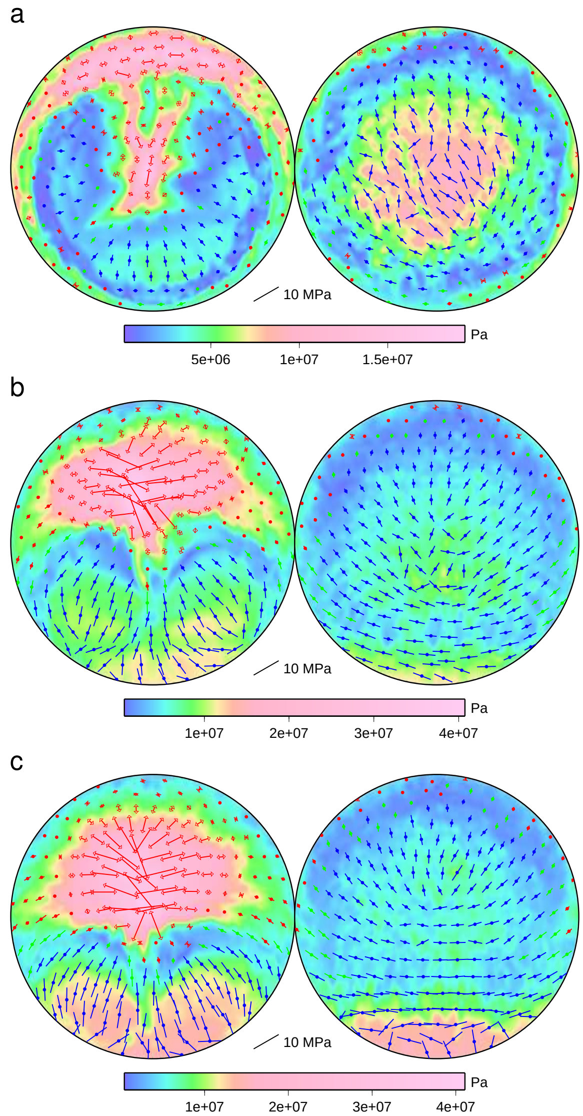

Figure 3: Stress field at the surface of the lithosphere in Model 2 at non-dimensional times 5.6×10^{-4} (a), 9.6×10^{-4} (b) and 1.8×10^{-3} (c). For each time, the upwelling is centered in the left hemispherical maps.

References

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