Mantle-earthquake geothermometry of rejuvenated Proterozoic lithosphere, western Saudi Arabia

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Harrat Lunayyir is a Quaternary volcanic field above a 2009 dyke intrusion located in the Arabian Shield ~100 km east of the Red Sea rift. We use 3D common conversion point stacking of P-wave receiver functions to show that the Moho is at 38 ± 2 km depth, close to the 40-km crustal thickness measured in the center of the Arabian craton, whereas the lithosphere-asthenosphere boundary is at 60 ± 5 km depth (Figure 1), far shallower than the 150 km seen further east in the Arabian shield. We re-located 64 high-frequency earthquakes with $m_L \leq 2.5$ at depths of 42–48 km, clearly beneath the Moho, ~30 km east-southeast of the 2009 dyke-intrusion beneath Harrat Lunayyir (Figure 1). These brittle-failure earthquakes, that must have nucleated at temperatures T ≤ 900°C, show that the lithosphere is not in thermal equilibrium with the underlying asthenosphere that has a petrologically calibrated potential temperature of ~1350°C at 60 km depth (Blanchette et al., 2018).

We take the maximum depth of crustal earthquakes as marking the crustal brittle-ductile transition, thereby constraining the 350 ± 50 °C isotherm. We take the maximum depth of sub-Moho earthquakes as marking the upper-mantle ductile-brittle transition, thereby constraining the 850 ± 50 °C isotherm. We can then model the thermal evolution of the shield margin from a stable cratonic geotherm (derived from observed surface heat-flow) prior to onset of Red Sea extension, while the lithosphere is eroded from ≥125 km to its modern 60-km thickness. Absence of earthquakes below 48 km constrains the lithosphere to have been thinned to 60 km no earlier than ~12 Ma, assuming earthquakes cannot nucleate at T ≥ 900°C. Absence of crustal earthquakes below 20 km constrains the lithosphere to have been thinned to 60 km no later than ~ 11 Ma, otherwise the aseismic lower crust would encompass temperatures ≤ 300 °C. Initial Red Sea extension at ~30 Ma must have been followed by a second phase of lithospheric thinning continuing until ~ 12 ± 2 Ma, consistent with onset of Younger Harrat magmatism and focusing of extension towards the Red Sea rift axis from ~12 Ma (Blanchette et al., 2018).

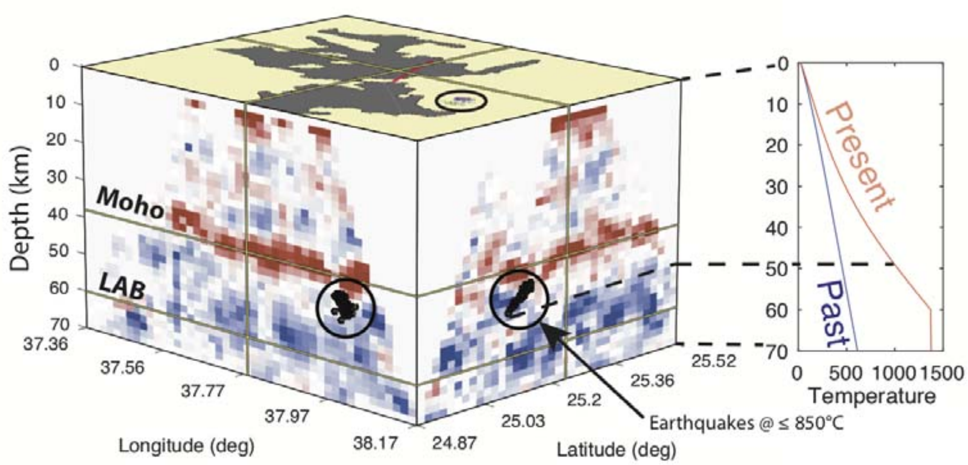

Figure 1. 3d CCP stack of P-wave receiver functions and re-located sub-Moho earthquakes (projected on to cube faces, within circles), with 2-km voxels. Blue (red) color indicates wave-speed decrease (increase) with depth. Vertical lines: locations of slices through the cube that are displayed on the west-east and south-north cube faces. Top face: geologic map. Surface trace of 2009 dyke: red line; Quaternary basalts: grey; Proterozoic basement: yellow. Graph: inferred modern non-equilibrium thermal gradient compared to pre-Neogene cratonic geotherm.

References

Blanchette, A.R., Klemperer, S.L., Mooney, W.D., and Zahran, H.M., 2018, Two-stage Red Sea rifting inferred from mantle earthquakes in Neoproterozoic lithosphere, Earth and Planetary Science Letters, 497, 92-101.