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The thermal field of the Arabian plate east of the Dead Sea Transform: implications from lithosphere composition and heat flow

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Knowledge of the thermal state of the lithosphere is essential for understanding the complicated geodynamic setting, which gave rise to the Dead Sea Transform (DST). The key question addressed in the multinational DESERT project is the understanding of the driving forces for the formation of this deep structure, i.e., why the DST formed, when the DST started to form, and why it is formed just where it is.

The DST extends from the northern tip of the Red Sea, where the Arabian plate separates from the Africa plate, to the Alpine convergence zone in the Taurus Mountains. It forms the boundary between the Arabian plate and the Sinai sub-plate, which is an appendage of Africa, and is one of the several plate boundaries and active rifts which formed since mid-Cenozoic times. The 1000-km-long DST accommodates a total left lateral motion of about 105 km, which may have begun 18-16 Ma ago (Garfunkel and Ben-Avraham, 1997). The origin and movement of the DST is accompanied by widespread mafic volcanism during Neogene to Quaternary. The magmatic activity resumed in this region is thought be related to the complex tectonics associated with the opening of the Red Sea-Gulf of Aden and the activity of the Afar mantle plume (Wilson et al., 2000). Recent studies of the basaltic volcanism, however, do not support the idea that the Afar plume has been channeled northwestwards beneath the Arabian plate and has played a significant role in producing the Jordan/Israel intraplate volcanism (Shaw et al., 2003).

The DESERT sub-projects “petrology” and “geothermics”, which heavily depend on each other and take advantage of the great wealth of geophysical data obtained in interrelated subprojects, are aimed to (1) delineating a lithosphere model with regard to composition, radiogenic heat production, and thermal conductivity, (2) determining the surface heat flow, (3) estimating the recent P-T conditions in the upper mantle from xenoliths entrapped in the young basalts, and (4) relating this T information to a steady-state geotherm. In a first stage, the regional focus was the lithosphere east of the DST, i.e., beneath Jordan.

Available petrological and geophysical data imply that the upper 10 kilometers of the 19-km-thick upper crust are mainly composed of sediments and granites/granodiorites with intercalated metamorphic rocks, while the lower part is, on average, monzodioritic yielding a bulk density of 2.7 x 10^3 kg/m^3 (derived from gravity modeling). The $\sim$18-km-thick lower crust is variable with respect to texture, mineralogy, and geochemistry and has a mean density of 2.9-3.0 x 10^3 kg/m^3. The major portion is built up of plagioclase-rich mafic granulites, with the remaining 5-7 km comprising two-pyroxene mafic granulites. Various peridotites form the lithospheric mantle.

The lithosphere beneath Jordan shows a

common radiogenic heat production (A). A_{mean} in the uppermost mantle ranges from 0.02 ± 0.01 μW/m^3 (NE Jordan) to 0.03 ± 0.01 μW/m^3 (central Jordan) and matches the global average of 0.03 μW/m^3 (Rudnick, 1998). A_{mean} in the lower crust (plagioclase-rich mafic granulite: 0.09 μW/m^3; pyroxene-rich mafic granulite: 0.03 μW/m^3) closely resembles the worldwide average of 0.18 μW/m^3 (Rudnick and Fountain, 1995). Heat production in the upper crust averages 1.18 μW/m^3 for metamorphic rocks and 1.88 μW/m^3 for igneous rocks. Highest values are observed in alkali-feldspar granites (3.66 μW/m^3).

Table 1 lists the simplified 3-layer petrological model for the Jordan lithosphere and the thermal parameters (thermal conductivity=TC and heat production=A), on which the geotherm calculations are based. Distinct from most other shields is the low average TC of the lower crust (1.7 *vs.* 2.3 W/m/K) measured in xenolith samples, which is reflection of its plagioclase-rich composition.

The most critical parameter in geotherm calculation, which stills needs substantiation, is the surface heat flow Q_S. Our preliminary estimate for Jordan is on the order of 60 mW/m^2. Additional high-precision temperature measurements in deep boreholes have been completed in October 2003 and are currently under evaluation. The calculation of steady-state geotherms using surface heat flows of 50 and 60 mW/m^2 yield Moho temperatures of resp. 600 ^{o}C and 840 ^{o}C, and mantle heat flows of 22 and 32 mW/m^2. Both these temperatures do not match the recent xenolith P-T field for central Jordan (850–1050 ^{o}C, 1.2–1.8 GPa), which argues for transient conditions in connection with thermal perturbations owing to lithosphere thinning. Our data for Jordan are in strong contradiction to what is implied from the most recent geotherm for the Dead Sea area in Israel (Aldersons et al., 2003). This geotherm, starting from Q_S = 40 mW/m^2, suggests a considerably colder lithosphere west of the DST, with a Moho temperature as low as 390 ^{o}C. The significance of this geotherm is questioned because it cannot explain the absence of earthquakes generated in the uppermost mantle, underestimates the xenolith P-T field for Israel by around 500 ^{o}C, and did not consider the P-T dependence of rock thermal conductivity.

In conclusion, our data for the area east of the DST argue for an already thermally weekend crust beneath Jordan. The bulk of the transient heat associated with the onset of the DST, however, has not yet reached the surface and is stuck somewhere at the mantle/crust boundary according to thermo-mechanical modeling.

Depth (km)	Main Rock Type	TC (W/m/K)	A (μW/m^3)
0–19	Pan-African igneous and metamorphic rocks	2.6	1.4
20–37	Pan-African plag-rich mafic granulites	1.7	0.1
38–75	Peridotites	4.1	0.03