Thin-shell thermo-mechanical modeling of lithospheric deformation in the Middle-East region

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We employ in this study the thin-shell neotectonic modelling program SHEELS, powered by [1, 2], to study at large scales the parameters controlling the dynamic of the Dead Sea Transform (DST). The Dead Sea Fault is a major fracture zone and physiographic feature that extends from the northern Red Sea spreading centre to the Taurus/Zagros zone of plate convergence. The Dead Sea Transform is the left-lateral strike-slip system of faults that has accommodated about 105 km of the relative motion between the African and Arabian plates during the last 15-20 Ma [3] (see Fig. 1, left). The slip rate at the southern part of DST is between 0.3-0.6 cm/year.

An important question related to the Dead Sea Transform Fault is: What should the rheological properties of the lithosphere beneath the DST be, to allow it to work as a transform plate boundary with the slip rate of few millimeters per year?

The thickness of the lithosphere directly beneath the DST is not well constrained by seismic data, but thermo-mechanical modelling study [4] suggests that thickness of mantle lithosphere beneath the DST can be as low as 20-30 km. Another important localizing factor of deformation represents the fault friction coefficient. The behaviour of many major faults on Earth can only be explained if they are assumed to be much weaker than predicted by Byerlee's law. In this context [5] proposed a low value of fault friction coefficient 0.1-0.17 for California faults. The fault friction coefficient has not been extensively examined at the Dead Sea region yet. Therefore we compute in this work a two-parameter suite of models with different fault friction coefficient and mantle lithosphere thickness values beneath the DST to find out the range of parameters compatible with the slip rates at the DST of 0.3-0.6 cm/yr.

Regional topography data, available deep seismic as well as surface heat flow data are used to estimate the lithosphere structure and thermal regime under the assumptions of steady state and Airy isostasy.

We have examined the rheological conditions for the Dead Sea Transform to allow observed slip-rate of 0.3-0.6 cm/year. In particular, we examined the trade-off between fault friction coefficient and mantle lithospheric thickness below the Dead Sea Transform Fault. To do so, a variety of models were tested with different fault friction coefficient values (varying from 0.05 up to 0.40) and different mantle lithosphere thickness values (varying from 10 km to 40 km) beneath the Dead Sea Transform (Fig. 1).

We also analyze the effect of the shape of fault by considering (i) a large segment of DST extending from the Gulf of Aqaba through Dead Sea and the Lebanon Mountain Belt until East Anatolian Fault and (ii) a short segment without considering the bending northern part, which comprises the region from the Lebanon Mountain Belt until the East Anatolian Fault (see Fig. 1 left). Based on the plate velocity field, which is one of model's predictions, we conclude on possible rheology in terms of the trade-off between fault friction coefficient and lithosphere thickness.

The modeling shows that the observed slip rate of 0.3-0.6 cm/year at the DST can be achieved only if the average friction coefficient at DST is lower than 0.10 (see Fig. 1 right). Hence, the friction at DST appears to be as low as for the world's weakest transform fault, the San Andreas Fault in California [5]. The reason why such low friction is required at the DST to allow observed slip rates is the irregular shape of the DST, especially the bending in its northern part. Without its bending northern segment, DST would allow observed slip rates being much stronger. Model results also suggest that mantle lithosphere below DST must be thinner than 20-30 km, in accordance with predictions of the thermo-mechanical model [4].

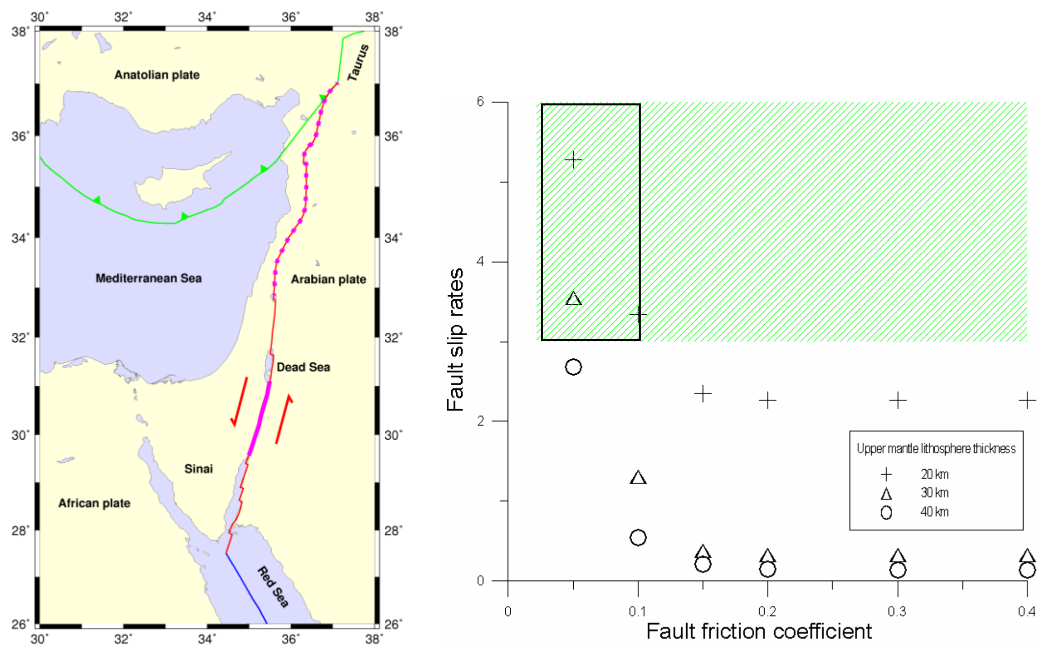

Fig. 1: (Left) Tectonic setting of the study region. *DST is depicted with red line, extending from the Gulf of Aqaba through Dead Sea and the Lebanon Mountain Belt until the East Anatolian Fault. Northern bending part of DST is highlighted with pink dots. (Right) fault slip rate versus fault friction coefficient when considering the whole segment of the DST. Green rectangle represents the area of observed fault slip rates. Different symbols represent different mantle lithosphere thicknesses.*

References

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