# Supplementary Information

## Strain heating in process zones; implications for metamorphism and partial melting in the lithosphere

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### A. Localised and distributed deformation in analog experiments of indentation on plasticine

Experiments of indentation in plasticine block, that have been used to exemplify the extrusion process due to continental collisions (Peltzer and Tapponnier 1988), also involve a combination of localised and distributed deformation. Although lateral extrusion along large-scale tectonic faults is a dominant feature of the deformation pattern, it cannot accommodate all the strain (Figure A). Where the boundary conditions prevent material escape while resulting in highly variable directions of shear, plastic strain accumulates in a distributed manner.

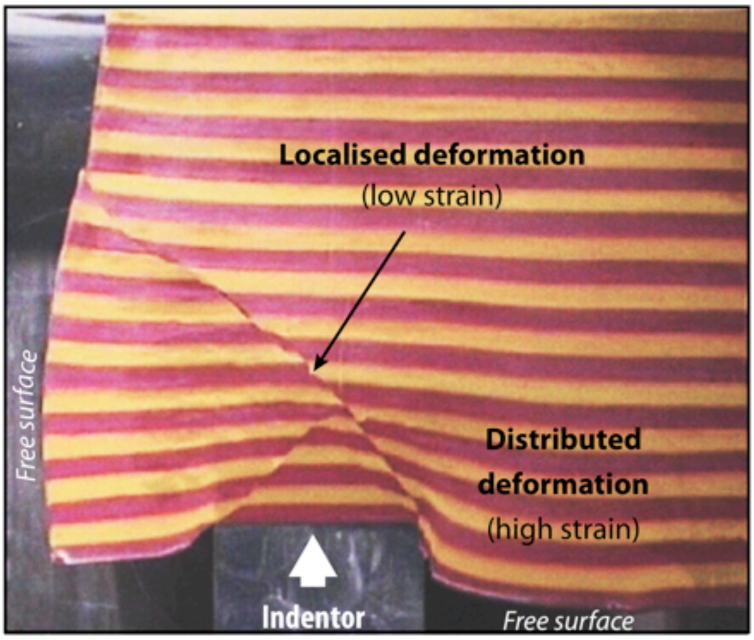


**Figure A. Plane strain experiments of indentation on a plasticine block**, adapted from Peltzer & Tapponnier (1988). As predicted by slip line theory (Tapponnier & Molnar (1976)), soon after the onset of indentation, faults grow along trajectories of pure shear dictated by the applied boundary conditions. Note the appearance of small-scale complexities like bends along the faults. In this experiment, opening voids can accommodate the kinematic incompatibility associated with these geometric complexities. Under high confining pressure however, these complexities would have been associated with off-fault deformation creating process zones of distributed deformation at a smaller scale. Where the boundary conditions result in highly variable shear directions, plastic strain accumulates in a distributed manner. These experiments illustrate well the complementary role played by two distinct styles of deformation, localised and distributed, in strain softening materials. It has been shown to provide a good analogy for the pattern of deformation observed in major collision zones such as Tibet and Anatolia. Figure modified from Devès et al. (2011).

### B. Simplified thermal problem: example of a process zone associated with the termination of a vertical strike-slip fault

The thermal problem can be sketched with a single roughly cylindrical source and neglecting the variations in heat production with respect to θ (Figure B). The initially long and thin cylindrical source (light red) tends to transform into a shorter and larger cylindrical source (dark red).

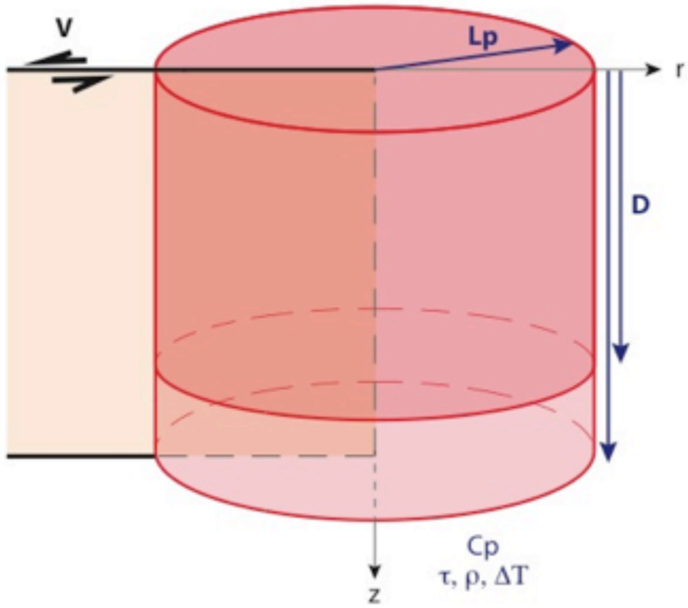


**Figure B.** Sketch of the heated zone. It can broadly be sketched as a cylinder of radius *Lp* and of length *D* extending in the z-direction from the surface.

Considering heating of the crustal section of the lithosphere, *D* tends to decrease with time as finite motion accumulates on the main fault and thermal softening weakens the ductile part of the crust. The same thing is expected to happen in the ductile part of the mantle lithosphere. The exact evolution of the process zone shape would be more complicated however, notably because the strain rates are higher close to its centre. This tends to increase the heat production in the early stage and to decrease it in the later ones. The heat production will hence tend to decrease more quickly in the centre of the process zone than elsewhere.

## C. Quantifying kinematic incompatibility: the case of Karliova junction

Only ridge-ridge-ridge junctions are stable (McKenzie & Morgan, 1969). A junction involving 2 strike-slip faults cannot be stable whatever the third structure is (Figure C). The kinematic incompatibility associated with such a junction can be derived assuming that the two slip vectors must define a closed triangle with a missing third one. Thus,

$$(a1)\ \overrightarrow{A/B} + \overrightarrow{B/C} + \overrightarrow{C/A} = 0 \rightarrow \overrightarrow{C/A} = -(\overrightarrow{A/B} + \overrightarrow{B/C}).$$

Application of the trigonometry law of cosines for an oblique triangle on a plane then gives the amplitude of the missing slip:

$$(a2)\ \| \overrightarrow{C/A} \| = (\| \overrightarrow{A/B} \|^2 + \| \overrightarrow{B/C} \|^2 - 2 \times \| \overrightarrow{A/B} \| \times \| \overrightarrow{B/C} \| \times \cos\alpha)^{1/2}$$

Application of the trigonometry law of sines for an oblique triangle on a plane gives the angle of that slip vector with respect to the other ones:

$$(a3)\ \sin\beta \ / \| \overrightarrow{B/C} \| = \sin\alpha \ / \| \overrightarrow{C/A} \|$$

Application to Karliova junction for the parameters given earlier predicts that the missing third fault should make an angle of 27° from the NAF direction and slides at a rate of 17 mm/yr. This corresponds well to the Arabia/Eurasia plate motion recorded from geodetic measurements but no single well-localised tectonic structure could be mapped that would accommodate it. The two main structures that have been mapped so far are the Varto and Mus fold-and-thrust systems. Projecting onto the x and y-direction (approximately the direction of the two structures), one obtains that the kinematic incompatibility could be released by right-lateral sliding at ~15 mm/yr on the Varto fault system, and by thrusting at ~ 8 mm/yr on the Mus system. The junction is unstable and should translate as those faults move. In 3Ma, it should translate by 45 km along the Varto fault, which is approximately the offset that can be mapped. The Mus system should have taken 24 km of shortening, of which we have no constraints today. In the last 3 Ma, the incompatibility might have been partly released by finite motion along these structures. There is no evidence however that those existed before. Since we are interested in what happened before the eruption of the Bingöl/ Turna lavas, it is therefore reasonable to consider a configuration with only the two main faults and not yet any structure able to release their incompatibility. Can process zone heating generate enough heat to melt the lithosphere and to weaken it sufficiently to allow the development of the Mus and Varto system that would come to re-equilibrate the kinematic incompatibility, at least in part?

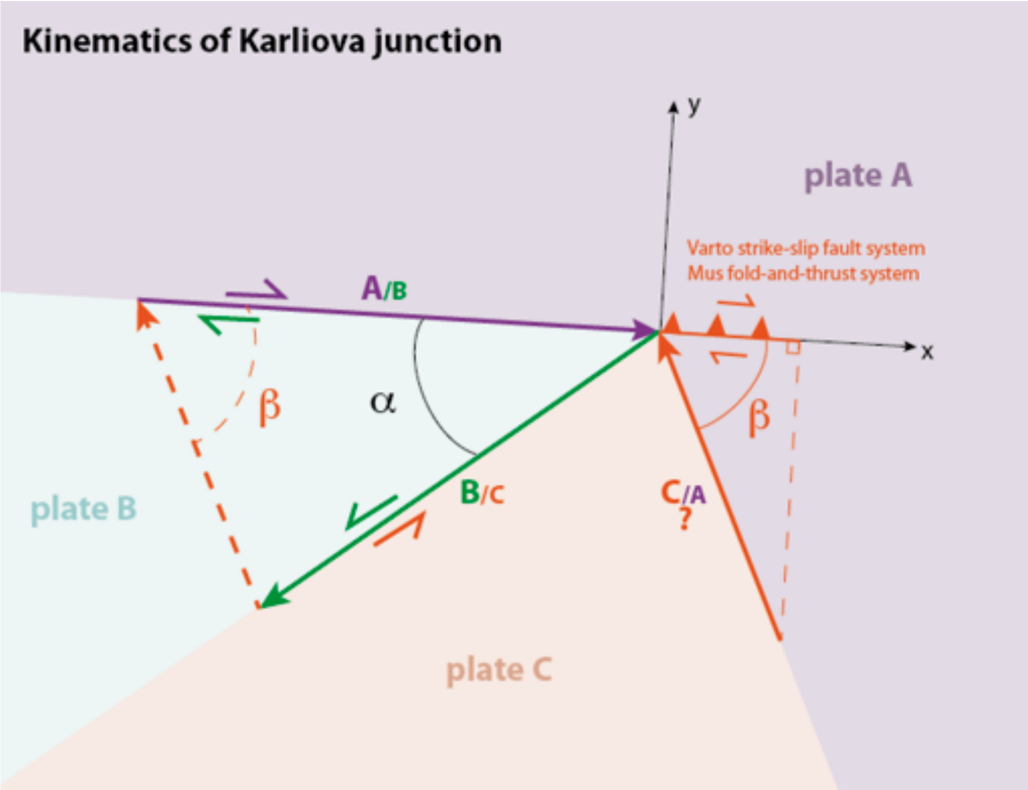


**Figure C.** The kinematics of Karliova junction can be understood by considering three plates (A-Eurasia, B-Anatolia, C-Arabia) in relative motion with one another whose relative displacement vectors must define a closed triangle. corresponds to the right-lateral slip vector along the NAF, to the left-lateral slip vector along the EAF and to the slip vector that would release the kinematic incompatibility introduced by the interaction between the two former ones. See comments in Supplementary Information A.

## REFERENCES

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