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Localised and distributed deformation in the lithosphere: Modelling the Dead Sea region in 3 dimensions

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The Earth's lithosphere behaves as a strain softening elasto-plastic material. In the laboratory, such materials are known to deform in a brittle or a ductile manner depending on the applied geometric boundary conditions. In the lithosphere however, the importance of boundary conditions in controlling the deformation style has been largely ignored. Under general boundary conditions, both laboratory and field scale observations show that only part of the deformation can localise on through going faults while the rest must remain distributed in 'process zones' where spatially varying shear directions inhibit localisation. Conventional modelling methods (finite difference, finite or discrete elements) use rheologies deduced from laboratory experiments that are not constrained as a function of the geometry of the applied boundary conditions. In this paper, we propose an alternative modelling method that is based on the use of an appropriate distribution of dislocation sources to create the deformation field. This approach, because it does not rely on integrating differential equations from more or less well-constrained boundary conditions, does not require making assumptions on the parameters controlling the level and distribution of stresses within the lithosphere. It only supposes that strain accumulates linearly away from the dislocation singularities satisfying the compatibility equations. We verify that thismodel explains important and hitherto unexplained features of the topography of the Dead Sea region. Following the idea that strain can only localise under specific conditions as inferred from laboratory and field scale observations, we use our model of deformation to predict where deformation can localise and where it has to remain distributed. We find that ∼65% of the deformation in the Dead Sea region can localise on kinematically stable through-going strike-slip faults while the remaining ∼35% has to remain distributed. Observations suggest that distributed deformation occurs at stress levels that can be ten times greater than that associated with motion on well-localised faults. Thus, although only representing a minor part of the total deformation, distributed deformation should provide the greatest source of resistance to motion along this part of the Levant plate. These results can change dramatically our view of the behaviour of this and other plate boundaries. If the lithosphere can be regarded as a strain softening elasto-plastic material then similar behaviour should occur throughout, with important implications not only for its mechanical behaviour, but also for heat generation and related issues like metamorphism or magma genesis.