Geophysical Research Abstracts
Vol. 13, EGU2011-8961, 2011
EGU General Assembly 2011

Pinch and swell boudins during high-strain simple shear

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Extension of a layer with low competence contrast to its surrounding host rocks may lead to the formation of a characteristic pinch and swell geometry in two-dimensional sections parallel to the stretching direction (Ramberg, 1955, Schmalholz et al., 2008), eventually leading to isolated drawn boudins (Goscombe et eal., 2004). Similar micro-scale geometries may also result from ductile deformation of single crystals in a finer grained matrix.
In this study we compare natural examples of isolated pinch-and-swell objects, which have been subjected to layer parallel simple shear deformation with results of mechanical numerical models. Using the finite element code MILAMIN (Dabrowski et al., 2008), we model a pinch and swell shaped object with different aspect ratios and competence contrast initially oriented with the long axis parallel to the shear plane. Pinch and swell objects rotate out of the shear plane with increasing rotation rate until the long axis of the object is perpendicular to the shear plane, after which the rotation rate is decreasing again. At early stages, although different in its mechanical evolution, the structure resembles the geometry of a delta clast. The object may be approximately described as consisting of an intactly rotating core and the tail sections that experience a differential rotation and substantial stretching. For a low viscosity ratio ($\sim$10), a complex structure develops where the tails exhibit extreme stretching and form multiple spirals around the core. Here, an even more prominent dichotomy is established between the core and the tail section in terms of their thickness. The growth of the tails in expense of an eroding core is observed. For a high viscosity ratio ($\sim$1000), the stretching of the tails is less pronounced except for an intermediate aspect ratio of the core ($\sim$2). As the tails rotate into the contractional field of simple shear, they are subject to folding which is promoted by stretching and associated thinning of the tails. Since this structure has to our knowledge not been described before, we suggest the name delta folds. During on-going shearing the delta fold may unfold again resulting again in a pinch and swell shaped objects.
The proximity of shear zone boundaries has a prominent effect on the behaviour of a reworked pinch and swell object. Long thin objects rotate antithetically with respect to the boundary simple shear sense, eventually reaching a quasi-stable position. The final structure exhibits a sigmoidal “mica-fish”-type geometry.
Natural examples of both, back-rotated pinch and swell objects and delta folds, are frequently observed in highly strained rocks from micro- to macro-scale. If the orientation of the shear plane is known, both structures are excellent shear sense indicators but record little information on the finite shear strain, which led to their formation.

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