

Change of deformation mechanisms during low temperature flow of rocks — observation from micron to nanometer scales

Vortrag

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Recent studies on nano-materials in materials science revealed that nano-materials may have fantastic features due mainly to size-effect of the materials. For example, nano ceramics may have very high ductility at room temperatures and pressures, even though normal ceramics is easily deformed by brittle fracturing.

What and how much do we know about the nature of nano or nano to micron scale geological materials? What factors contribute to their occurrence? How do they flow at geological conditions and how do they affect the rheology of rocks? Upper crustal deformation is characterized by low temperature flow of rocks under unsteady state, which results in progressive grainsize reduction and leads to the occurrence of micron to nano meter scale materials in fault zones. The examples of naturally-deformed upper crustal rocks presented in the paper help to unravel the importance of nano to micron scale rock materials during the low temperature flow of rocks.

Cataclastically faulted marble, limestone and dolomite from the Autseib fault zone, Namibia, and micro-breccias from detachment fault zones in several metamorphic core complexes (mcc's), e.g. the Whipple mountains mcc in Western USA, Jinzhou mcc, and Huh-

hot mcc in North China are studied with optical microscope, CL microscope, SEM, and TEM. It is shown from the present study that micron to nano scale materials do occur during natural faulting at low temperatures in the upper crust. Macroscopic brittle features are shown primarily by the field occurrence of zones of microbreccias or cataclasites. Angular clasts with straight or irregular boundaries are randomly distributed in extremely fine-grained matrix and they do not show any evidence of preferred dimensional or lattice orientation. There is either clear or vague transition from clasts to matrix along the clast boundaries, which is also clearly shown by SEM studies. The matrix materials are extremely fine grains from micron to nano meter scales. They have optically irregular or vermiculate forms and are either fine clasts of grain aggregates or single grains. At the highest strain zones, rare clasts are observed. Single grains, however, predominate in the matrix and often have polygonal forms. TEM studies reveal great differences in dislocation patterns between coarse-grained clasts and fine-grained matrix. Dislocation substructures are widespread in grains of different sizes and origins. Tangled dislocations are the most common dislocation substructures in coarse-grained clasts, although free dislocations, dipoles, dislocation loops, dislocation walls and irregularly connected dislocations are also observed either jointly or separately in deformed grains in the clasts. A general tendency is that dislocations are more and more regularly organized towards clast boundaries. Tangled and irregularly connected dislocations occur mostly in the central grains of relatively big clasts, while walls of well-organized disloca-

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tions occur mainly near the boundaries, constituting subgrain boundaries. It is shown from TEM observations that tangled dislocations occur mainly in clasts with sizes greater than several tens of microns and well-organized dislocations and subgrains predominate clasts with sizes smaller than that limit. Fine-grains are $0.02\ \mu\text{m}$ to $3\ \mu\text{m}$ in sizes and characterized by polygonal shapes. They have regular and straight boundaries, and are generally dislocation free or contain only very few free dislocations. Grain sizes of the fine grains vary in the range from hundreds of nano meters to tens of microns. The fine grains generally have no preferred dimensional orientation. Due to extremely fine grain sizes their lattice orientation is undetectable.

On the other hand, there are often micropores along grain boundaries between the fine grains. This, together with the cathodoluminescence difference between big clasts and fine matrix may imply the importance of fluid phases during flow of the fault rocks.

The above evidence lead to the following conclusions:

1. Micron to nano meter scale geological materials are common in highly deformed crystalline rocks. Their occurrence is attributed to unsteady state progressive shearing and grain size reduction along fault zones in the upper crustal level.
2. Variation of grain sizes at micron to nano meter scales in rocks has strong effects on the flow of the rocks at natural strain rate and deformation conditions. The grain-size range from $n \times 10^{-1}\ \mu\text{m}$ to $n \times 10^1\ \mu\text{m}$ is an important range

of grain sizes for the transition of deformation mechanisms deformed at low temperatures in the upper crust. Grains with sizes greater than $n \times 10^1\ \mu\text{m}$ can be deformed by either crystalline plasticity or cataclasis. Grains with sizes smaller than that limit are deformed only by crystalline plasticity. The minimum size of clasts deformed in a brittle manner is $n \times 10^1\ \mu\text{m}$.

3. Variation in deformation mechanisms at micron to nano meter scales is interpreted as the results of grain-size reduction to a very high level at unsteady state and the effects of fluid involvement in the deformation of the extremely fine-grained rock materials. There is a sharp decrease in surface area with grain sizes. Such an increase and fluid flow may both enhance diffusion of atoms or lattice defects towards grain boundaries and from grain to grain. Both effects contribute to the variation of deformation mechanisms of naturally deformed rocks at upper crustal levels.