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Deformation of the lithosphere and what microstructures can tell us about it (Stephan Mueller Medal Lecture)

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The lithosphere is a roughly stratified and heterogeneous rock body that constitutes the outer layer of our planet. It is subdivided into irregularly shaped stiff plates that move with respect to one another deforming each other along their margins. At the large scale the lithosphere is usually modeled as a flat-lying multi-layer, its rheological profile being based on flow laws determined experimentally for key minerals of the crust and upper mantle. At the somewhat smaller scale of field observations, geometrical and physical complexities become apparent: rocks are folded, sheared and fractured, and - in general - quite heterogeneously deformed. And finally, at the even smaller scale of mechanical testing and microscopic investigations, rocks are seen as polycrystalline aggregates or granular composites whose bulk properties depends both on the composition and shape of the individual grains and the spatial arrangement of the crystals with respect to one another. In other words, the physical properties of the lithosphere and the inferred style or type of deformation depend very much on the scale of observation.

Microstructures and textures (crystallographic preferred orientations) of deformed rocks provide a wealth of information: when used as archives of the deformation history, they allow us to unravel the tectonic evolution of the lithosphere at plate boundaries. At the same time, they enable us to assess past and/or present geophysical properties. By comparing the microstructures of experimentally and naturally deformed rocks it is possible to infer the active deformation mechanisms and thus to extrapolate flow laws to geological time scales.

With the advent of digital image processing, microstructure and texture analysis have taken a great leap forward. By amalgamating methods from neighbouring disciplines such as mathematical morphometry, stereology, geostatistics, material sciences, etc., microstructure and texture analysis have come a long way since the early days of strain analysis and X-ray texture goniometry.

During my lecture, I will try to retrace this development: we will start by taking a dive down to the nanoscale, deep into the ductile regime, and inspect the shape, alignments and preferred orientations of sub-grain boundaries during simple shear deformation. What can the microstructure tell us about the deformation mechanism and the amount of strain that the rock material has undergone, and is it really 'strain' we are looking at? We will also look at orientation images and track the development in space and time of crystallographic orientations with temperature, strain rate and strain: do we reach a 'steady state'? We will then come up in scale and look at various definitions of grain size and test the validity of piezometers: how precise is the flow stress that we determine, does it really only depend on grain size, and what do we mean by 'grains size'? Back at the surface, we will look at brittle microstructures and consider distributions: fractal distributions of grain size and spatial distributions of grains: how can we get a handle on the microstructures of cataclastic deformation or granular flow? - At each step, I hope that it becomes apparent that there is more to microstructure and texture than the aspect ratio of an ellipse, the diameter of a grain, or the maximum of a c-axis pole figure...