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Deformation mechanisms in nature and experiment

Since the late 1960s, there have been many studies on the deformation mechanisms and microfabric of rocks. Many important studies on rock deformation had been carried out before this time, but the identification of dislocations and dynamic recrystallization in deformed rocks was the start for an ever increasing interest in deformation processes in rocks. The 1970s and early 1980s, in particular, were a revolutionary period during which earth scientists were catching up with the knowledge accumulated in the metallurgical and materials science literature. This has led to the widespread application of laboratory results and microfabric analyses to field-oriented and/or large scale tectonic studies. Consequently, the work of experimentalists started to strongly influence structural geology, and the dialogue between experimentalists and field geologists was excellent. Both communities met on a regular basis in a series of informal conferences held in two-year-intervals ever since the first meeting in 1979, which was organized by the famous Leiden school (now at Utrecht).

During the past ten years, progress in both experimental and field studies has been substantial. However, as the subjects became increasingly more complex, the dialogue between experimentalists and structural geologists became more difficult. Many geologists focussed on field-oriented applications in structural geology, while laboratory people concentrated on deforming increasingly pure or even synthetic starting materials since they considered ordinary rocks to be too complex and too ‘dirty’ to be rigorously studied in the lab. Nevertheless, interest in process-oriented studies of natural rock deformation has never really stopped.

At present, a closer look at microstructural features studied and described ten to twenty years ago reveals that many processes and mechanisms, which appeared to be clearly resolved in naturally deformed rocks, are indeed rather poorly understood in detail. A great deal of our knowledge about deformation mechanisms of rocks originates from the engineering material sciences or from a comparison of natural microstructures with those obtained in engineering materials, most notably in metals. However, as we investigate microstructures and deformation processes in more detail, the differences between metals and earth materials pose more and more restrictions on the direct applicability of materials science results to the study of deformed rocks. Consequently, earth materials science has become a field of research in its own right.

Another difference between engineering materials research and earth materials science is the ultimate goal of the application or, rather, the perspective of the research: for engineering applications, the goal is to control and modify processes to manufacture materials with special properties, whereas earth scientists are interested in understanding or reconstructing the processes and conditions involved in the ‘production’ of the structures and microstructures of rocks. In order to successfully understand these processes, earth materials scientists have to combine results from observational studies on naturally deformed rocks with theoretical and experimental studies to infer deformation mechanisms or processes of microstructural evolution, and to apply these results to the study of the formation of the deformed rocks that we find in nature. All of these aspects cover a wide range of investigations and methods of study. Considering the complex nature of the geological objects of our research, it becomes obvious that the range of such studies is usually too wide to be covered in depth by individuals.

This situation makes it desirable and necessary to

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have conferences devoted to earth materials science in the sense described above, to exchange ideas and to get an update on recent developments. We wanted to create a forum where field geologists could get information on the state of the art of experimental and theoretical studies, and where theoreticians as well as experimentalists could debate the problems and questions posed by natural geologic structures. The discussions between researchers in these different fields are important for the mutual recognition of common interests and discrepancies, and for the identification of first-order-problems for future research. It was the main goal of the Basel 'Conference on deformation mechanisms in naturally and experimentally deformed rocks' to foster this kind of discussion between researchers in the different disciplines. This volume, consisting of 17 papers, covers a range of topics presented at the meeting and represents an overview — although certainly not a complete one — of the present activities in the field of deformation studies on rocks.

The grouping of the contributions into the three main topics probably reflects the main research activities in the field of deformation studies today. Texture analysis has received a new impetus and direction from the development of electron backscatter diffraction techniques. Consequently, most of the texture studies in this volume have used this new technology. Almost all studies employ imaging techniques in order to combine crystal orientation data with microstructural information. This combination of data sets, first used by Bruno Sander in the 1940s (the so-called 'Achsenverteilungsanalyse'), now referred to as orientation imaging, allows one to infer the mechanisms that lead to the formation of preferred orientations and to recrystallization.

Modelling, especially numerical modelling, has become widespread and far more refined than earlier attempts due to the readily available computer power nowadays. Also, the use of analogue materials, including transparent quasi-crystalline substances, has greatly stimulated our thinking about the deformation processes and their mutual interactions. The power of numerical and analogue modelling is that they permit us to watch the often complex development of deformational structures, microstructures or textures, and to assess their dependence on intrinsic parameters and boundary conditions.

The third section illustrates that microstructures are among the most important tools for the analysis of deformation mechanisms. This field, which is complemented by the studies of reactions and chemical effects on deformation, is the one where experimental studies can make the greatest progress, and where the immediate application of experimental results to field studies is possible. The variety of papers in this section illustrates the widespread activities and strong interest in this field. We hope that the combined interest of field and laboratory scientists in all these fields continues and grows in the future!

1. Textures and recrystallization

(1) Fliervoet, T.F., Drury, M.R. and Chopra, P.N.: The influence of deformation and recrystallisation mechanisms on crystallographic preferred orientations (textures) and grain misorientation relations in experimentally and naturally deformed olivine rocks.
(2) Prior, D.J. and Wheeler, J.A.: Feldspar fabrics in a green schist facies albite-rich mylonite from electron back scatter diffraction.
(3) Leiss, B. and Barber, D.: Mechanisms of dynamic recrystallization in naturally deformed dolomite inferred from EBSP analysis.
(4) Trimby, P.W. and Prior, D.J.: Microstructural imaging techniques: a comparison between optical and scanning electron microscopy.
(5) Van Daalen, M., Heilbronner, R. and Kunze, K.: Orientation analysis of localized shear deformation in quartz fibres.

2. Numerical and analogue modelling

(1) Barnichon, J.D., Hoffer, B., Charlier, R., Jongmans, D. and Duchesne, J.C.: The deformation of the Egersund–Ogna anorthosite massif, South Norway. Finite element modelling of diapirism.
(2) Casey, M. and McGrew, A.: One-dimensional kinematic model of preferred orientation development.
(3) Herwegh, M., Handy, M. and Heilbronner, R: Evolution of mylonitic fabrics (EMM), a computer application for educational purposes.

3. Deformation mechanisms and microstructures

(1) Rutter, E.H.: On the relationship between the formation of shear zones and the form of flow law of four rocks.

(2) Post, A. and Tullis, J.: A recrystallized grain size piezometer for feldspar.
(3) Handy, M.R., Wissing, S. and Streit, J.E.: Strength and structure of mylonite with combined frictional–viscous rheology and varied bimineralic composition.
(4) Newman, J., Drury, M.R., Lamb, W.M. and Vissers, R.L.M.: Reaction-enhanced grain size reduction and deformation in a peridotite shear zone from the northern Pyrenees.
(5) Kruse, R. and Stünitz, H.: Deformation mechanisms and phase distribution in mafic high temperature mylonites from the Jotun Complex, Norway.
(6) Bialek, D.: Chemical changes associated with deformation of granites under greenschist facies conditions: the example of the Zawidow Granodiorite (SE Lusatian Granodiorite Complex, Poland).
(7) Küster, M. and Stöckhert, B.: A preliminary note on high differential stress and sublithostatic pore fluid pressure in the ductile regime — microstructural evidence for short-term post-seismic creep in the Sesia Zone, Western Alps.
(8) Vollbrecht, A., Stipp, M. and Olesen, N.O.: Crystallographic orientation of microcracks in quartz and inferred deformation processes — a study on gneisses from the German continental deep drilling (KTB).
(9) Stöckhert, B., Wachmann, M., Küster, M. and Bimmermann, S.: Low effective viscosity during high-pressure metamorphism due to solution precipitation creep: the record of HP-LT metamorphic carbonates and siliciclastic rocks from Crete.

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