Journal of the Virtual Explorer, 2000
Volume 02
Paper 16
http://virtualexplorer.com.au/

Deformation microstructures in quartzo-feldspathic rocks

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Keywords: deformation , microstructure , quartzites , quartzo-feldspathic rocks

Abstract: These images illustrate optical microstructures resulting from a variety of deformation processes that are operative in the crust, ranging from localized faulting to distributed microcracking to pressure solution to dislocation creep to grain boundary sliding and diffusion creep, with and without accompanying phase changes. However most of the images illustrate microstructures produced by dislocation creep, because this is perhaps the dominant deformation mechanism in the mid to lower crust, and also has been well studied experimentally.

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Table of Contents

Preface

In the past decade there has been enormous progress in our understanding of the deformation mechanisms and rheology of Earth materials, due to progress in experimental rock deformation studies as well as detailed studies of naturally deformed rocks from well-characterized settings. Microstructures form the link between experimentalists and field geologists, and similarities of microstructures provide the principal criterion for inferring operation of the same process, although at quite different conditions. We now can have reasonable confidence in using the microstructures in naturally deformed rocks to extract useful information about the deformation conditions. Thus it seemed a good time to compile some examples of deformation microstructures from experimentally and naturally deformed samples, as well as our interpretations of them, to illustrate some important processes of rock deformation. These may serve as a reference and teaching tool for Earth scientists interested in rock deformation as well as providing a starting point for further discussion among researchers in this field (who may or may not agree with our interpretations). Naturally, such a small collection of only 100 photos can only present a few examples, and is biased by the preferences and perspectives of the authors.

These images illustrate optical microstructures resulting from a variety of deformation processes that are operative in the crust, ranging from localized faulting to distributed microcracking to pressure solution to dislocation creep to grain boundary sliding and diffusion creep, with and without accompanying phase changes. However most of the images illustrate microstructures produced by dislocation creep, because this is perhaps the dominant deformation mechanism in the mid to lower crust, and also has been well studied experimentally.

We have included a very selective reference list for further reading which is referred to at the end of the introductions to the chapters. This list is by no means complete or in any way representative. It reflects the research interests of the contributors.

Experimental studies on quartz aggregates have identified three distinct regimes of dislocation creep, defined by different mechanisms of dynamic recrystallization. These regimes are operative at different temperature-strain rate conditions, and produce different mechanical behavior, and they result in distinctively different microstructures. These same distinct microstructures have been recognized in naturally deformed quartzites, although at much lower temperatures at the slower natural strain rates. The lowest temperature dislocation creep regime has also been identified in experimentally deformed feldspars, and the higher temperature regimes have been inferred from the microstructures of high grade naturally deformed anorthosites. Thus it may be possible to infer the temperature or strain rate of the natural deformation from analysis of the dislocation creep microstructures in quartzo-feldspathic rocks and comparison with experimentally deformed samples. We hope that the images we have collected here of experimentally and naturally deformed quartzo-feldspathic aggregates will help people to recognize and distinguish the microstructures produced by the three different mechanisms of recrystallization in these two minerals.

Another very important microstructural parameter is the size of dynamically recrystallized grains, which is largely dependent on the flow stress in single phase aggregates. Thus the recrystallized grain size may provide a paleopiezometer by which the flow stress can be inferred. If such flow stress estimates are combined with information about the temperature or strain rate inferred from the dislocation creep regime microstructures, plus experimental flow laws, we can begin to put good constraints on the deformation conditions. Obviously great caution is necessary in making such inferences; however, we believe the prospects are promising, and can only improve as field geologists provide feedback to experimentalists as to how good or bad the match appears to be!

This collection of images concentrates on the deformation microstructures of quartzo-feldspathic rocks. The examples start with experimentally deformed samples, because in experiments the deformation conditions of pressure, temperature and strain rate (as well as chemical environment) can be controlled, and therefore the dependence of microstructures on ambient deformation conditions can be well demonstrated. The images of naturally deformed aggregates which follow each set of images of experimentally deformed samples have been chosen to illustrate a wide range of similar features that have been found in many rocks. The collection starts with microstructures developed in single phase aggregates of quartz, and then of feldspar, and then progresses to include polyphase quartzo-feldspathic aggregates. The natural deformation of polyphase aggregates often includes the additional complication of chemical disequilibrium and metamorphic phase changes, which may in turn have significant effects on the deformation by allowing a switch in the dominant deformation mechanism to grain boundary sliding and diffusion creep. A few examples of this situation have been included.

Apart from the wealth of information that can be derived from a microstructural analysis of rocks, the microstructures themselves are often very beautiful. Thus we hope that this collection serves not only as a useful teaching tool but that it is also pleasant to look at, and in this way we can contribute to what (Earth) science should be: fun!

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