Preface

Interest in the plastic deformation of rocks arises mainly from its application in the Earth sciences, especially in structural geology and tectonics. Its experimental study has consequently been pursued mainly in laboratories associated with geology or geophysics departments or institutes. However, the physical mechanisms involved are of considerable interest in materials science and some workers in the field of rock deformation have had a materials science affiliation.

There are a number of aspects to the study of rock deformation, including

- Establishment of the rheological laws for the rocks, that is, the stress-strain-time relationships under particular conditions,
- Mechanisms of the deformation and the relationship between these and the specific rheological laws and microstructural features of the rock,
- Role of environmental variables (pressure, temperature, chemical activities, pore pressure) on the deformation behaviour,
- Development of fabric and multi-grain structural features on scales accessible in the laboratory, e.g. crystallographic preferred orientations, cleavages, microfolding, metamorphic differentiation, etc.,
- Relation of the deformation aspects to petrological and other aspects of the rock, involving questions of influence of stress or strain on phase transformation and stabilities, rates of metamorphic change, preservation of the setting of radioactive clocks.

The study of the plastic deformation of minerals and rocks is also of considerable interest as a topic in materials science. The knowledge of the deformation behaviour of materials involving ionic and covalent bonding is extended by including minerals, and, in particular, the silicate minerals comprise an especially interesting group of materials in which the silicon–oxygen bond plays a special role, particularly in regard to the influence of water. Our subject will in fact be presented here mainly as an aspect of the materials science of rocks and minerals, a topic both of intrinsic interest and of underlying importance for application in geology and geophysics.

In the application of the results of laboratory studies on rheology of rocks to natural situations in the earth, the extrapolation to the geological timescale presents severe difficulties. Limitations of time and equipment restrict the strain rates that can be reasonably investigated in the laboratory to a range of 10^{-2} or 10^{-3} s^{-1} to about 10^{-6} or 10^{-7} s^{-1} if strains of at least a few percent are required, whereas the strain rates of interest in the earth are generally less than 10^{-10} s^{-1} and, in the majority of applications, probably in the range 10^{-12}–10^{-14} s^{-1}. Thus measurements made over a range of three or four orders of magnitude have to be extrapolated over a further range of six to eight orders of magnitude, a daunting prospect. Several difficulties are involved in such an extrapolation. First, there tends to be considerable scatter of results of tests on rock specimens and so the accuracy of the rheological relations established in the laboratory tends to be inadequate for such a long extrapolation; however, careful selection of material for uniformity, and testing of a sufficient number of specimens can minimise the uncertainties from scatter. More serious is the question of determining whether the nature of the deformation behaviour studied in the laboratory is the same as that involved in the natural situation so that the same rheological laws can be expected to apply; it therefore has to be established that the deformation process is the same in both cases, which requires particular study of the microstructural imprints of these mechanisms. The study of the mechanisms of deformation therefore takes on a particular importance in experimental rock deformation, not only for its intrinsic interest in a materials science sense, but also for establishing the nature of the microstructural evidence that must be correlated with that observed in the naturally deformed rocks in order to justify extrapolation of the laboratory results to the natural situation on the grounds that the same processes are dominant in both situations.

The nature of the extrapolation problem can be illustrated with reference to a so-called deformation mechanism map. Such a diagram illustrates that there are a number of modes or mechanisms of deformation, each with its own flow law; the particular mode that dominates is determined by the combination of stress (or strain rate) and temperature that is imposed on the rock. It follows that extrapolation of a particular flow law is only justified within the stress (or strain-rate) and temperature domain within which that mechanism predominates. It is also to be emphasised that a particular deformation mechanism map only applies for a particular combination of environment and structural state of the specimen; for example, changing the grain-size or the activities of minor chemical components may change both the values of the parameters in a given flow law and the limits of the domain within which it is valid. Extrapolation to geological conditions is therefore a difficult matter and one in which it can only be expected that approximate conclusions or limits can be arrived at after detailed considerations of evidence bearing on mechanisms of deformation.

Since the mid-nineteenth century when Sorby and other pioneers introduced microscopical studies of the materials of technology, any comprehensive approach to the mechanical properties of materials has included some attention to the deformation processes at the microstructural level. At first the focus tended to be on processes at the scale of the crystals in polycrystalline materials, and it is of particular historical interest in the present context that the earliest studies in crystal plasticity were carried out with the minerals, halite and calcite. However, work on metals soon came to dominate the scene for several reasons, including the ductility and technical importance of metals and the development of methods for growing large single crystals and for revealing their crystallographic details by X-ray diffraction. It thus came about that it was in the field of metallurgy that many of the basic concepts of crystal plasticity and of the flow of polycrystals were developed. Consequently, it was from this field that many basic concepts were later carried over for application to other materials such as rocks, although independent lines of approach were also developed in particular areas as interest arose, for example, in soils and polymers.

Such was the situation up to the 1950s. However, during the recent decades the scope of research on mechanical and related properties and its application has broadened out considerably and has come to encompass as well a wide variety of non-metallic materials in a more integrated approach. Consequently the term "materials science" has commonly replaced "metallurgy" when speaking of the study of the fabrication and properties of materials of potential technical application. There is now considerable knowledge of the properties of materials in such distinctive categories as metals, semiconductors, ceramics, oxides in general, glasses, plastics and elastomers, nanomaterials, soils and ice, and there are valuable insights to be gained from comparative studies between the various groups. The category of minerals and rocks, although the subject of some engineering and geological interest since time immemorial, is one of the latest to "come of age" in materials science extending again the range of this subject into yet further regions of distinctive behaviour while still demonstrating much that is common with other materials. The first chapter summarises some of the characteristic aspects of minerals and rocks as materials.

Much of the present text was written in the 1980s. However, the basic material science concepts of relevance to the study of rock deformation were already established by this time and so it is felt that this presentation is still of relevance. A limited amount of updating has been done and some later references added.

I am very indebted to Ian Jackson for careful reading of the text and to John Fitz Gerald for assistance in the preparation of the micrographs.

http://www.springer.com/978-94-007-5544-4

Materials Science for Structural Geology
Paterson, M.S.
2013, XIV, 250 p., Hardcover
ISBN: 978-94-007-5544-4