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Rock deformation in the continental crust (Louis Neél Medallist Lecture)

Ernest H. Rutter
School of Earth, Atmospheric and Environmental Sciences University of Manchester, Manchester M13 9PL United Kingdom

Unlike engineering materials, the mineralogical variety of rocks and the enormous range of pressures and temperatures under which they become deformed through natural tectonic processes leads to an immense range of mechanical properties and microstructural evolutions being displayed. Rock deformation behaviour can be studied by means of both experimental rock mechanics and field observations, and there is no doubt that each approach can provide inspiration to studies by means of the other approach. Over several decades I have been privileged to be able to take both approaches, and I take this opportunity to share some of the insights I have been able to obtain.
At elevated temperatures solid rocks are usually macroscopically ductile through various combinations of intracrystalline plasticity, flow by diffusive mass transfer and granular flow with plastic or diffusive accommodation processes. The latter mechanisms are markedly grain size-sensitive. Amongst crustal materials carbonate rocks have proved relatively easy to deal with, either using natural rocks or synthetic hot-pressed aggregates, yet display this full range of deformation mechanisms. Somewhat more difficult are quartz rocks, but on account of their importance I have invested some effort into understanding grain-size sensitive flow in such rocks. Another area of strong interest is the flow of partially molten granitic rocks and the problem of the extraction of these viscous melts from their melting protoliths to form plutons. We have made a number of attempts at the experimental determination of their flow behaviour.
Field observations of deformed rocks show that metamorphism and deformation can be strongly linked. Serpentinite has proved to be particularly well suited to laboratory experiments that demonstrate these effects. It displays the effects of changes in effective pressure through water evolved in the dehydration reaction, the effects of transiently fine-grained reaction products and the effects of generation of collapsible porosity.
Brittle deformation and localization of deformation into faults leads to a family of characteristic microstructures that can be seen in rocks deformed in the laboratory and in the field. In recent years we have developed new research on the Carboneras fault zone, in SE Spain. This is a large strike-slip fault system that allows a detailed chronology of movements to be established through related sedimentation and volcanism, and provides an unparalleled opportunity to ground-truth shallow seismic observations against the observed geology and laboratory measurements of rock physical properties. The mechanical behaviour of porous rocks is of particular importance to areas of applied rock mechanics, and links through to soil mechanics via critical state theory. At the same time, critical state theory also provides a useful framework for understanding some aspects of high-temperature rock mechanics such as deformation/metamorphism interrelationships and the flow of partially molten rocks, when they can be considered as deforming, fluid-saturated porous solids.