A General Description of Brittle Versus Ductile Failure of Rocks

By Eric Buer

Throughout the Grand Canyon visitors can observe many interesting geologic features from the intrusions of the Zoroaster Granite into Vishnu Schist to folds and faults. Every formation implies a different process, and two of the most interesting are the formation of folds versus the formation of faults.

Faults are the result of rocks behaving in a brittle fashion, much like cold glass or hard steel. While the mineralogy and rock fabric may favor brittle or ductile behavior, the most important variables are the temperature and pressure at the time a stress is applied. For most people rocks are only seen at the surface of the earth, and so while some are better indurated or more dense than others, all of them appear brittle. In fact, much like the steel used to make horseshoes, or glass blown into wineglasses, given great enough temperature and pressure the properties of rocks similarly change from hard and brittle to soft and ductile, eventually melting entirely into liquid magma.

A cold rock under relatively little lithostatic pressure will under most circumstances break along a surface which can alleviate the stress being applied. In the earth, these processes take place at reasonably shallow depths. The process of breaking rocks to relieve stress is what generates earthquakes, and the tremors felt at the surface of the earth are the release of potential energy which has built up as the applied stress increased on the rock body. The failure forms a fault, a plane on which rocks have moved up, down, left, right, or some combination thereof. After faulting occurs, lithostatic and tectonic stresses usually lock the fault, and movement ceases until applied stress becomes sufficiently large to force movement again. In some cases it is more favorable to break new faults than continue slip on old ones. Faults in the Grand Canyon can be recognized anywhere two layers of the same rock suddenly show a break in continuity. These discontinuities may be small across a single joint, or huge displacements observed from one canyon wall to the other.

Folds in rocks are the result of ductile failure. This is similar to what modeling clay or thick cookie dough experiences when being kneaded. This type of deformation typically occurs at higher temperatures and pressures than those which favor faulting.

Stress is alleviated in folding as material is displaced, similar to how applied stress is reduced as blocks are displaced along a fault. The resulting folds can be seen throughout the Grand Canyon, and often appear similar to what several sheets of paper that were loosely bent into arcs, “S,” and “Z” shapes would look like if made out of stone. The process of folding need not take place at extreme depths within the earth, where both the temperature and pressure are known to be very high. The Zoraster Granite intrusions are testament to the active history of intrusions and geologic activity which the Grand Canyon has experienced. The temperature and pressure can be increased sufficiently by a large magma intrusion in the region to produce local ductile rather than brittle failure.

Sources

There is a tremendous body of writing about brittle and ductile failure, folds, and faults. Some of it I have read, none of it has been quoted. The following titles offer much more thorough and detailed information than the very brief summary I have provided in this field log.

R. Compton. Geology in the Field. W.H. Freeman and Company, 1985.

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E. Moores and R. Twiss. Structural Geology. W.H. Freeman and Company, 1992.

F. Press and R. Siever. Earth. W.H. Freeman and Company, 1998.