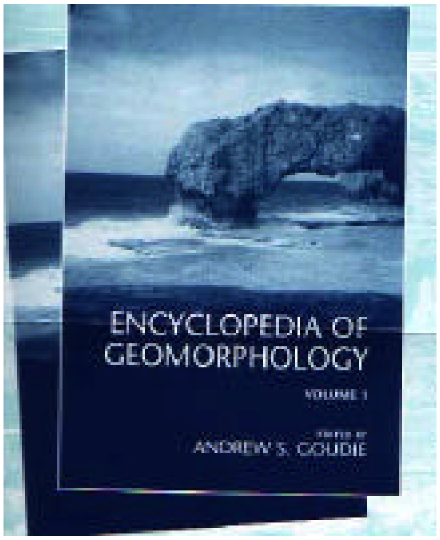

Routledge, London 2004
ISBN 0-415-27298-X (2 volume set)

Dorn, R.I. 2004. Case hardening, in Encyclopedia of Geomorphology , ed. A.S. Goudie, Routledge: London, 118-119.

CASE HARDENING

Case hardening describes rocks with outer shells more resistant to erosion than interior material. This hardening is sometimes called induration. Although case hardening is occasionally used as a synonym for DURICRUST, case hardening most frequently refers to differential weathering of the same rock type — often associated with intricate weathering features such as tafoni (Campbell 1999).

Two general types of processes create the appearance of case-hardening: core softening of the interior; and case hardening of the exterior. James Conca proposed a lithologically-based explanation. Crystalline rocks such as granite tend to core soften, whereas clastic rocks such as sandstone tend to case harden. The dichotomy has to do with the way the minerals bond together. Since sandstone grains are held together by cementing agents, a greater accumulation of cements at the surface causes case hardening. In contrast, the greatest change in hardness in a crystalline rock takes place when bonds are broken by CHEMICAL WEATHERING. Core softened boulders are seen in locales of most intense chemical weathering.

The early literature advocates the view that hardening occurs by solutions that are mobilized from the rock's WEATHERING RIND, drawn out by evaporative stresses, and then reprecipitated in the rock's outer shell. A growing body of evidence indicates that external agents also penetrate into outer shell of the host rock, hardening the surface. A variety of different hardening agents have been found within host rocks lacking these agents. Amorphous silica, calcite, calcium borate, clay minerals such as kaolinite, iron hydroxides, oxalate minerals, rock varnish, and other internally- and externally-derived agents penetrate about a millimetre to harden the very surface of the rock.

Case hardening, by definition, is not a ROCK COATING. However, a wide variety of rock coatings can act as case-hardening agents. Glazes of mostly silica and aluminum with some iron, only 20-30µm thick, impede erosion of greenschist in southern England (Mottershead and Pye 1994). The role of silica glaze can be striking for temperate sandstones; '[o]ne of the most important characteristics of many porous sandstones is their tendency to case-harden owing to the development of a surface crust or rind' (Robinson and Williams 1994: 382). In Antarctica, iron-stained silica glaze reduces permeability and channels moisture towards uncoated rock surfaces. Thus, rock weathering is concentrated away from the rock coatings (Conca and Astor 1987). Lichen-generated oxalates protect sandstone surfaces in the Roman Theater of Petra. Dark coatings of silica, oxides of iron/manganese, and charcoal case harden rock faces at Yarwondutta Rock, Australia (Twidale 1982). While lichens are usually erosional agents, these epilithic (rock surface) organisms sometimes protect the underlying rock from erosion.

Although case hardening is most commonly noted in warm deserts where little soil covers rock surfaces, case-hardened rocks occur in all terrestrial weathering environments. In the wet tropics, for example, case hardening is frequently seen on bedrock along rivers at stages only reached by wet-season floods. In alpine settings, case hardening helps preserve glacial polish. Silica glaze is an important case hardening agent in temperate (Mottershead and Pye 1994; Robinson and Williams 1994) and Antarctic areas (Conca and Astor 1987). Iron films can be seen splitting apart and also holding together weathering rinds in northern Scandinavia (Dixon et al. 2002).

Case hardening (Plate 20) often has subsurface origins in JOINTING. Mottershead and Pye (1994), for example, discerned a three-stage process. First, the host rock hardens along joint faces within the subsurface. Silica, aluminum, and some iron comprise the bulk of the case-hardening agent. Second, DENUDATION of the land surface exposes joint faces at the surface. Third, erosion of rock underneath the case-hardened surface creates cavities called *tafoni, that highlight the case-hardening. Rock engravings (petroglyphs) also emphasize planar JOINTING surfaces that were case hardened while in the subsurface. Road cuts of granitic rocks that weather to GRUS often reveal case hardened subsurface joints. Geothermal and other DIASTROPHISM processes often leave behind case hardened joints.

Considerable disagreement exists over how long it takes case hardening to form, with assertions in the literature ranging from months to thousands of years. James Conca studied rates of hardening in the Mono Basin of Eastern California, finding that changes take place on the time scale of thousands to tens of thousands of years. Rates of hardening, however, vary with climate and the particular hardening process.

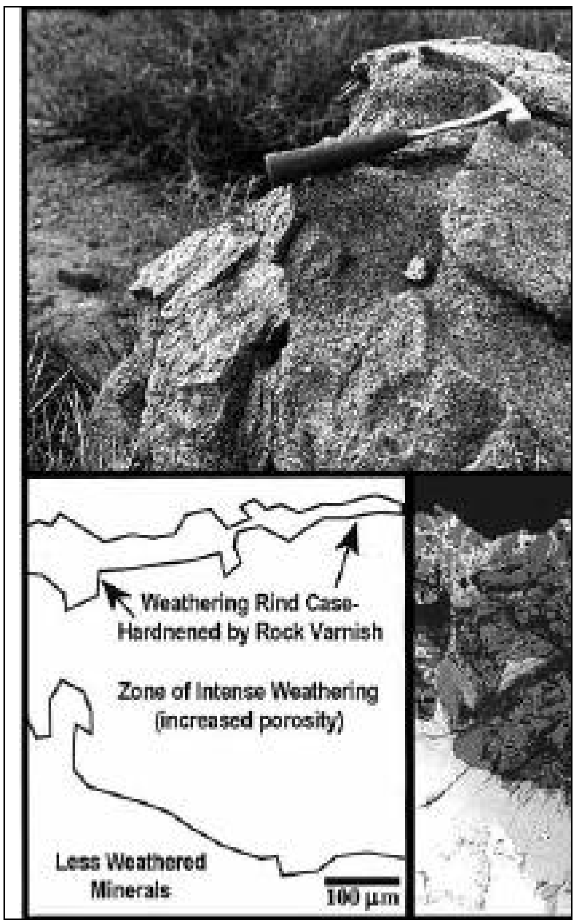

Plate 20: Case hardening on a ca. 140,000 year-old moraine boulder of the Sierra Nevada, California, where a combination of processes produce the differential weathering seen in the top image. Core softening of the host granodiorite boulder is the most important process. The electron microscope image and corresponding map shows a close-up of the area around the tip of the rock hammer. Some softening comes from *chemical weathering and some hardening takes place as a result of the penetration of desert varnish into the weathering rind.

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SEE ALSO: Chemical weathering; denudation; grus; jointing; rock coating; tafoni; weathering rind

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