Residual stress: Another source of strain energy to drive mechanical weathering

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1. Abstract

One theory holds that there are three general sources of stress that drive mechanical weathering to some degree—topographic, tectonic, and environmental (Eppes and Keanini, 2017). Here, I posit that a fourth source of stress might be just as important as the other three in driving subcritical cracks during the weathering processes. Residual stress gives the rock volume a component of thermodynamic energy, strain energy, which contributes an element of work that may ease the process of weathering through crack propagation, particularly at the microscopic scale. The idealized residual volumetric strain energy is on the order of 10^4 erg/cm^3 (Friedman, 1972) which is an order of magnitude larger than the effective fracture surface energy to cleave individual quartz crystals (Brace and Walsh, 1962). Grain-scale residual stress commonly resides within a rock matrix and is manifest by elastic strain within elements of an isolated body after all boundary tractions are removed (Engelder, 1993). The equilibrium volume is the smallest unit of free rock within which all forces balance (Varnes and Lee, 1972). Bimetal strips and prestressed-concrete beams are two examples of an isolated body carrying a residual stress (Figure 1). In rock, an equilibrium volume may vary in scale from the microscopic (Friedman, 1972) to the size of granite plutons (Savage, 1978) (Figure 2). Portions of the equilibrium volume may contain forces consistent in magnitude and orientation as is the case for a layered model for residual stress (Holzhausen and Johnson, 1979) (Figure 3). Double overcoring is a common technique for measuring residual stress in the near surface where weathering is most intense (Engelder et al., 1977) (Figure 4). Residual stress differs from remnant stress which may arise because of a removal of overburden under uniaxial conditions or drainage of a high-pressure fluid (Engelder and Sbar, 1977) (Figure 5). Tectonic stress, that component of stress arising strictly from boundary tractions—plate tectonics, glacial loading, topographic loading, etc.—may be captured and preserved as a component of either a residual stress or a remnant stress. However, the tectonic component within a boundary-free block of rock (locked in strains) must be balanced by a non-tectonic component of elastic stress

(locking strains) if the block is in equilibrium (Voight and St. Pierre, 1974) (Figure 2). In the near surface, residual stress is commonly manifest by an elastic expansion of the rock—commonly measured by overcoring—suggesting that the matrix of the rock is dominated by compressive stresses (Figure 6) (Sbar et al., 1984). If so, the mechanism for generating the tensile stress necessary for subcritical crack propagation is equivalent to a crack propagation either under grain-scale loads configured like a Brazilian test (compression leads to tension at right angles to the load) or grain-boundary loading equivalent to a Hertzian indenter. Residual stress tends to control the orientation of induced cracks (Friedman and Logan, 1970). Another manifestation of residual stress in rocks is the property of time-dependent stress relaxation which may also take place at the slow pace of natural mechanical weathering (Engelder, 1984).

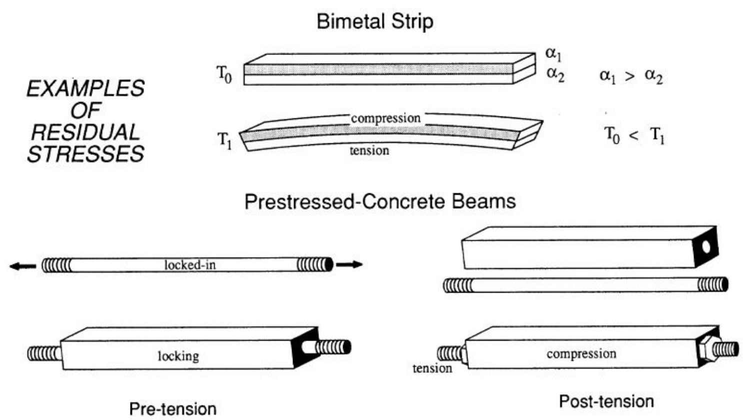

Figure 1. Examples of residual stresses in engineering (Engelder, 1993).

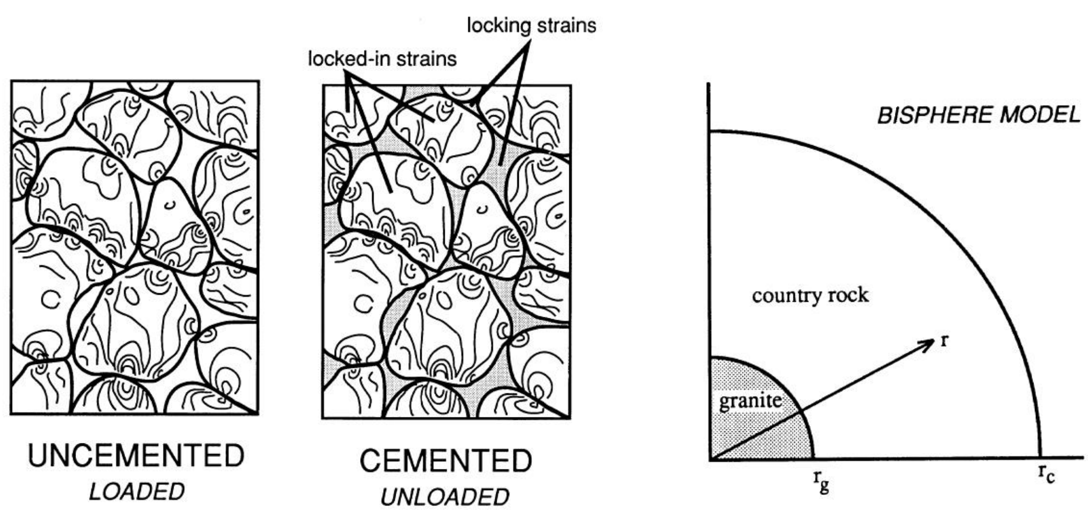

Figure 2. Examples of residual stresses in geology from the grain-scale to the size of plutons.

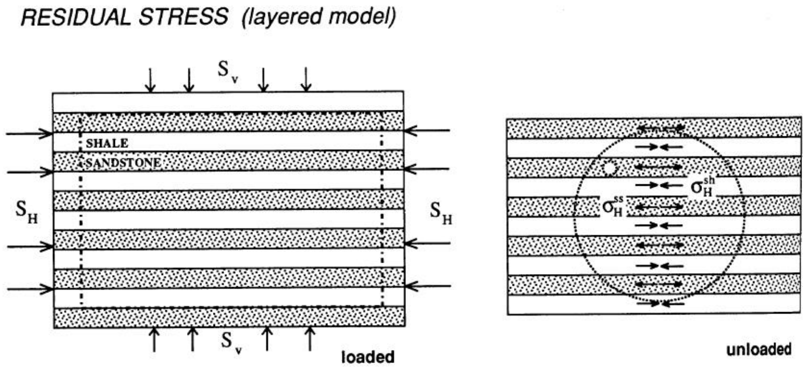

Figure 3. Layered model for residual stresses.

Figure 4. Double overcoring.of the Potsdam Sandstone near Plattsburgh, New York.

Figure 5. Post-glacial popup as a manifestation of remnant stress (Alexandria Bay, NY).

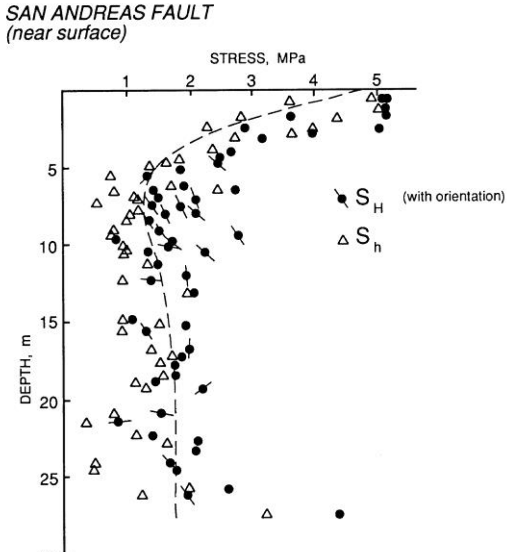

Figure 6. Thermoelastic stress in the near surface (Mojave Desert, California). Some models view temperature change as a source of variable residual stress.

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