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Reconstructing the regolith from erosionally exhumed corestone and saprock derived from the Cretaceous Val Verde tonalite, Peninsular Ranges, southern California, USA: A case study

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ABSTRACT

In temperate zones, an idealized profile of the regolith would consist of in descending order and decreasing weathering intensity, zones I, II, III, and IV. Each zone is characterized by a distinctive mineralogy and chemistry that reflects reactions between rocks and downward percolating fluids. Utilizing these principles, we attempted to reconstruct the original position within the regolith of erosionally exhumed corestone and saprock derived from the Cretaceous Val Verde tonalite at Yucca-Perris and Motte Rimrock, southern California.

Chemical index of alteration (CIA) values derived from saprocks at both sites range from 0.49 to 0.50. At Yucca-Perris, average weathering intensity values (t) are 0.03 ± 0.12 and at Motte Rimrock are 0.03 ± 0.02. Clay minerals at Yucca-Perris are smectite, kaolinite, and illite, and at Motte Rimrock vermiculite, kaolinite, and illite. No statistically significant loss of elemental mass or changes in bulk mass and LOI (i.e., water + volatiles) occurred at Yucca-Perris, while at Motte Rimrock a significant increase in LOI is evident. We interpret the significant increase in LOI to reflect the stronger intensity of weathering at Motte Rimrock where incongruent dissolution was responsible for modest leaching and removal of Na, Ba, and Sr masses from plagioclase. The mass of La at Yucca-Perris, and the masses of Er, Tm, and Yb at Motte Rimrock were increased. Such increases imply that prior to removal of the overlying soil and upper parts of the regolith, acidic solutions mobilized the rare earth elements, and then transported them downward into the lower regolith where increasing pH resulted in their precipitation, exchange, and adsorption onto mineral surfaces. The above data suggest that at Motte Rimrock the sampled corestone and saprock formed initially at the transition between the upper and lower parts of zone II and at Yucca Perris at the transition between the upper and lower parts of zone III.

1. Introduction

An idealized profile of the regolith developed by Nesbitt et al. (1997) and Nesbitt and Markovics (1997) is shown in Fig. 1. Within this idealized profile unweathered granitic bedrock grades upwards into saprock, saprolite, and finally soil. Such a model is supported by a large number of studies including those by Brock (1943), Wahlstrom (1948), Butler (1953, 1954), Lovering (1959), Grant (1963, 1975), Wolff (1967), Nesbitt et al. (1980), Melfi et al. (1983), Minarik et al. (1983), Fritz (1988), Nesbitt and Young (1984, 1989), Nesbitt et al. (1996), White et al. (2001), Girty et al. (2003, 2008, 2013), and many others. Saprock is defined as in situ material in which <20% of the weatherable minerals are altered (Anand and Paine, 2002; Graham et al., 2010; Velde, 1995). In contrast, saprolite is defined as in situ material in which >20% of the weatherable minerals are altered. Often spheroidal to ellipsoidal relicts of bedrock are preserved within saprock and saprolite as corestones.

The above textural components of the regolith make up in descending order weathering zones I, II, III, and IV (Fig. 1) (Nesbitt et al., 1997). In zone I, the zone of residual weathering, primitive weathering solutions are dilute and charged with CO_2 and organic acids (Nesbitt and Young, 1984). The solutions are therefore acidic and the products and residues of their reactions with the primary minerals making up the granitic bedrock commonly are gibbsite, kaolinite, quartz, and the Al, Fe, and Ti oxyhydroxides (Fig. 1). As weathering solutions descend through the intermediate zone of weathering (i.e., zones II and III) they become progressively more evolved, and with increasing depth approach or achieve equilibrium with vermiculites, illites, and smectites (Nesbitt and Young, 1984). As a result, feldspars and quartz progressively become more abundant downward through zones II and III. In the clay fraction kaolinite and gibbsite become less important as vermiculites, illites, and smectites become more dominant (Fig. 1). Similarly, though rock fragments in zone II make up only a minor component of the regolith, they become increasingly more abundant downward into zones III and IV. In zone

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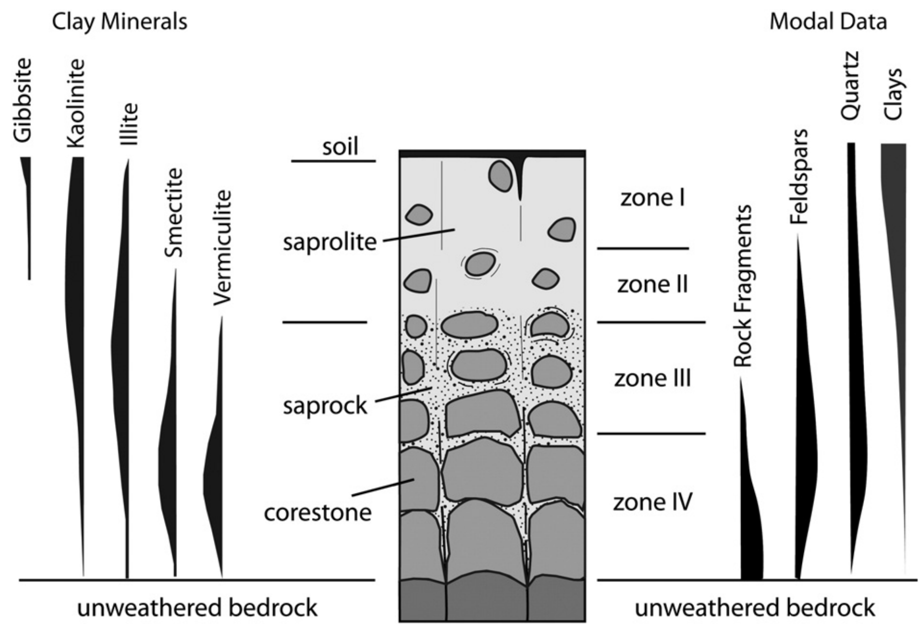

Fig. 1. Idealized profile of granitic regolith based on data presented and discussed in Nesbitt et al. (1997).

IV, the zone of incipient weathering, mature weathering solutions achieve equilibrium with respect to many, but not necessarily all, of the primary phases of the unweathered granitic bedrock (Nesbitt and Young, 1984). Hence, in zone IV the regolith has abundant rock fragments, feldspar and quartz grains, and a minimal development of clay minerals (Fig. 1).

If erosion exceeds the rate of regolith production, then the upper zones (e.g., zones I and II) may be stripped away leaving the lower zones (e.g., zones III and IV) exposed at the land surface (Fig. 2) (Nesbitt and Markovics, 1997). Such a condition exists throughout large portions of the seismically active Peninsular Ranges of southern California, where erosion has resulted in a landscape that is commonly dotted by exposed or partially exhumed corestones (tors).

This paper represents a case study for utilizing the above model to reconstruct the regolith of erosionally exhumed corestone and adjacent saprock at Yucca-Perris and Motte Rimrock, both located within the Peninsular Ranges batholith, southern California (Fig. 3). Both sites lie within the zone of precariously balanced rocks of Brune et al. (2006), and contain corestones and saprock derived from the Cretaceous Val Verde tonalite (Morton, 2001). As outlined in a later section (see Discussion and conclusions section), saprock and corestone sampled during this study are interpreted to have originated sometime between the early Pliocene and about 24,000 years ago (late Pleistocene).

In our assessment of the chemical alteration patterns at each site we utilized the statistical and mathematical foundations for evaluating compositional data established by Aitchison (1986), along with the non-central principal component analysis techniques described by von Eynatten et al. (2003). Below we first discuss the climate and timing of corestone and saprock development, and then our sampling,

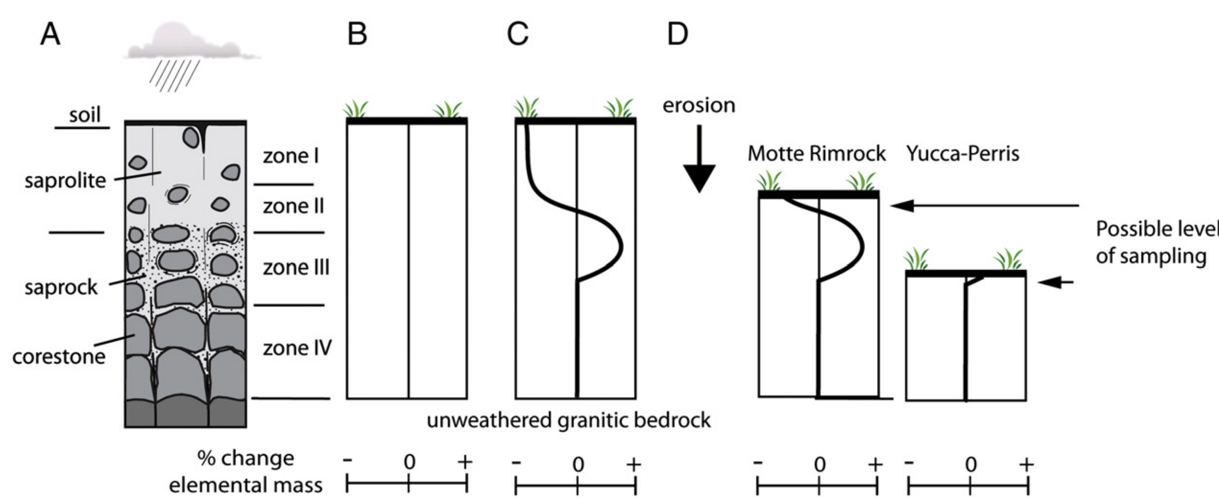

Fig. 2. Effects of erosional exhumation on idealized profile of granitic regolith. Modified from Nesbitt and Markovics (1997). (A) General attributes of typical section of granitic regolith. (B) Prior to development of regolith, no change in elemental mass has occurred. (C) As immature highly acidic fluids leave the A-horizon of the overlying soil, they react with the solid base, leaching elementals from the upper regolith (zone I and upper part of zone II). During downward migration, the pH of the fluids increases, and some elements precipitate, or are exchanged or adsorbed onto mineral surfaces within a zone of accumulation (lower part of zone II and upper part of zone III). (D) If the rate of regolith development is less than the rate of erosional exhumation, then the upper part of the regolith may be removed, leaving the lower part exposed at the land surface. The approximate levels of erosion at Yucca-Perris and Motte Rimrock are schematically shown.