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Assessing volumetric strains and mass balance relationships resulting from biotite-controlled weathering: Implications for the isovolumetric weathering of the Boulder Creek Granodiorite, Boulder County, Colorado, USA

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ABSTRACT

An important process often cited in the development of saprock and saprolite is the isovolumetric weathering of granitic bedrock. Evidence for isovolumetric weathering includes the observation that the texture of the granitic protolith often remains recognizable in its weathered products. In contrast to the above often cited view, we present results from a study of two sites located on the 1.65 Ga Boulder Creek Granodiorite near Boulder, Colorado, USA, in which weakly chemically altered saprock derived from tonalitic and granodioritic–tonalitic bedrock records volumetric strains on the order of 7.6%–8.5% and 7.9%–8.2% respectively. We show that dilation is likely due to the alteration of biotite to vermiculite during the early stages of weathering, and is associated with an expansion normal to the {001} cleavage of ~40%. Theoretical calculations of volumetric strains based on the modal biotite present in the protolith support such an interpretation.

1. Introduction

The in situ weathering of granitic protoliths commonly results in the formation of corestone, saprock, and saprolite. Saprolite is soft, friable, thoroughly decomposed rock derived from chemical weathering in which more than 20% of the weatherable minerals present are altered (Birkeland, 1999; Graham et al., 1994; Tandarich et al., 2002). In contrast to saprolite, of the weatherable minerals present, less than 20% are altered in saprock (Graham et al., 2010). Grus, an accumulation of fragmental material derived from the in situ granular disintegration of granitic rocks, is a product closely related to saprolite and saprock (e.g., Bates and Jackson, 1987; Le Pera et al., 2001; Migoń and Thomas, 2002). Corestones, commonly enclosed in saprock or saprolite, represent relatively unweathered, spheroidal to ellipsoidal remnants of the parental rock.

Isovolumetric weathering "…involves the removal (and/or addition) of elements from the weathering profile without dilation or compaction …" (Gardner, 1980). Because the texture of the parent material remains recognizable, isovolumetric weathering is often assumed or stated to be a general property of the in situ development of the regolith (e.g. Dethier and Bove, 2011; Gardener et al., 1978; Gardner, 1980; Grant, 1963; Pavich and Obermeier, 1985; Velbel, 1990; Witanachchi, 2004). However, a few published studies suggest that splitting and dilation of biotite during weathering is a significant factor in regolith development (Graham and O'Geen, 2010; Isherwood and Street, 1976; Nettleton et al., 1970). For example, Nettleton et al. (1970) showed that regolith developed on tonalite in southern California, USA, produced linear extensibilities (LE) that were consistent with the transformation of biotite to vermiculite. Such transformations followed the relationship $LE = \sqrt[3]{40 * b}$, where b is the fraction of biotite in the parent rock, and 40 is the percent expansion in the biotite grain due to its conversion to vermiculite. Subsequently, Isherwood and Street (1976) showed that grus and saprock development in the Boulder Creek Granodiorite near Boulder, Colorado, USA was associated with the alteration of biotite to vermiculite and the resulting expansion perpendicular to {001} cleavage planes. This transformation involved the replacement of interlayer K by hydrated exchangeable Mg and the release and oxidation of octahedral Fe (Graham and O'Geen, 2010; Isherwood and Street, 1976; Nettleton et al., 1970). Because of this process, the thickness of an individual structural unit of biotite, as measured perpendicular to the {001} cleavage, would have increased from 10.0 Å prior to alteration to vermiculite, to ~14.0 Å after alteration. This transformation would have resulted in an ~40% increase in the volume of an individual biotite structural unit (Graham and O'Geen, 2010; Graham et al., 2010; Nettleton et al., 1970). The results of the work by Nettleton et al. (1970), and Isherwood and Street (1976) are important because they imply that positive dilational strains are possible during

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regolith development, a result that is not consistent with isovolumetric weathering.

Because of the conflicting results of the studies summarized above, we undertook an investigation that would build upon the earlier work of Isherwood and Street (1976) by assessing in more detail the petrological, mineralogical, chemical, and volumetric strains associated with the development of regolith derived from the Boulder Creek granodiorite near Boulder, Colorado, USA. In the following pages, we first characterize the changes in petrology, texture, and clay mineralogy resulting from the conversion of the Boulder Creek granodiorite to saprock, and then quantify the degree of chemical weathering through use of the Chemical Index of Alteration (CIA) (Nesbitt and Young, 1984). We then use the multivariate statistical analysis and modeling techniques of von Eynatten et al. (2003) and von Eynatten (2004) to assess whether or not our chemical data follow a compositional linear trend. Subsequently, we attempt to quantify the relative intensity of weathering through orthogonal projection onto calculated compositional linear trends. Finally, we asses elemental and bulk mass changes, and present our new measurements for volumetric strains.

2. Geologic setting and site characteristics

The two locations selected for this study are the Gold Hill and Sugarloaf sites (Fig. 1). Each site is located upslope from road surfaces where contamination from road salt was unlikely.

Located at 40°03′12.52″N and 105°24′02.66″W (Fig. 1) at an elevation of ~2379 m, the Gold Hill site is partially exposed in a road cut on a steep SE facing 48% slope. At this location, partially exhumed corestones and patches of bedrock protrude from the Mollisols of the variably eroded Juget series (Moreland and Moreland, 1975; Soil Survey Staff, 2013). In the surrounding area, north-facing slopes are densely forested whereas south facing slopes contain patchy grasslands with sparse forest cover. At the Gold Hill site, the 34 × 33 cm in size,

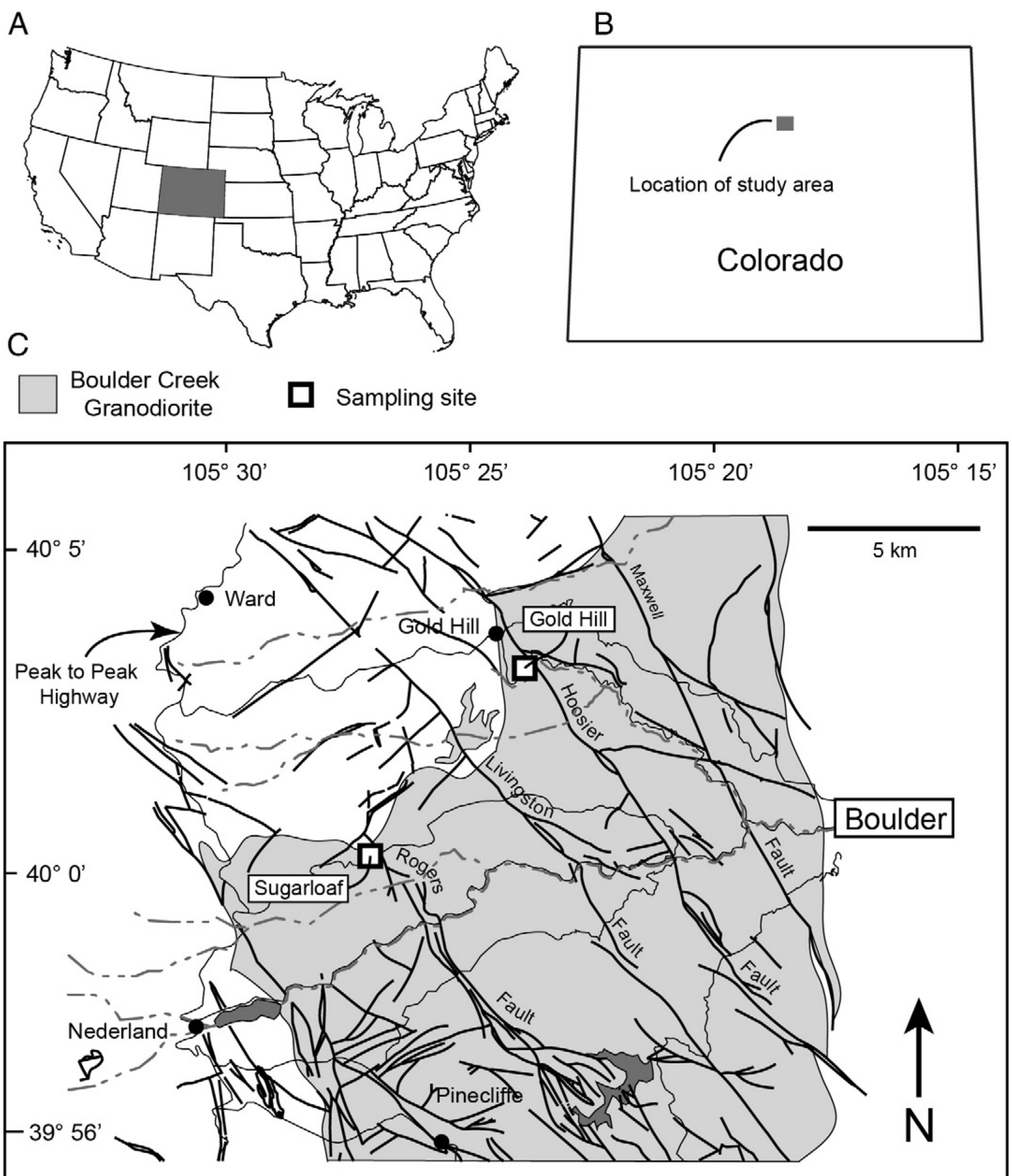

Fig. 1. (A) Map of USA showing Colorado highlighted in gray. (B) Location of (C) shown in enlargement of Colorado. (C) Generalized map of the Boulder Greek Granodiorite showing the location of the Gold Hill and Sugarloaf sampling sites. Map is modified from Gable (2000).