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A case study of a precariously balanced rock, its partially exhumed corestone platform, and encasing saprock and soil

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ABSTRACT

Lying between the Elsinore and San Jacinto faults, ~0.5 km SE of Roundtop, is a tonalitic corestone perched precariously on an exhumed corestone base. Such features are referred to as precariously balanced rocks (PBRs). Cosmogenic ^{10}Be data listed in an online abstract suggest a tentative exhumation age of the PBR near Roundtop at ~35,000 years ago. The absence of PBRs adjacent to the Elsinore and San Jacinto faults implies that they were shaken free from their perches during ground shaking. Alternatively, their absence may reflect a more highly fractured and intensely weathered terrane. Because the weathering histories of PBRs have not been studied previously, we analyzed the texture, clay mineralogy, and geochemistry of the Roundtop PBR to answer several basic questions. Can the characteristics of the regolith that once encased the precariously balanced rock be reconstructed? What chemical processes operated in the regolith prior to exhumation, and are these processes still occurring? Following exhumation, did new fracture development modify the original regolith? To answer these questions, we extracted three ~1 m long cores from the PBR near Roundtop, and collected 23 saprock and 9 pebbly sandy loam samples from a trench excavated near the base of the corestone platform. Plagioclase and biotite alteration, along with the concomitant loss of Ca, Na, Sr, Ba, K, Mg, Mn, Nb, and P mass, are the primary evidence of weathering intensity within the saprock. Additionally, the presence of mostly kaolinite, and lesser quantities of mixed-layer biotite/smectite in the saprock, along with the above observations and data, point to significant fluid/rock interations during saprock development. Subsequent formation of pebbly sandy loam appears to have been accomplished primarily through pedoturbation within the uppermost portions of the underlying already weathered saprock, and produced little additional chemical weathering. Hence, our data support the general idea that Roundtop is an area of weak ground shaking, and that since current exhumation little weathering has affected this PBR locality.

1. Introduction

Approximately midway between the San Jacinto and Elsinore faults is a band of precariously balanced rocks (PBR) (Fig. 1A) (Bell et al., 1998; Brune et al., 2006; Rood et al., 2012). Such rocks are large boulder-sized (> 256 mm in diameter) corestones that developed initially within the regolith, and have been exhumed through subsequent erosion. They are similar to tors and, currently rest on jointed basement rocks, or on partially exhumed corestone platforms along subhorizontal dipping joints. The maximum ground motion acceleration required to topple a precariously balanced rock ranges from 0.20*g* to 0.49*g* (*g* = acceleration due to gravity) (Brune et al., 2006). Hence, the corridor of precariously balanced rocks is interpreted to represent a zone of minimum ground motion acceleration produced by ruptures along the bounding San Jacinto and Elsinore faults (Fig. 1A).

One such precariously balanced rock is exposed along a ridge on the southeast flank of Roundtop (Figs. 1B and 2A), a locally prominent bornhardt standing ~789 m in elevation, ~20 km NE of Temecula, California, Riverside County, USA. The PBR was chosen for study, because sampling would require use of a large portable gas powered, water cooled drill, and thus accessibility by vehicle. A cosmogenic ^{10}Be age of ~35 ± 1 ka for the PBR at this site is reported in an online abstract (Rood et al., 2012). Unfortunately, a detailed accounting of these data have yet to be published, and as result, we view the ^{10}Be age to be tentative. Cosmogenic nuclides, like ^{10}Be, are produced when cosmic rays interact with quartz in the uppermost 1 m of the Earth's surface (Von Blanckenburg, 2005). Hence, the tentative ^{10}Be age for the PRB records its integrated history as it passed through the upper 1 m of

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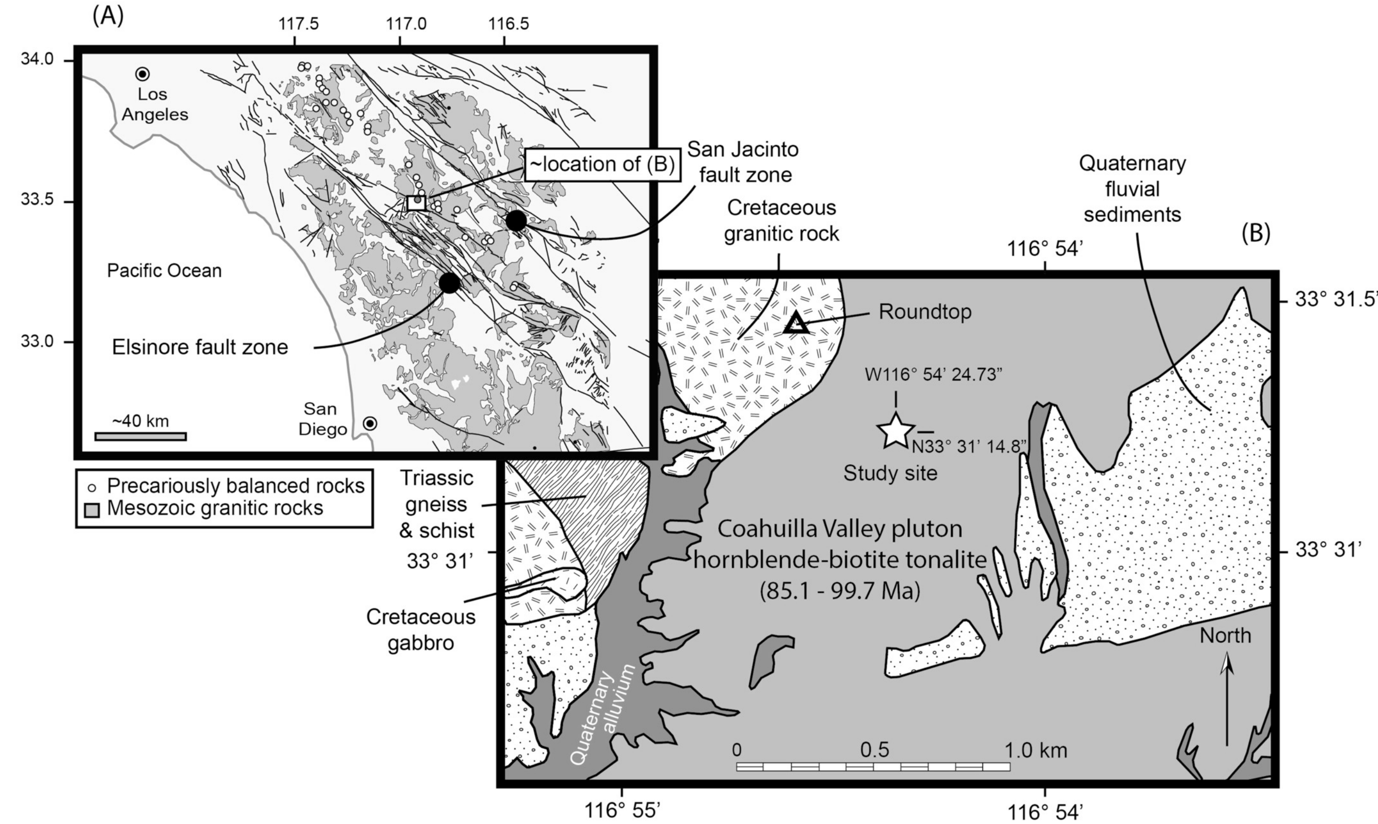

Fig. 1. (A) Generalized map of southern California showing location of (B) between San Jacinto and Elsinore faults. (B) Geologic map showing study site SE of Roundtop. Map is modified from Heath et al. (Heath et al., 2015).

the regolith, i.e., it represents an exhumation age (Von Blanckenburg, 2005). Though the cosmogenic ^{10}Be data suggest that the precariously balanced rock at Roundtop likely was exhumed during the late Pleistocene, an attempt at reconstructing its weathering history has not been undertaken. This statement is generally true for the entire band of precariously balanced rocks (Fig. 1A). Although our understanding of how granitoids weather has advanced over the last tens of year (e.g. (Begonha & Sequeira Braga, 2002; Bornyasz et al., 2005; Borrelli et al., 2014; Campodonico et al., 2014; Frazier & Graham, 2000; Graham et al., 1997; Martins et al., 2012; Mazurier et al., 2016; Perri et al., 2015; Perri et al., 2016; Sequeira Braga et al., 2002; Taboada et al., 1990)), the processes through which PBRs, composed of granitoids, are exhumed and modified are not well understood at this time. We therefore undertook a study aimed at addressing the following questions. Can the characteristics of the regolith that once encased the precariously balanced rock be reconstructed? If so, then prior to erosional exhumation, what chemical processes were operative within the regolith? Following erosional exhumation, did new soil and fracture development modify the original regolith?

2. Geologic setting, physical characteristics, and climate

The study site is located at 33° 31′ 14.80″ N and 116° 54′ 24.73″ W, ~0.5 km SE of Roundtop (Fig. 1B). At this location, a PBR identified initially by Brune et al. (Brune et al., 2006) lies just to the SE of a NE-SW trending ridgeline. Drainage at the study site is to the SE at a grade of ~8%.

Hornblende-biotite tonalite of the Cretaceous (85.1–99.7 Ma U-Pb zircon ages) Coahuilla Valley pluton underlies the area in and around the study site (Fig. 1B) (Morton & Kennedy, 2005). Erosionally exhumed corestones of variable shape and size dot the landscape and rest upon or are partially embedded in a variably eroded ≤ ~36 cm thick Entisol (Typic Xerorthent) composed of pebbly sandy loam (Wachtell, 1978).

The exhumed PBR (~4.42 m tall), and the partially exhumed corestone platform upon which it rests (~1.63 m high), extends 6.05 m above the land surface (Fig. 2A). The contact between the partially exhumed corestone platform and the PBR is a subhorizontal dipping joint. Cracks within the precariously balanced rock are interconnected and form a web-like arrangement (Fig. 2B). On close inspection, some cracks are coated or infilled with a dark gray to black clay-like material, a characteristic feature observed in other exhumed or partially exhumed corestones in and around the study site (Fig. 2C). Such observations, along with the tentative cosmogenic ^{10}Be exposure age, suggest that prior to late Pleistocene exhumation some unknown thickness of regolith likely once encased the PBR and its partially exhumed corestone platform. Lacking any obvious internal horizonation, enclosing the base of the partly exhumed corestone platform is a partially eroded ~13 cm thick Entisol composed of massive poorly consolidated brown (10YR 4/3) pebbly sandy loam (Fig. 3). Within the pebbly sandy loam, rooting, and small pockets of void space derived from the burrowing activities of organisms such as tarantulas and centipedes are evident (Fig. 3B). A thin and highly discontinuous < 2 cm thick O horizon composed of plant litter caps the pebbly sandy loam.

Underlying the pebbly sandy loam is white to orangish saprock of unknown total vertical thickness. The contact between the pebbly sandy loam and saprock is relatively sharp but is extensively cracked and contains pockets infilled by the overlying pedoturbated material (Fig. 3). For example, rooting more commonly observed in the pebbly sandy loam, extends into the underlying saprock, and pebbly sandy loam is dispersed along cracks and infills irregular shaped regions possibly vacated by roots (Fig. 3). In places, white to pale orange centimeter-scale fragments of saprock, pulled or sloughed off the walls