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## MORPHOGENESIS OF GRANITIC BOULDER SLOPES IN THE MOJAVE DESERT, CALIFORNIA<sup>1</sup>

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### ABSTRACT

Examination of quartz monzonite residuals in the western Mojave Desert indicates that current weathering of exposed granitic rocks is not renewing the boulder mantles characteristic of this region. Boulder mantles are presently disintegrating to expose massive outcrops that change thereafter only by the detachment of exfoliation shells. The existing boulders were originally isolated as corestones by subsurface chemical weathering and have been exposed by the stripping of a thick weathered mantle formed during pre-Tertiary periods of greater moisture availability. North of the San Bernardino Mountains deep-weathering profiles characterized by brick red surface horizons, rubefied calcrete crusts, and the presence of corestones in a *grus* matrix are widely encountered beneath basaltic remnants having radiometric ages in excess of 8 m.y. Continuity between these relict weathering profiles and present boulder mantles establishes the boulders as inherited features. The gradual onset of aridity during the later Tertiary terminated subsurface weathering and accelerated surface erosion, bringing about the massive exposure of Tertiary corestones and the land-controlled Tertiary "weathering front." Slope retreat and pedimentation occurred here in the absence of a soil cover; thus the extensive granitic pediments of the region are also relict forms inherited from the Tertiary landscape.

### INTRODUCTION

Throughout the deserts of the southwestern United States, hillslopes developed on granitic rocks have a distinctive appearance proceeding from their characteristic armor of naked boulders, which, together with more massive rock slabs, ribs, and dunes, give rise to landscapes unlike those associated with any other geological terrain. Since the pioneer essays of Lawson (1913) and Bryan (1923, 1925) concerning granitic landforms in the southwestern United States, American physiographers have not dissented from the view that boulders mantling granitic slopes are products of continuing near-surface weathering effects in well-jointed rock (Davis 1938;

Gilluly 1946; Melton 1965*b*). Under the present float of more or less spheroidal boulders, a second crop is assumed to be in formation through a concentration of chemical weathering at joint intersections, which tends to round the apices of originally plane-faceted blocks. Bryan (1925, p. 85-86) described the process as follows: "As the bedrock of the mountain slope disintegrates, and the rain washes away the finer fragments, protuberances of the bedrock are left that consist of the most compact rock between the most widely spaced joints. The protuberances are cut loose from the bedrock by the same process that formed them, and a new crop of boulders comes into existence. By these slow but continuous processes the mountain front recedes, maintaining its angle of slope according to the spacing of joints and the granular structure of the granite."

Davis (1938, p. 1360-1361) shifted the

emphasis to the subsurface, stating that "inasmuch as a supply of subsoil boulders is always ready to be laid bare," the retreat of granitic mountain faces is at the rate of inward penetration of subsurface chemical decomposition. He noted that "the boulders which now conspicuously cover the faces of desert granitic mountains are homologous [*sic*] with the invisible boulders of similar mountains in humid regions, although these are covered with a forested soil, as I have elsewhere shown."

According to either of these views the general character of granitic inselberg surfaces in desert settings could not be expected to change through time; boulder-clad slopes are retreating, and retreating slopes remain boulder clad. Likewise, the processes currently observable are assumed to account for all the forms seen.

More recently, Melton (1965*a*, 1965*b*) has suggested that boulder production has been accelerated periodically by the mechanical effects of lowered temperature, concluding that exceptionally coarse alluvial deposits in southern Arizona, and possibly also the boulders still mantling granitic slopes, are a consequence of intensified freeze and thaw cycles during the Pleistocene. This climatic hypothesis has not been accepted without argument (Lustig 1966). Simultaneously, however, Melton (1965*b*, p. 720) supports the conclusion of Bryan that boulders are continuing to be produced by the weathering of well-jointed rock. In a remark that could easily be overlooked, Melton makes the important observation that some of the weathering he noted was probably relict from an undetermined age.

Meanwhile, investigators of certain Old World and Southern Hemisphere deserts have identified boulders, tors, and massive outcrops in these regions as relict features inherited from antecedent morphogenetic regimes. The boulders are regarded as former corestones isolated in the subsurface by chemical weathering along joint planes and exposed at the surface as a consequence of climatic desiccation and stripping of a weathered mantle formed under prior humid

conditions. Examples have been identified in the central Saharan highlands (Dresch 1959), and the outstanding analyses of Australian desert landscapes by Mabbutt (1961, 1965) are predicated upon this view.

My own observations of the granitic terranes of the Mojave Desert of California likewise suggest that the present character of slopes in the latter area is not a consequence of continuous arid morphogenesis, as is ordinarily supposed (e.g., Warnke 1969). In this region, as in the central Sahara and the Australian deserts, a variety of evidence indicates recent erosional stripping of a weathered mantle, and further discloses that the ubiquitous boulder cloaks are but a transitional form in an evolutionary development triggered by regional climatic changes initiated in the late Tertiary. The familiar landform types of the present Mojave Desert are thus viewed as both new and ephemeral, bearing little resemblance to the forms of a few million years ago but predicated upon the development of those forms, and at the same time displaying a residual disequilibrium with the existing climatic regime.

Accordingly, points to be discussed include the derivation of boulders from solid outcrops and deep weathering profiles, the fossil nature of deep-weathering profiles in the Mojave Desert, and the significance of prior weathering and landscape development in the evolution of the contemporary landscape of this region.

### CHARACTERISTICS OF THE STUDY AREA

The evidence for this interpretation of the geomorphic history of the Mojave Desert has been gathered in the course of studies pursued intermittently over several years in that portion of the desert marginal to the San Bernardino and Little San Bernardino Mountains between Victorville and Dale Lake (fig. 1). Within this district the areas of Lucerne and Johnson Valleys and Joshua Tree National Monument have received closest attention.

Lucerne Valley and neighboring Johnson Valley lie in the rain shadow of the 10,000-

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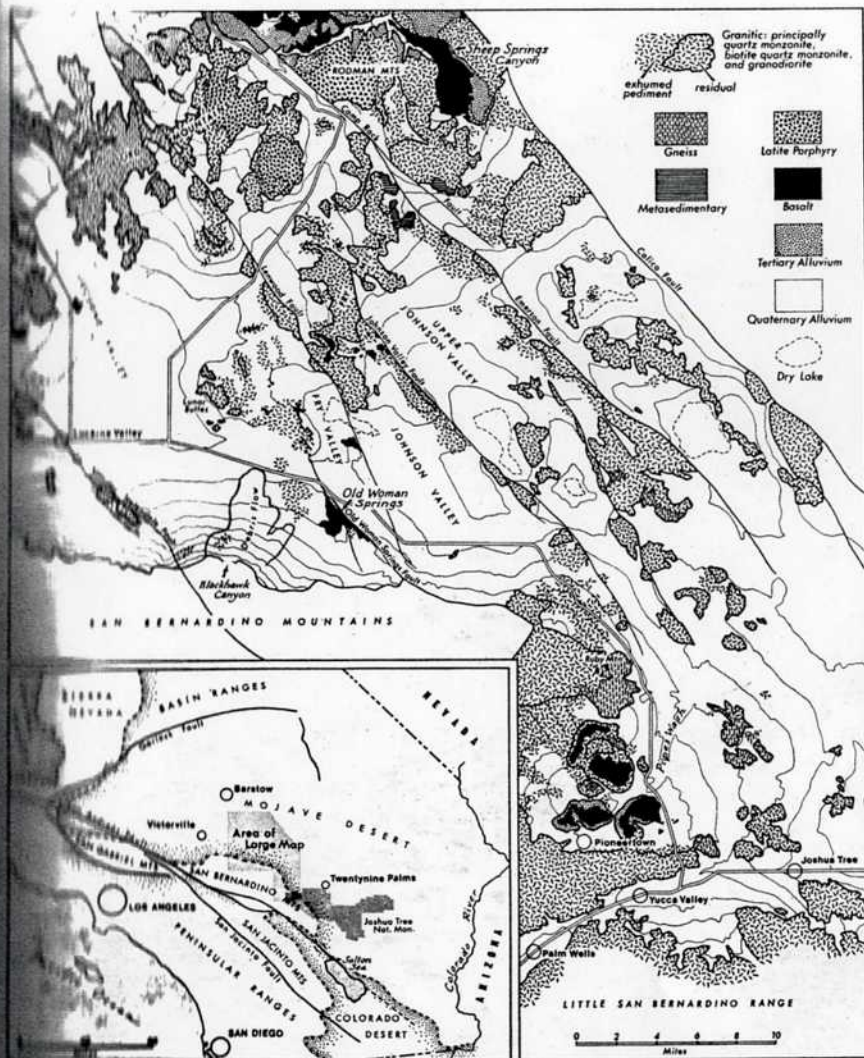


FIG. 1.—Location and general geologic map. Contours are drawn on quaternary alluvium at 200-foot intervals. Absence of bold line around outcrops indicates no topographic break.

from San Bernardino Mountains, while Joshua Tree National Monument is located east of the Salton Depression and includes portions of the Little San Bernardino Mountains. Both areas receive less than four inches of precipitation annually, with a strong winter maximum. Creosote bush

(*Larrea divaricata*) is dominant on alluvial aprons and pediments, with *Yucca schidigera* and Joshua trees (*Y. brevifolia*) encountered above 3,000 feet. All drainage presently terminates in closed basins occupied by dry lake beds lying at elevations between 2,500 and 2,800 feet. Morpho-

logically diverse granitic divides rise about 2,000 feet higher, with pediments and alluvial aprons accounting for more than half of the local relief in certain areas.

The majority of bedrock erosional forms are developed in quartz monzonite of Mesozoic age, which, in a variety of textures, is ubiquitous in the western half of the Mojave Desert. As described by Dibblee (1964a, 1964b, 1967a, 1967b), this rock is characteristically gray white, massive, medium grained, equigranular (average grain size usually 2–3 mm), and weakly coherent where weathered; breaks down by separation of grains; is composed of quartz, potassic feldspar (orthoclase or microcline), and plagioclase (oligoclase or andesine) in generally equal proportions; and contains 2%–7% biotite and a total of less than 2% sphene, apatite, zircon, magnetite, and hornblende—the latter being rare. Granite, granodiorite, gneiss, and metavolcanics are encountered locally.

**Granitic relief features.**—The positive relief forms of the region consist of short comb ridges and clusters of juxtaposed rock pediments, portions of which display a diversified relief of bouldery tors, more massive rock bosses, and extensive plane surfaces scored by gullies along open joints. A few tabular granitic massifs are also present; these exhibit little erosional development in certain instances, as shown by an absence of peripheral pediments and by the wide separation between young canyons that occasionally interrupt the steep margins of the massifs.

The positive granitic relief forms in this area, as in most granitic terranes, consist of wash slopes, boulder-clad slopes, and massive outcrops. Wash slopes are encountered locally on pediments and the larger residual masses wherever the bedrock is too thoroughly decomposed to release solid boulders (fig. 2). They are smooth surfaces, veneered with coarse grus in downslope transport, and may attain angles in excess of 30°.

More commonly, the steeper slopes are a jumble of subangular to spheroidal boulders



FIG. 2.—In the foreground, wash slopes on decomposed quartz monzonite in Joshua Tree National Monument. Typical boulder slopes in the distance. Boulders and tors of less decomposed rock are left in relief as the more thoroughly decayed material is removed by surface wash.

of a variety of shapes and sizes clearly derived from plane-faced blocks bounded by intersecting joints (fig. 3). The boulders may be either sound or well decayed, the latter often displaying various degrees of cavernous weathering under case-hardened veneers. Where the boulders remain in place, the joint configuration within the mass is usually apparent; however, nonorthogonal jointing frequently produces a chaos of enormous blocks, looming walls, and giant pinnacles.

By contrast, massive outcrops are normally broken by sheeting fractures, the



FIG. 3.—Characteristic boulder slope on well-jointed quartz monzonite west of Lucerne Valley. A variety of joint patterns is evident, but sheeting dominates.

