Development of Pediment Domes

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Large, well-developed bedrock domes form the crest of the Ivanpah Upland of Hewett (1956), a broad irregular highland that forms the south and west flanks of Shadow Valley in the north-central part of the East Mojave National Scenic Area (EMNSA) (fig. 32; see also Dohrenwend, 1988). More than 60 late Cenozoic lava flows of the Cima volcanic field, which cover large areas on the crests and flanks of these domes, record a 7.5–m.y. history of pediment-dome evolution in this area. Comparison of the relative positions of lava-flow-covered pediment remnants and modern pediment surfaces indicates the following: (1) downwearing has been the dominant mode of dome modification since at least latest Miocene time; (2) downwearing rates have been highest in crestal areas, have progressively decreased downslope, and have been significantly influenced by general base-level differences; and (3) the general form of the domes has changed little during the last 5 to 7.5 m.y. The ages of the youngest rock units that are truncated by these domes and of the oldest lava flows that overlie them indicate that they formed rapidly during a 3.5–m.y. interval of the late Miocene and have been a conspicuous landscape element in the general area of Shadow Valley since that time. No apparent mineralization is associated temporally with bedrock domes in the EMNSA.

Eleven bedrock domes have been more or less continuously evolving in the Ivanpah Upland over the past several million years, and the remnants of at least three other domes have been partly buried and preserved by lava flows of the Cima volcanic field (fig. 32). Although termed "domes," these landforms are more conical than domelike in cross section (Sharp, 1957), having slopes that typically vary by less than ±0.75° along any radial profile. The domes are low (0.1–0.4 km high), broad (5–16 km across), and, therefore, gently sloping (1.5°–4.5°) (fig. 33). Although in places interrupted by inselbergs, surfaces are generally smooth and regular, and local relief is commonly less than 5 m. Locally, networks of shallow drainageways have incised these surfaces into irregular patchworks of dissected and undissected areas. Undissected areas are mostly flat, having anastomosing drainageways and indistinct interfluves; dissected areas are scored by shallow, subparallel valleys separated by low, rounded interfluves.

These pediments have been the subject of several geomorphic analyses (Davis, 1933; Sharp, 1957; Warnke, 1969; Oberlander, 1974; and Dohrenwend and others, 1987). Davis (1933) speculated that Cima Dome, the largest of these domes (fig. 32), was formed primarily by the backwasting of bounding scarps on an upfaulted terrain of low relief. Sharp (1957) explained Cima Dome and adjacent domes as the product of upwarping of an ancient erosion surface combined with subsequent erosional modification and regrading. Warnke (1969) argued that downcutting followed by lateral corrosion and backwasting were the most important processes of pediment formation and concluded that the combined presence of suitable rock types, specifically granitic rocks and their sedimentary derivatives, and a temporary local base level is the principal determinant of pediment formation in this area. Oberlander (1974) interpreted the present pediment domes as relict forms produced by erosional stripping of deeply weathered terrains developed during periods of greater effective moisture. Dohrenwend and others (1987) documented a latest Tertiary and Quaternary history of essentially continuous downwearing. Rates of downwearing have been greatest in crestal areas and have progressively decreased downslope to midflank areas, which have remained in a state of approximate topographic equilibrium.

As all these workers have observed, the distribution of pediments in the Ivanpah Upland is largely controlled by lithology. Most pediment surfaces cut indiscriminantly across both Mesozoic granitic rocks of the Teutonia batholith (pl. 1) and Tertiary terrigenous clastic rocks, whereas inselbergs of Proterozoic metamorphic rocks stand as much as 180 m above these surfaces. At least three separate Cretaceous plutons probably are present within the area of the Cima volcanic field, and these rocks are intruded by swarms of Tertiary dikes (Wilshire, 1988). The plutonic rocks are typically deeply weathered; low-energy seismic measurements indicate pervasive subsurface weathering to depths in excess of 40 m (K.D. Mahrer, written commun., 1985; see also Dohrenwend and others, 1987) . The Tertiary sedimentary rocks vary in composition from clastic materials derived mainly from Teutonia granitic sources to those derived mainly from Proterozoic metamorphic sources, including gneisses and carbonate, and granitic and volcanic rocks. These rocks consist of gravel, fine-grained

sandstone, siltstone, claystone, and, generally near the base, coarse avalanche breccias, extremely coarse debris-flow deposits, and, in places, gravity-slide blocks (as much as 0.5 km across) of various breccias, including abundant clasts of dolomite. These materials were deposited in several steep-sided basins. Locally, they are significantly deformed, having dips as steep as 70° NE. to SSE. Relief on their contact with the Cretaceous granitic rocks locally exceeds 150 m (Sharp, 1957; Wilshire and others, 1987). Lithologic, biostratigraphic, and paleomagnetic correlations suggest an 18.5– to 9–Ma age for these rocks (Reynolds and Nance, 1988).

Available K–Ar ages indicate three principal periods of late Cenozoic volcanic activity in the Cima volcanic field (Dohrenwend and others, 1984; Turrin and others, 1984, 1985). The earliest period, dated at between 7.5±0.2 and 6.5±0.2 Ma, is represented by one small, deeply eroded vent-and-flow complex in the southeast corner of the field. Lavas of the latest period, which spans the last 1.1 m.y. of Quaternary time, were confined to the southern part of the field and flowed generally west and southwest toward Soda Lake Valley. An intermediate period, dated at between 5.1±0.2 and 3.3±0.1 Ma, was the longest and most volumetric. Flows of this period form the northern part of the field and are the most significant lavas in the present discussion.

Flows of the intermediate period form mesa caprocks that preserve remnants of the pediment surfaces that flanked the west side of Shadow Valley in latest Miocene and early Pliocene time. North of Interstate 15, flows were erupted between 5.1±0.2 and 4.2±0.2 Ma from several vents. At least five flows moved down shallow valleys southwest toward Soda Lake valley and northeast toward Shadow Valley. South of Interstate 15, more voluminous flows were erupted between 4.8±0.2 and 3.3±0.1 Ma from at least 16 vents. These flows, including several overlapping and superimposed lava sheets, were erupted near the crest of a large bedrock dome. The lava sheets spread east and northeast across the dome's east flank toward Shadow Valley and south to southeast toward what is now the Quaternary part of the Cima volcanic field. In addition, several smaller flows extended west and southwest toward Soda Lake valley down valleys between several small pediment domes along the west edge of the field (pl. 1).

Comparing differences in height between the late Tertiary erosional surfaces buried by these lava flows and adjacent modern pediment surfaces enables the reconstruction of a detailed 5–m.y. history of pediment evolution in the Ivanpah Upland. Topographic relations demonstrate that the Cima lava flows have been erupted into a continually downwearing, erosional environment that has been active since before inception of the volcanism. Progressively younger flows have buried progressively lower surfaces so that each caprock-protected pediment remnant now stands above the modern surfaces at a height that is directly related to the age of its overlying basalt flow (Dohrenwend and others, 1987).

Average downwearing rates, determined from the height differences between lava-flow-covered and modern surfaces, have been strongly influenced by distance from dome crests and general base-level elevations. On pediments sloping toward Soda Lake Valley, where the basin floor elevation is about 280 m, average downwearing rates have ranged between 1.2 and 2.8 cm/10^3 yr on upper flanks and between 0.0 and 0.4 cm/10^3 yr in midflank areas. Lower flanks have probably aggraded to some extent (Dohrenwend and others, 1987). On pediments sloping towards Shadow Valley, where the axial elevation is 1,100 to 1,200 m, average downwearing rates have ranged between 0.5 and 0.9 cm/10^3 yr on upper flanks and between 0.0 and 0.3 cm/10^3 yr in midflank areas. Thus, downwearing has been greatest in crestal and upper-flank areas and has progressively decreased downslope so that overall pediment degradation, in areas unprotected by resistant caprocks, has followed a general pattern of crestal lowering, upper-slope decline, and midslope stability. Also, as might be expected, average downwearing rates have been substantially greater on those pediments which drain westward to the relatively low basin floor of Soda Lake Valley than on those which drain eastward toward the much higher level of Shadow Valley. However, even the most rapid of these rates indicate relatively little landscape change during the past 5 m.y., no more than 50 m of downwearing in crestal and upper-slope areas and little to no change in midslope areas.

Relations between the pediment surfaces of the Ivanpah Upland, the rock units truncated by these surfaces, and the lava flows that overlie them indicate that these surfaces formed rapidly during the late Miocene and have been a conspicuous landscape element in the Shadow Valley area since that time. The oldest basalt flows that cap an extensive pediment surface have been dated by K–Ar methods at 5.1±0.2 Ma (Turrin and others, 1985), and the age of the truncated terrigenous clastic rocks has been estimated on the basis of biostratigraphic and

paleomagnetic correlations at approximately 11 Ma (Reynolds and Nance, 1988). Therefore, dome formation occurred between 11 and 5 Ma. Moreover, limited occurrences of lava flows as old as 7.5±0.2 Ma that lie at or very close to the levels of both modern and remnant latest Miocene pediment surfaces suggest that these surfaces may have been in existence before 7.5 Ma. Thus, the bedrock domes of the Ivanpah Upland likely formed within a period of less than 3.5 m.y.

For those few instances in the Basin and Range Province where field relations have permitted estimates of average long-term rates of range-front retreat and pediment formation, estimates reach a maximum of 1 km/10^6 yr (Wallace, 1978; Menges and McFadden, 1981; Saunders and Young, 1983; Dohrenwend, 1987). However, formation of the large bedrock domes of the Ivanpah Upland in the EMNSA by slope retreat would appear to require rates of at least 1.5 to perhaps as much as 3.5 km/10^6 yr. Thus, it would appear that either general slope retreat proceeded at a significantly faster rate in this area than elsewhere in the Basin and Range Province or that some other process, or combination of processes, was responsible for the formation of these bedrock domes.

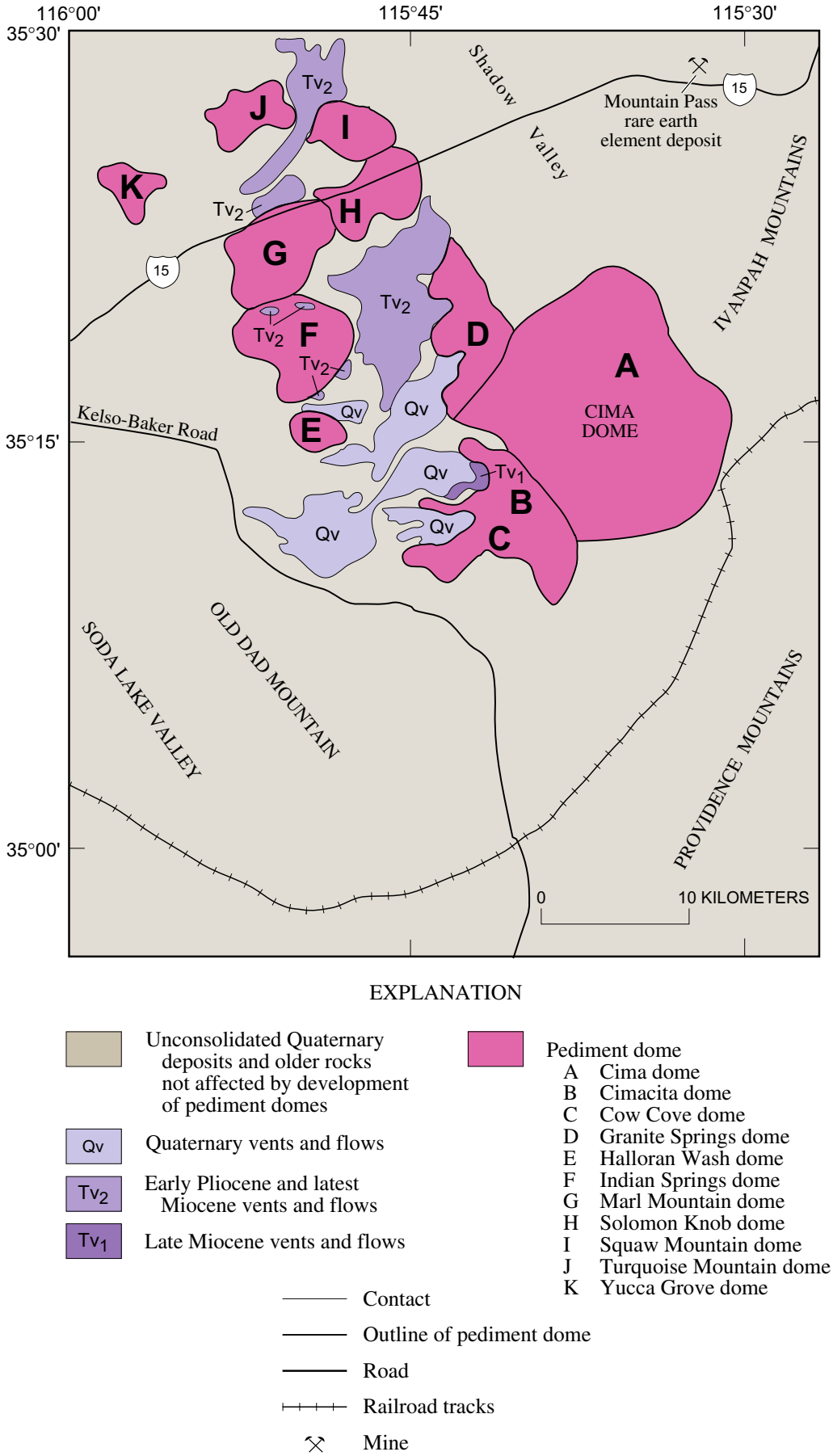

Figure 32. Generalized map of Cima volcanic field, East Mojave National Scenic Area, Calif., showing locations of major bedrock domes and pediment domes (from Dohrenwend, 1988).

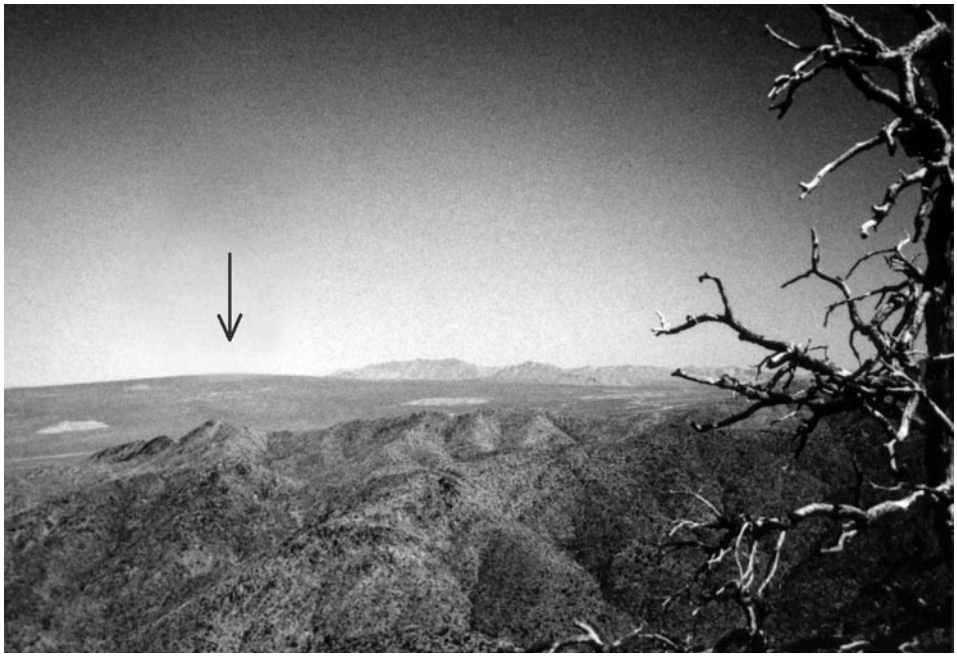

Figure 33. Cima Dome (at head of arrow), East Mojave National Scenic Area, Calif. Ivanpah Mountains form skyline on right. View to west from New York Mountains (fig. 2).