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RATES AND TRENDS OF LATE CENOZOIC LANDSCAPE DEGRADATION IN THE AREA OF THE CIMA VOLCANIC FIELD EASTERN MOJAVE DESERT, CALIFORNIA

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ABSTRACT

The overall landscape of the Cima area is dominated by eleven evolving pediment domes. Lava flows of the Cima volcanic field, superimposed upon these domes, provide precise time control for documentation of four million years of pediment downwasting. Progressively younger flows spread across and partly bury progressively younger and lower pediment surfaces, and the caprock covered remnants of these surfaces now stand above the modern surfaces. Comparison of topographic profiles of remnant and modern pediment surfaces indicates that downwasting has been the dominant mode of pediment modification over the past four million years. Down wasting has ranged between 1.1 and 3.5 cm/10^3 yr and has proceeded through time at an average rate of 2.1 cm/10^3 yr. Degradation has been greatest in crestal areas and has progressively decreased downslope. Mid flank areas have remained in a state of approximate equilibrium, and lower flanks may have aggraded to some extent. Canyon downcutting, localized in areas capped by lava flows, has proceeded at rates as high as 20 cm/10^3 yr., approximately an order of magnitude faster than the average rate of pediment downwasting.

INTRODUCTION

Pediments are one of the least understood and most controversial of all arid landforms. "Disagreement often begins with the problem of definition ....and continues throughout all subsequent phases of inquiry" (Cooke and Warren, 1973, p. 188). Lack of reliable long-term time control in most pediment related research is one of the primary reasons for this limited understanding. This paper uses detailed radiometric dating of late Cenozoic lava flows in the Cima volcanic field of southeastern California and extensive exposures of remnant pediment surfaces buried by these flows to document four million years of pediment evolution. Topographic positions of remnant and modern pediment surfaces are compared and both temporal and spatial variations in pediment erosion rates are determined for selected areas of the field.

PEDIMENTS OF THE CIMA AREA

The largest and best developed pediment domes in the eastern Mojave Desert are located in the area immediately surounding the Cima volcanic field. In this area, eleven pediment domes have been continuously evolving over the past several million years, and the remnants of at least three other pediment systems have been partly buried and preserved by flows of the Cima volcanic field (Fig. 1). These pediment domes are more nearly conical than domelike in overall form (Fig. 2), and slope profiles are essentially straight (Sharp, 1957). The domes are broad, 5 to 16 km. across; low, 0.1 to 0.4 km. high; and gently sloping with 1.4 to 4.5 degree average gradients. Although occasionally interrupted by prominent irregularities including inselbergs and atypically deep drainageways, overall dome form is smooth and regular with a local relief of generally less than 5 m. Locally, this general surface uniformity gives way to more complex morphology (Fig. 3). Numerous shallow drainageways, radial in plan, incise the pediment surfaces into irregular patchworks of dissected and undissected topography: (1) areas of temporary aggradation and transport that are mostly flat and featureless with anastomosing drainageways and low indistinct interfluves (Fig. 2); and (2) areas of degradation scored by well-defined subparallel drainageways (3 to 10 m. deep) that form shallow regularly-spaced valleys separated by rounded interfluves (Fig. 4).

Lithology has significantly influenced the distribution and development of pediments in the Cima area. Most pediment surfaces cut indescriminantly across Cretaceous plutonic rocks, primarily the Teutonia Quartz Monzonite, or across Tertiary terrigenous clastic rocks (Hewett, 1956; Sharp, 1957). However, inselbergs of Precambrian metamorphic rocks including biotite hornblende gneiss and marble, stand as much as 250 m. above the pediment surfaces. The Teutonia Quartz Monzonite is a light-gray holocrystalline rock composed of 20 to 75 mm. diameter orthoclase crystals in a groundmass of 5 to 15 mm. diameter quartz and feldspar grains with sparse plates of biotite (Hewett, 1956). This rock weathers rapidly into its constituent mineral grains, but this grus appears to be relatively resistant to further decomposition. Indeed, the entire piedmont surrounding the area of the Cima volcanic field is dominated by this grus. The Tertiary clastic rocks are poorly to strongly indurated and highly variable in

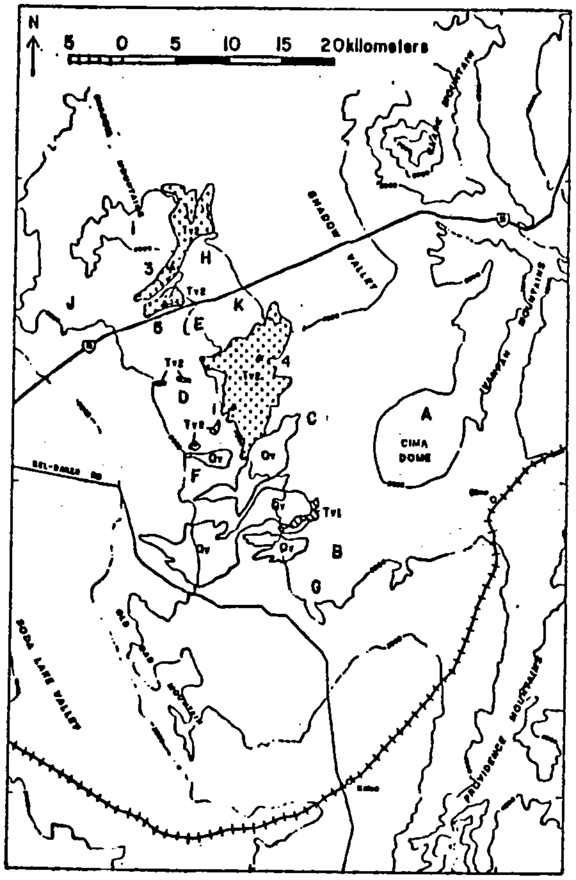

FIGURE 1: Generalized map of the Cima volcanic field showing the locations of major pediment domes: Tv_1 - late Miocene flows; Tv_2 - latest Miocene and early pliocene flows; Qv - Quaternary flows. Letters Cimacita mark the locations of pediment domes: A = Cima dome; B = dome; C = Cow Cove dome; D = Granite Springs dome; E = Halloran Wash dome; F = Indian Springs dome; G = Marl Mountain dome; H = Solomons Knob dome; I = Squaw Mountain dome; J = Turquoise Mountain dome; K = Yucca Grove dome.

FIGURE 2: Cima dome, the largest pediment dome in the vicinity of the Cima volcanic field. This dome is approximately 16 km. across and 0.4 km. high. Aerial view east. Photograph by J. C. Dohrenwend.

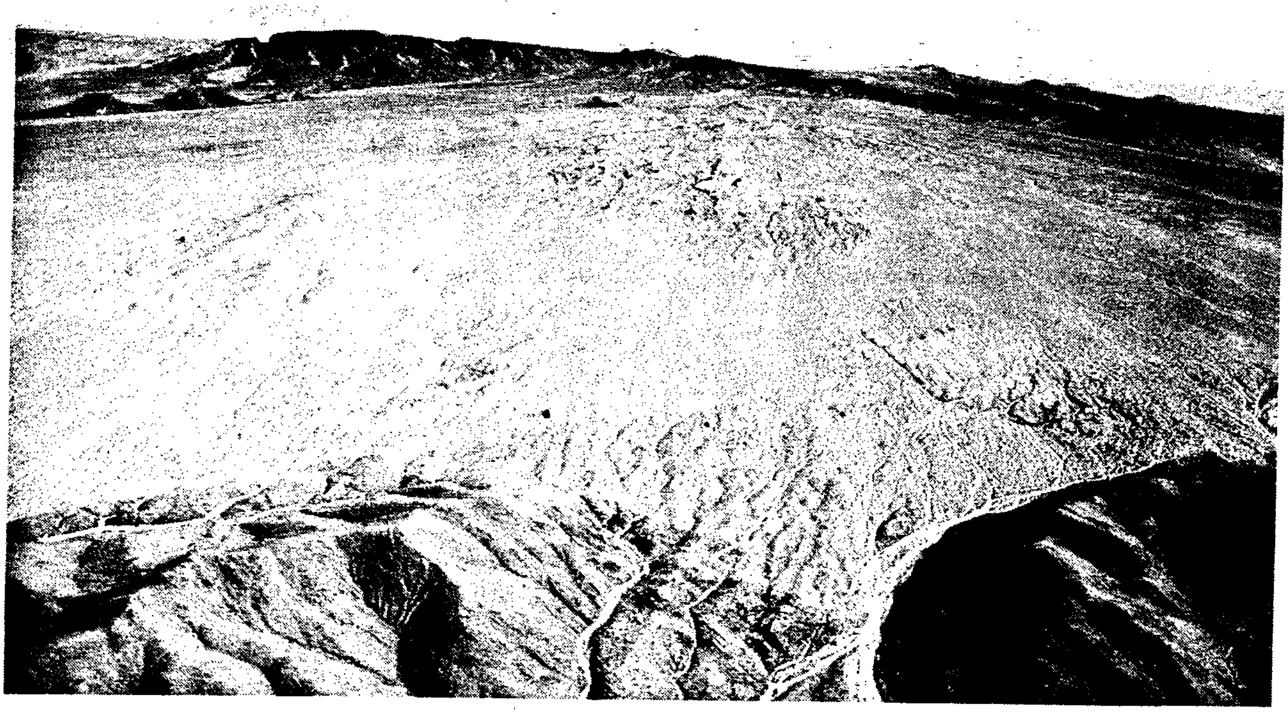

FIGURE 3: Granite Springs pediment dome. 100 to 200 m. high erosional scarp on the west flank of the pliocene lava flows. These flows cap an ancient pediment dome that truncates quartz monzonite and terrigenous sedimentary deposits. The Granite Springs pediment dome, which is also cut across quartz monzonite, extends from the foreground to the erosional scarp. Note the irregular patchwork of dissected and undissected terrains on the flank of this dome. Aerial view east. Photograph by J. C. Dohrenwend.

composition and texture. Although fluvially deposited grus constitutes the bulk of many exposures, clast-supported monolithologic boulder conglomerates of quartz monzonite and intercalated beds of exotic gravel, sand, silt and mudstone are also present. The exact nature of the contact between the Tertiary deposits and the underlying plutonic rocks is not well understood; however, it is characterized by substantial irregularity and high relief and probably includes both faults and unconformities.

The spectacular pediment domes of the Cima area have been the subject of several lengthy and detailed geomorphic analyses (Davis, 1933; Sharp, 1957; Warnke, 1969; and Oberlander 1974). Davis (1933) described many of the pediment domes of the Mojave region and proposed two general mechanisms of pediment formation, one involving backwasting of bounding scarps on upfaulted terrains and the other involving downwasting of upwarped masses. Sharp (1957) marshaled geomorphic, geologic, and geophysical evidence to explain the present form of Cima dome and adjacent granitic domes in the Cima area as the product of broad upwarping of an ancient erosion surface with subsequent erosion and regrading. Warnke (1969) concluded that pediment evolution in the Halloran Hills on the northwest margin of the Cima volcanic field could be described in terms of Davisian stages of geomorphic evolution. Oberlander (1974) developed a model of landscape inheritance wherein the present granitic domes were produced by erosional stripping of late Tertiary deep-weathering profiles. The present paper resolves some of the differences between these previous investigations by documenting a history of continuous pediment surface downwasting in the area of the Cima volcanic field.

RELATIONS BETWEEN LAVA FLOWS AND PEDIMENT SURFACES

The majority of the vents and flows that comprise the Cima volcanic field have been superimposed across several of the Cima pediment domes. Volcanic activity within the Cima field has been sufficiently continuous to produce flows of widely ranging late Cenozoic age but sufficiently limited to produce small and spatially separated flows that have only partly buried these pediments. Field relations indicate that the pediment surfaces below these flows were either active or relatively stable just prior to flow emplacement. Many flows rest directly on planar bedrock surfaces; others bury soils developed in thin alluvial veneers. This combination of circumstances has created an ideal situation for the study of pediment evolution: a series of pediment remnants that can be radiometrically dated and whose vertical positions, relative to modern pediment surfaces and to each other, record progressive downwasting through an extended period of time.

The basaltic flows of the Cima field collectively cover an area of approximately 150 km^2 (Fig. 1). These lavas flowed down pediment dome flanks and along major drainages between domes and coalesced into caprock veneers across the crest and upper flanks of at least one dome (Fig. 3; Turrin et al., this volume, Fig 6.) Three principal periods of volcanic activity span latest Miocene through latest Pleistocene time (Dohrenwend et al., 1984; Turrin et al.; this volume). An initial period, from approximately 7.6 to 6.5 m.y.[1] formed a small vent and flow complex on the northwest flank of Cimacita dome. An intermediate period, from 5.1 to 3.6 m.y., veneered a large pediment dome in the northern part of the field with a voluminous sequence of coalescing flows. In addition, less extensive lavas of this period flowed down paleovalleys between the pediment domes immediately west and north of the field. The latest period of activity, almost uniformly spanning the last one million years, formed most of the southern half of the field (Figs. 5 and 6). Lavas of this period flowed westward down the lower flanks of Cimacita dome and across an irregular, partly dissected pediment terrain of low to moderate relief (Dohrenwend et al., 1984; Turrin et al., this volume).

Cima lava flows, 0.1 to 1.7 km. wide and as much as 9 km. long, form a continuum between two distinct morphologic

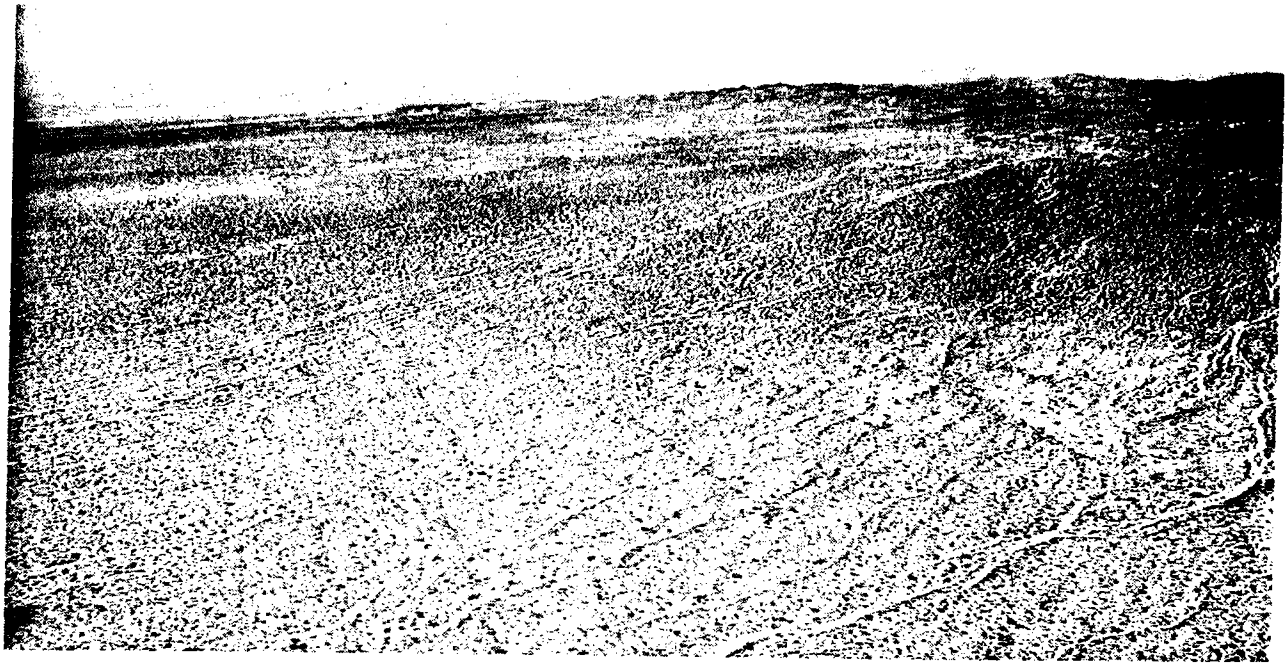

FIGURE 4: The west flank of the Halloran Wash pediment dome is partly dissected into a washboard of subparallel valleys and low, rounded interfluves. Aerial view northeast. Photograph by J. C. Dohrenwend.

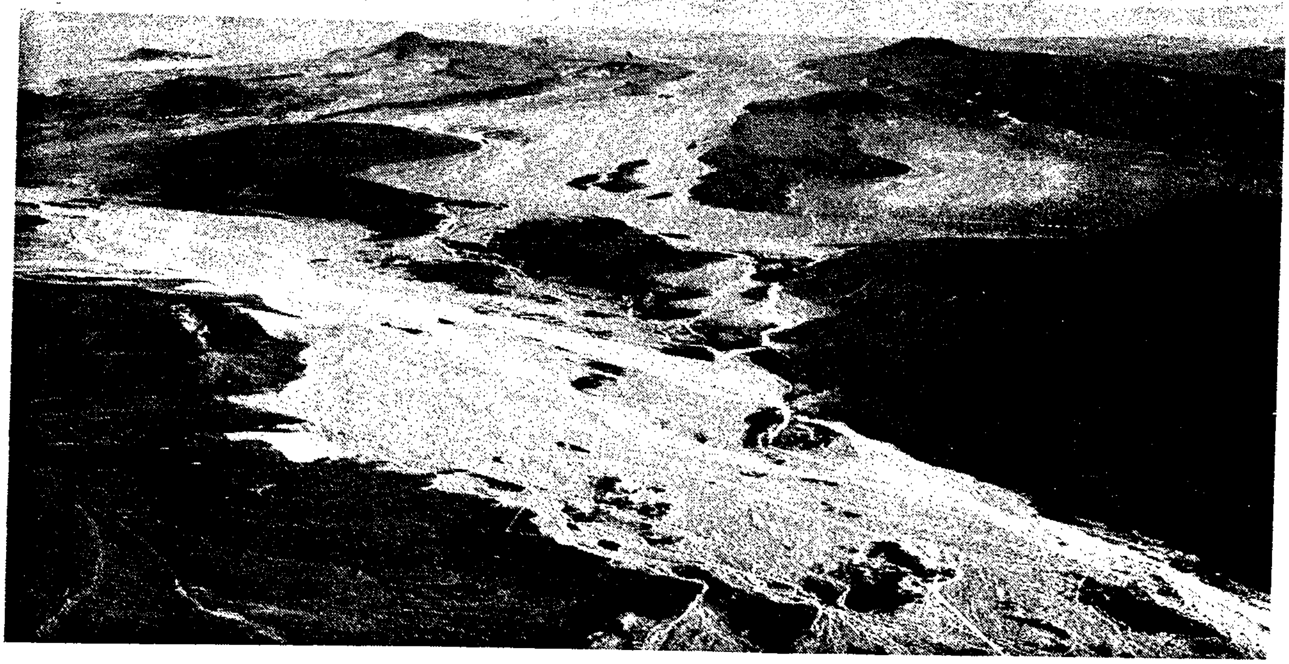

FIGURE 5: Quaternary cones and flows of the southern part of the Cima volcanic field. Aerial view east towards Cimacita pediment dome and the New York Mountains. Photograph by J. C. Dohrenwend.

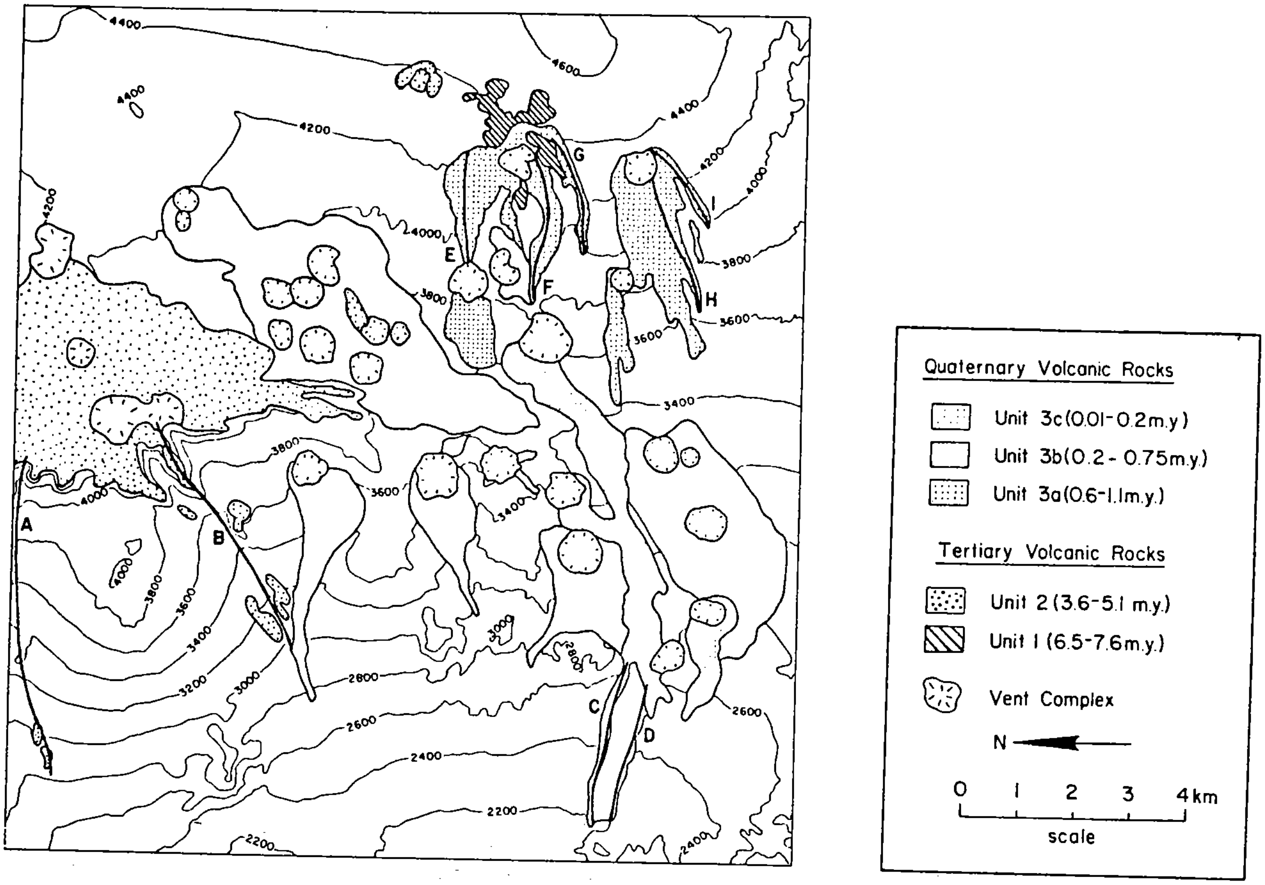

FIGURE 6: Generalized geologic map of the southern part of the Cima volcanic field showing the approximate locations of longitudinal topographic profiles on pediment remnants buried by the Cima lavas. Letters A through I correspond with the profile designations in Figures 7, 8, and 9.

types: thin elongate flows having low gradients and low surface relief and thick equant flows having somewhat higher gradients and higher surface relief. Elongate flows, the most extensive flow type at Cima, are usually extruded during the earlier eruptive phases of a vent complex and commonly rest directly on nonvolcanic land surfaces. Consequently, these flows are more useful for analysis of pediment downwasting. Elongate flow thicknesses generally range between 2.5 and 4 m. except where locally ponded, and constructional relief on flows greater than 0.25 m.y. seldom exceeds one meter. Flow surface gradients generally range between 3 and 6% and are essentially parallel to the underlying pediment remnants which they bury.

Topographic relations demonstrate that the cones and flows of the Cima volcanic field have been erupted into a progressively downwasting erosional environment that has been active since before inception of the volcanism. The Cima lava flows form caprocks that protect the relatively nonresistant grusforming quartz monzonite and poorly indurated terrigenous clastic rocks from fluvial erosion. With the eruption of each flow, part of an active pediment surface is buried and removed from the active erosional environment. Progressively younger flows bury progressively younger and lower surfaces; thus each caprock protected remnant now stands at an average height above the modern pediment surface that is directly related to the age of its overlying basalt flow.

TOPOGRAPHIC PROFILES OF PEDIMENT REMNANTS

Longitudinal profiles were constructed for nine remnant pediment surfaces in the Cima volcanic field. Profiles were also constructed for modern pediment surfaces and fluvial valley floors immediately adjacent to these remnants. Profile locations are shown in Figure 6, and representative examples are presented in Figures 7, 8, and 9. To supplement these longitudinal profiles, pediment remnant heights were also measured in the field at random locations along the profiles and along other pediment remnants that were too small for profiling.

Because elongate flows in the Cima field are uniformly thin and flow surfaces are nearly parallel to the remnant pediment surfaces which they bury, topographic profiling of these pediment remnants is facilitated. Longitudinal profiles of the surfaces of the overlying lava flows were first constructed using measurements from 1:62,500 scale, 40-foot contour topographic maps. Profiles for the underlying pediment remnants were then approximated by subtracting 3 m. from each flow surface profile. Flow thicknesses were measured at several locations along each flow surface profile, and in all cases measured thicknesses were within one meter of the approximate three meter average.

Comparison of remnant and modern pediment surface profiles indicates that downwasting has been the dominant mode of pediment modification over the past four million years. Although remnant surfaces are, in all cases, nearly parallel to modern surfaces, they slope more steeply than the modern surfaces. Slope differences between Pleistocene and modern surfaces are 0.5° or less, and slope differences between Pliocene and modern surfaces range between 0.9 and 1.5°.

DOWNWASTING RATES

Average rates of surface downwasting in the vicinity of each pediment remnant were determined by dividing the average remnant height above the modern surface by the K-Ar age of the basalt flow capping that remnant. These average downwasting rates are summarized in Table 1 and plotted against time in Figure 10. Downwasting has ranged between 0.9 and 4.6 cm. per thousand years (cm./10^3 yr.). This variation is, in part, a reflection of local erosional perturbations induced by drainage deflection around lava flows. Downwasting has proceeded at an average rate of 2.1 cm./10^3 yr., and this average rate has not varied substantially over the past four million years.

The 2.1 cm/10^3 yr. average downwasting rate on the Cima pediments is very similar to the 2.5 cm/10^3 yr. regional dissecton rate averaged over the last seven million years for the west margin of the Colorado Plateau (Hamblin et al., 1981). However, the Cima rate is significantly (two to four times) less than average dissection rates for more tectonically active terrains such as the Grand Wash-Hurricane fault area of the western Colorado Plateau or the Mount Taylor area along the west margin of the Rio Grande Rift (Hamblin et al., 1981; Grimm 1982), and it is substantially (two to ten times) greater than average rates in tectonically quiescent areas such as the east flank of the Great Dividing Range in New South Wales, Australia (Young, 1983).

PEDIMENT DOME EVOLUTION

Stratigraphic relations between the Cima lava flows, the pediment surfaces underlying these flows, and the rock units truncated by the pediment surfaces indicate that pediment domes have been a dominant landscape element in the Cima area since at least late Miocene time. The late Tertiary lava flows of the Cima field cap extensive pediment surfaces cut across both Cretaceous quartz monzonite and late Tertiary terrigenous clastic rocks. The contact between these two rock units is characterized by high relief and substantial irregularity, yet the pediment surfaces pass smoothly and uninterruptedly across this contact. This indicates that a substantial period of time elapsed between deposition of the Tertiary sediments and formation of the pediment

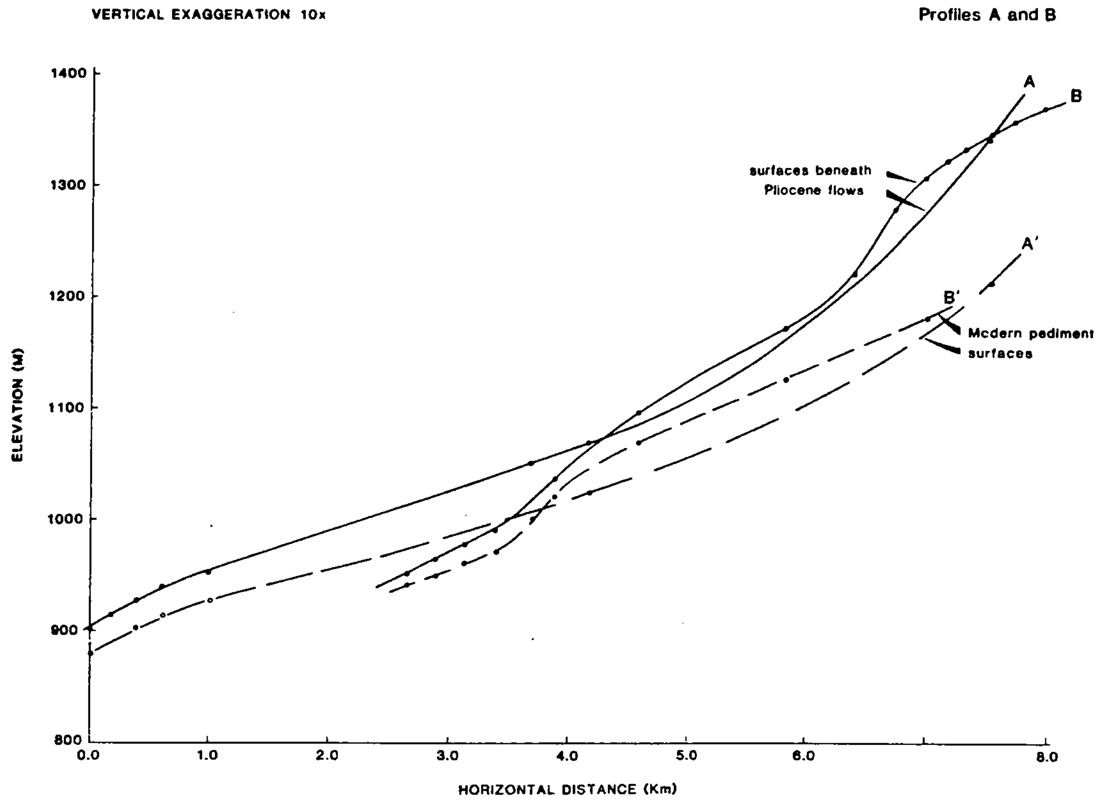

FIGURE 7: Longitudinal profiles A and B comparing modern and early pliocene pediment surfaces.

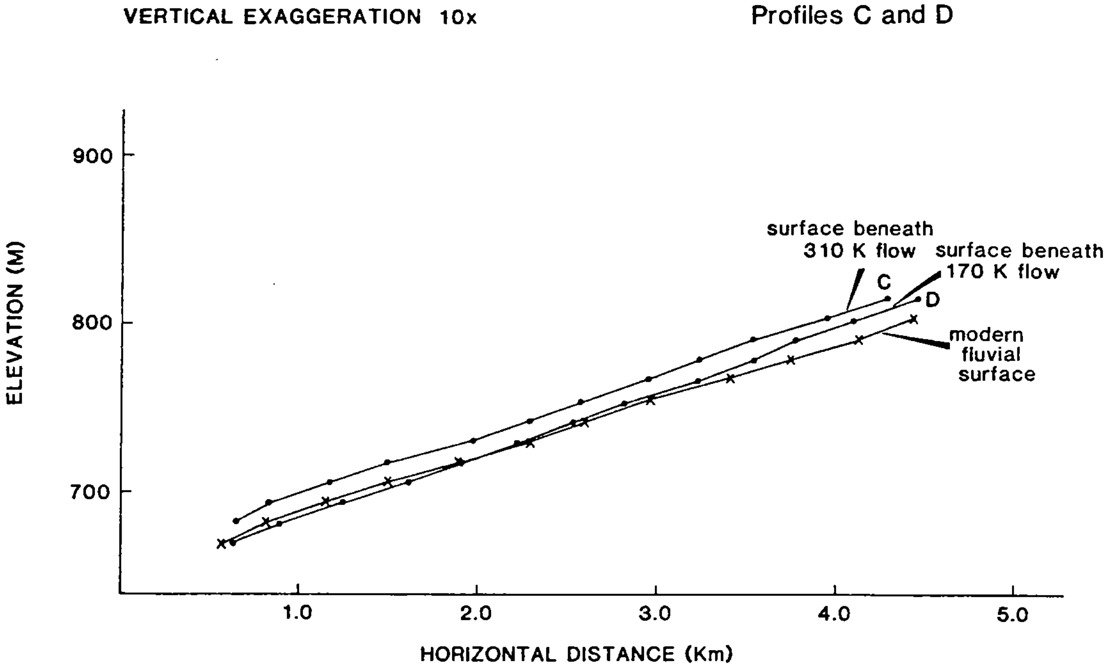

FIGURE 8: Longitudinal profiles C and D comparing modern and middle Pleistocene pediment surfaces.

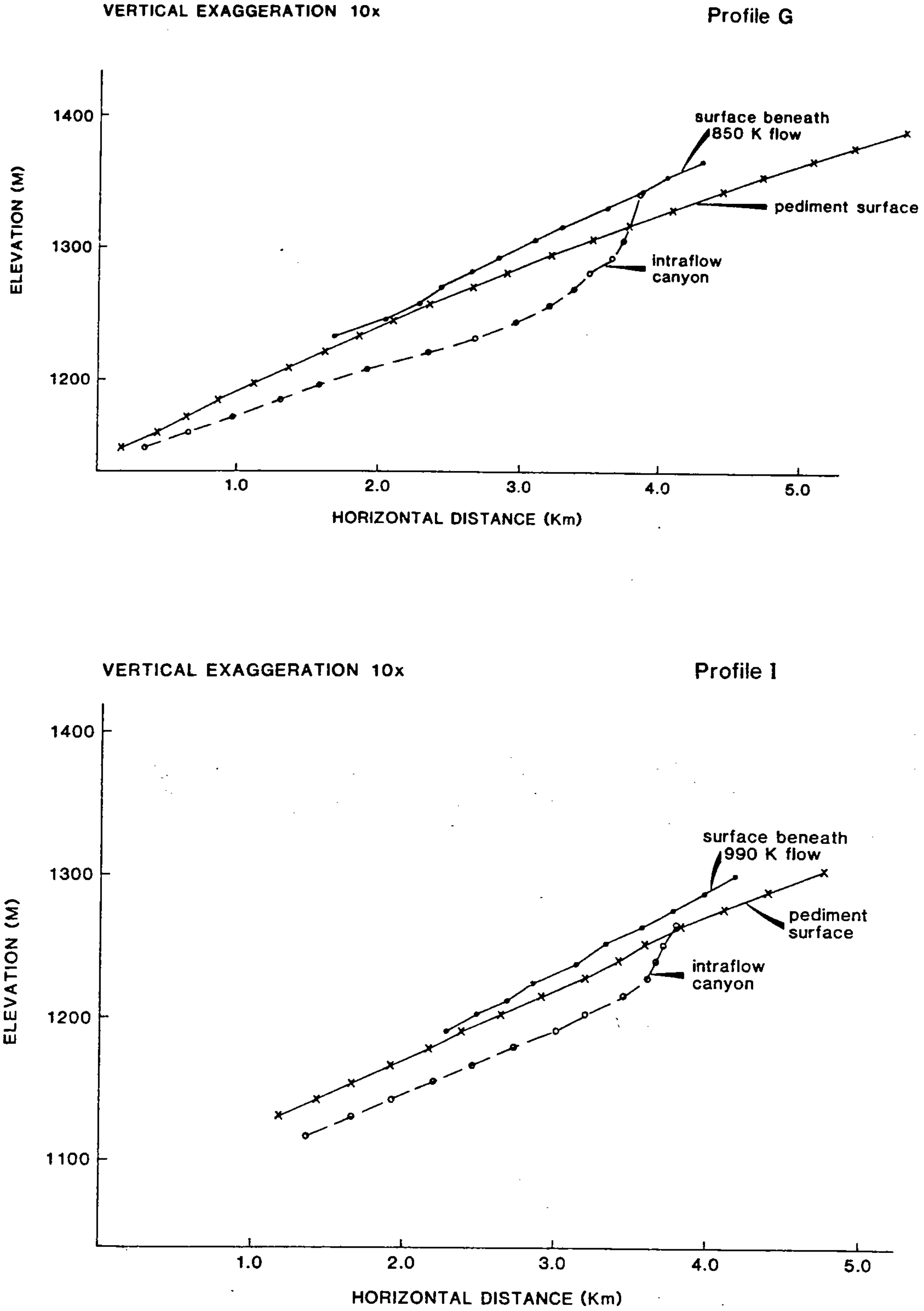

FIGURE 9: Longitudinal profiles comparing modern and early Pleistocene pediment surfaces with intraflow canyon surfaces: a) profile G; b) profile I.

surfaces and that a significant part of that time was required for pediment formation. Absence of precise chronologic control prevents any detailed reconstruction of the actual process of pediment dome formation or of early dome evolution.

After emplacement of the late Tertiary lava flows, however, rates and trends of dome evolution are relatively well documented. Over the past four million years, pediment dome degradation has followed a general pattern of crestal lowering and slope decline (Fig. 11). Crestal and upper flank areas have downwasted at a nearly constant rate through time. Downwasting has been greatest in crestal areas and has progressively decreased downslope. Mid flank areas have remained in a state of near equilibrium, with little or no net downwasting or aggradation over the long term, and lower flanks may have aggraded to some extent.

CANYON FORMATION BY DRAINAGE SOURCE ON LAVA FLOWS

An instructive constast to the general scenerio of uniform downwasting on the Cima pediments is provided by canyon downcutting within areas capped by lava flows. Deep, steep-sided and locally flat-floored valleys have been cut into several of the older lava flow complexes of the Cima field. These canyons, as much as 400 m. wide and 65 m. deep, were carved by surface drainage heading on the lava flows. They are carved through the flows and cut deeply into underlying pediment surfaces. The floors of these canyons lie as much as 45 m. below the pediment surfaces surrounding the lava flows and longitudinal gradients along the lower reaches of these canyons are signifiantly less than the gradients of the modern pediments (Fig. 9).

An insight into the development of these canyons is provided by dated lava flows and associated pediment remnants in

Table 1. Downwasting rates in the Cima volcanic field

Flow Designation	Flow Age (m.y.)[a]	Maximum Height Above Modern Surface (m)	Approximate Downwasting Rate (cm/10^3yr)
z_1	0.27 ± 0.11	6.5	2.4
t_2	0.27 ± 0.05	6.6	2.5
j'_1	0.33 ± 0.03	4.0	1.2
m_3	0.39 ± 0.08	3.5	0.9
g_x	0.58 ± 0.16	12	2.1
s_2	0.64 ± 0.05	17	2.6
	11 (t_2)[b]	3.0[b]	
z_3	0.67 ± 0.13	18	2.7
	10.5(z_1)[c]	2.6[c]	
r_2	0.70 ± 0.06	32	4.6
r_3	0.85 ± 0.05	25	2.9
k_3	0.99 ± 0.07	19	1.9
Tv	3.88 ± 0.09	120	3.1

[a] Radiometric ages from Turrin et al. (this volume); ± values are 2 sigma error ranges.

[b] Difference in height between the base of flow s_2 and the base of flow t_2; dissection rate for the period 0.64 to 0.27 m.y.

[c] Difference in height between the base of flow z_3 and the base of flow z_1; dissection rate for the period 0.67 to 0.27 m.y.

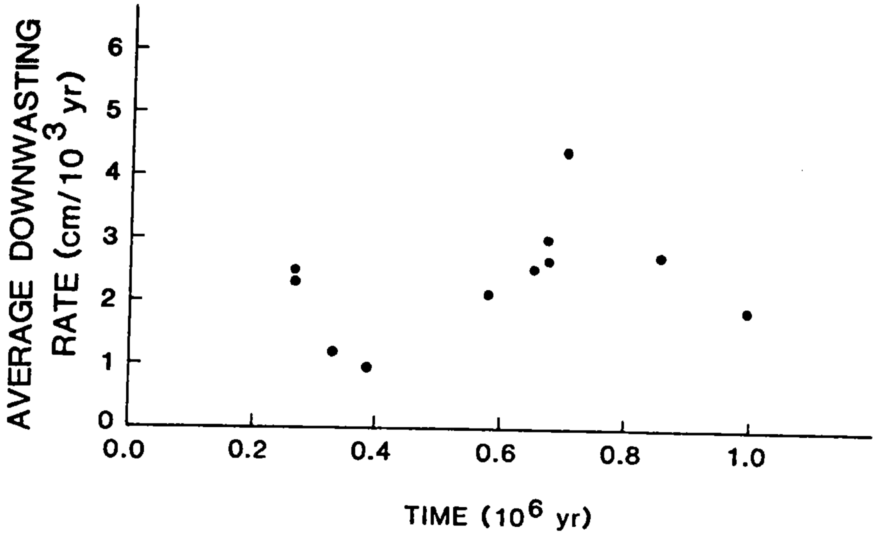

FIGURE 10: Average pediment downwasting rates through time. Downwasting has varied locally from 0.9 to 4.6 cm/10^3 yr. but has averaged 2.1 cm/10^3 yr. through time.

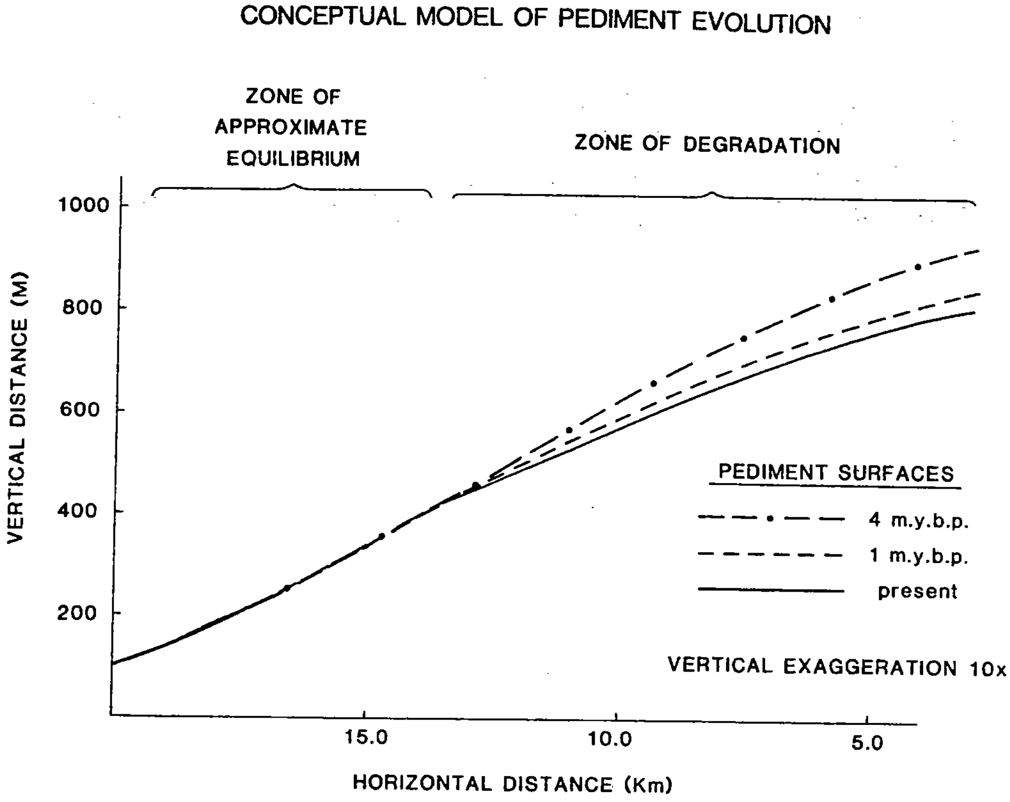

FIGURE 11: Model of pediment dome evolution synthesized from a generalized composite of the longitudinal profiles shown in Figures 6 through 9. Crestal and upper flank areas have downwasted, mid flank areas have remained in a state of approximate equilibrium (i.e. little or no downwasting or aggradation over time), and lower flank areas (not shown) have probably aggraded. Horizontal distance is measured from the summit of the dome.

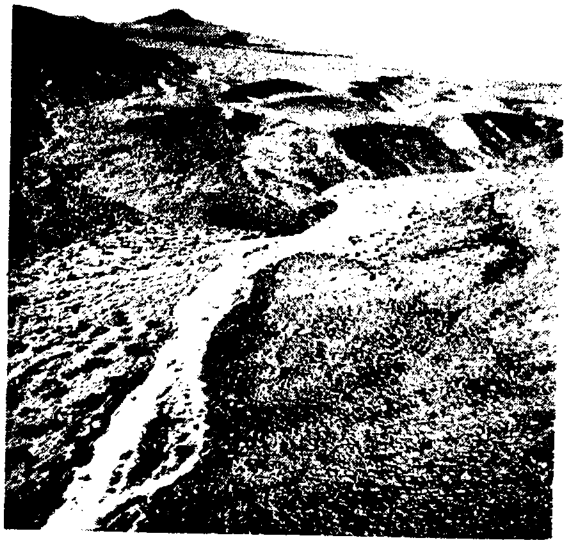

FIGURE 12: Canyons cut into lava flows of the Cima volcanic field. A 0.99 ± 0.07 m.y. flow caps flat-topped interfluves in the upper right. A 0.33 ± 0.03 m.y. flow, erupted from a small vent on the surface of the 0.99 m.y. flow (upper center), has flowed down into the main canyon (upper to lower center). The modern canyon drainage has cut across this younger flow. A 0.70 to 0.85 m.y. vent punctuates the upper left skyline. Aerial view east.

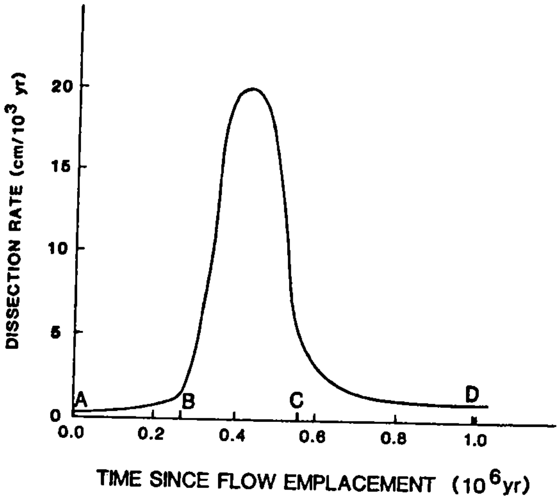

FIGURE 13: Canyon development through time in areas capped by lava flows. Canyons have been formed by relatively rapid and short-lived pulses of erosion. After emplacement of the lava flows (time A), little dissection occurs for at least 200,000 to 300,000 years. Canyon cutting then proceeds at rates ten to twenty times greater than average pediment downwasting rates (time B to time C). As equilibrium is approached (time C), dissection rates drop precipitously to the average downwasting rate of the surrounding pediment. Time D = 1984.

the southeast corner of the Cima field. In this area, a canyon that has incised a 0.99 ± 0.07 m.y. flow is partly floored by a 0.33 ± 0.03 m.y. flow (Fig 12). The canyon is 60 m. deep and the base of the 0.33 m.y. flow stands only 4 to 5 m. above the modern canyon floor. Lack of dissection of the younger lava flows at Cima indicates that at least 200,000 to 300,000 years are required to initiate canyon cutting. In addition, soils developed in boulder-protected alluvium on canyon side slopes suggest that these side slopes have been stable for probably more than 100,000 years (These soils are characterized by 2 m. thick Bk horizons (7.5 YR 5/4 dry) with abundant thin clay films and stage II to III carbonate accumulations). These relations can be summarized as a generalized plot of canyon downcutting through time (Fig. 13). After extrusion of a lava flow, little downcutting occurs for at least 200,000 to 300,000 years. Then an intense pulse of canyon downcutting is initiated and proceeds at rates as high as 20 cm/10^3 yr., almost an order of magnitude faster than the average rate of pediment downwasting. After a period of probably not more than 200,000 to 300,000 years, downcutting slows abruptly to the average downwasting rate of the surrounding pediment.

Canyon downcutting within areas capped by lava flows probably occurs because of (1) sediment load differences between streams draining the pediments and streams draining the lava flows, and (2) concentration of lava flow-sourced drainage between caprock protected valley walls. Pediment sourced drainage is highly charged with grus derived from weathering and erosion of the granitic rocks and terrigenous sedimentary rocks that underlie the pediment surfaces. Moreover, pediment sourced drainage is widely dispersed in large numbers of laterally migrating, braided drainageways. In contrast, lava flow-sourced drainage is confined and relatively sediment starved. The lava flows, serving as caprocks for the underlying pediment surfaces, inhibit general erosion of these pediments by concentrating drainage between canyon walls while yielding little sediment of their own to feed the streams that drain them. The resulting excess energy of lava flow-sourced streams is expended in downcutting. This downcutting continues until the canyons are deep enough to equilibrate with drainage from the surrounding pediment surfaces.

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