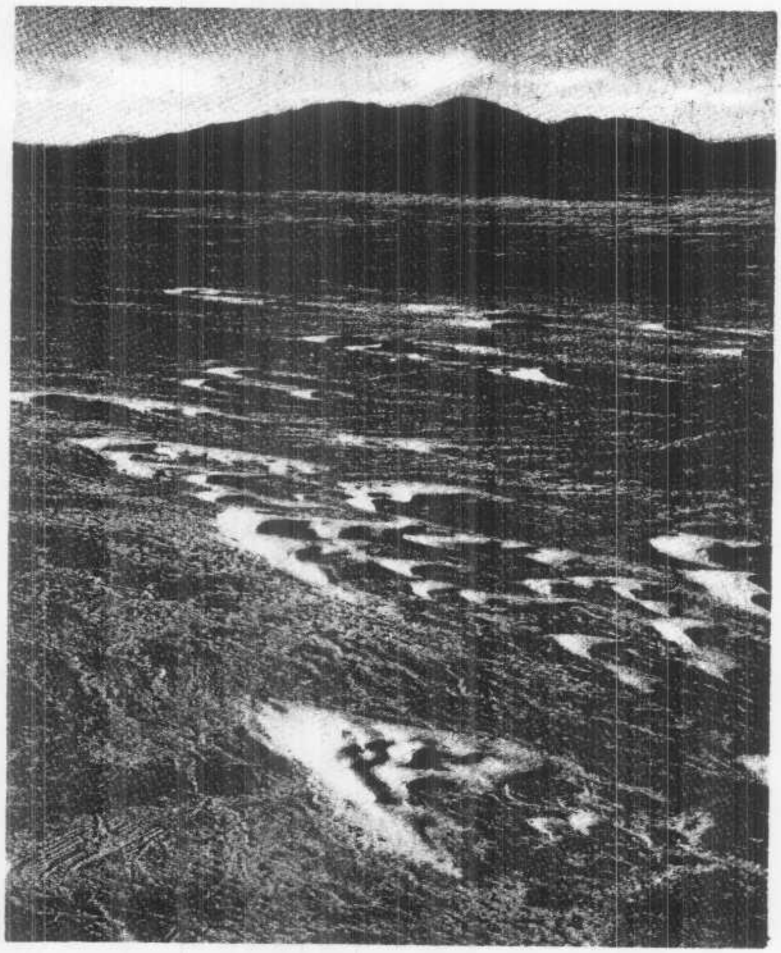
AEOLIAN FEATURES OF SOUTHERN CALIFORNIA:

A Comparative Planetary Geology Guidebook



Arizona State University, College of the Desert,
and NASA-Ames Research Center

Sponsored by Planetary Geology Program,
National Aeronautics and Space Administration

PREFACE

Recent spacecraft results, coupled with Earth-based observations and theoretical considerations, show that the surfaces of several terrestrial planets are subjected to aeolian, or wind, processes. Active dust storms are observed on Mars, along with a host of landforms related to wind, including dune fields and yardangs. Wind measurements on the surface of Venus suggest the possibility of wind transported particles. Titan, one of the satellites of Saturn, may have sufficient atmosphere for aeolian processes.

The Planetary Geology Field Conference on Aeolian Processes was organized to bring together geologists working on aeolian problems on Earth, and planetologists concerned with the modification of planetary surfaces by wind. The setting for the conference was chosen to afford the opportunity to visit several sites where problems in aeolian geology could be discussed in a field context.

This guidebook and the conference are part of a continuing program sponsored by the Office of Planetary Geology, National Aeronautics and Space Administration, Washington, D. C., to show the differences and similarities among the terrestrial planets. The guidebook is the result of the efforts of many individuals. The editors thank the contributors who generally provided their sections on time; we also acknowledge with thanks C. Greeley (typesetting), D. Stroud (graphics), P. Fry (photography), and L. Loftus (manuscript typing).

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Mojave Desert is divided into eastern and western parts of contrasting topographic character by the northward flowing reach of Mojave River between the San Bernardino Mountains and Barstow (Figs. 1-1 and 1-2). The western Mojave is a triangular-shaped wedge of relatively low relief and generally modest elevation (600 - 750 m) lying between the westward converging traces of San Andreas (south) and Garlock (north) faults. The eastern Mojave is much more rugged, especially in its easternmost part, featuring mountain ranges rising to 1500 m above alluvium-filled valleys and basins. Our concern will be with the eastern Mojave Desert.

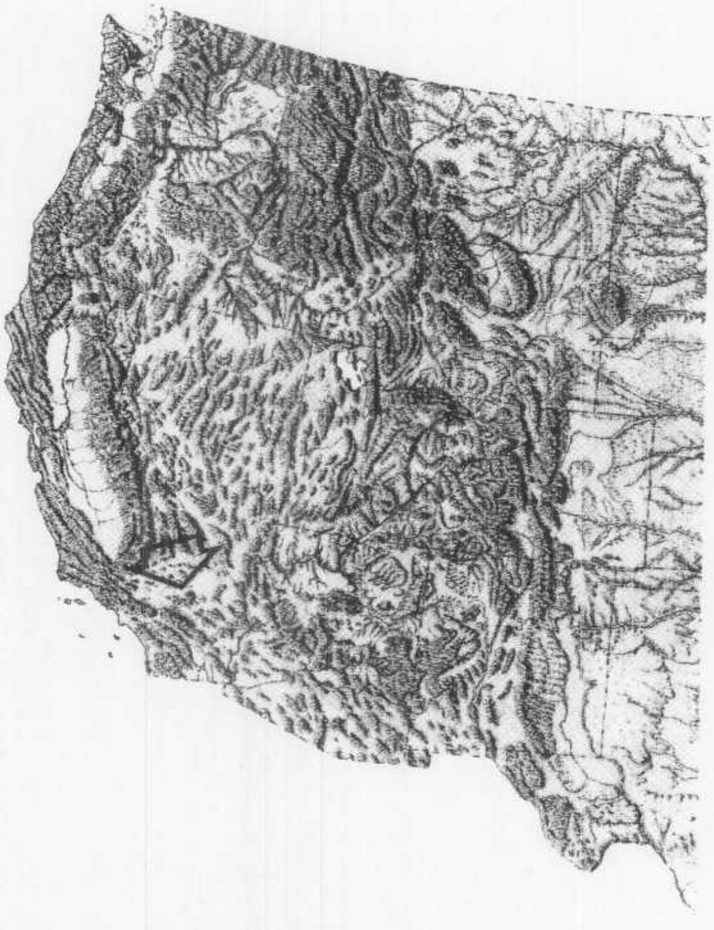

FIGURE 1-1. Physiographic diagram of part of western United States showing setting of Mojave Desert (arrow) (from U.S. Geological Survey, 1968).

FIGURE 1-2. LANDSAT mosaic of Mojave Desert.

Garlock fault provides a well-defined northern border for the eastern Mojave as far as the south end of Death Valley, beyond which the region begins to assume characteristics of ranges of the Great Basin. The south border is defined by the contrast of an east-west structural grain in the Transverse Ranges and the generally northwest grain of much of the eastern Mojave. An argument could be made on geological and topographic grounds that the eastern limit should be along a line running north-northwest and south-southeast through Baker, but in practice the Mojave Desert province is generally regarded as extending approximately to the California-Nevada border. The following comments concerning the eastern Mojave pertain to this more extended area.

Crystalline rocks exposed within this region are pre-Cretaceous metamorphics, partly Paleozoic and partly Mesozoic, intruded by late Mesozoic coarse-grained plutonic rocks. These pre-Tertiary rocks are overlain by varied, extensive, and locally thick accumulations of volcanics ranging in age from Miocene to Pleistocene. Relatively thick deposits (many thousands of meters of Miocene and Pliocene land-laid sedimentary strata) have accumulated in local basins. These beds are now deformed, uplifted and dissected. Structures within the eastern Mojave are generally complex and include warps, folds, and faults, both high- and low-angle, of several different ages and trends, with tectonic activity extending up to the present time.

In times past, some of the more highly deformed and coarsely recrystallized metamorphic rocks have been regarded as Precambrian, but direct proof of such a designation within the eastern Mojave, except for the section east of Baker, has not been forthcoming. The oldest metamorphics west of Baker may be largely upper Paleozoic, and locally they include marble units containing traces of fossils supporting that conclusion. However, most of this complex west of Baker is known to consist of Triassic metavolcanics. Both the Paleozoic and Mesozoic rocks are extensively intruded by late Mesozoic (Jurassic to Cretaceous) coarse-grained plutonic igneous rocks of predominantly silicic composition.

One of the notable features of that part of the eastern Mojave west of Baker is the scarcity of Paleozoic sedimentary rock which is surprising in view of the relatively thick Paleozoic sections in the Mojave east of Baker and in the Great Basin ranges to the north. It seems likely that these Paleozoic rocks once covered the area in view of scattered Paleozoic metamorphic pendants preserved within granitic intrusive bodies. The removal of the Paleozoic strata by erosion largely during early Tertiary time was no trivial task, as a conservative estimate places the thickness of rock at 4500 - 6000 m which implies an uplift of the Mojave block west of Baker of roughly corresponding magnitude.

It is clear that erosion reigned during the early Tertiary and by Miocene time had produced a surface of gentle relief onto which great thicknesses of heterogeneous volcanics were extruded. At about the same time, and also in subsequent periods, warping or faulting created local basins in which coarse to fine fluvial and lacustrine sediments, some rich in vertebrate animal remains and fragmental volcanic debris, accumulated.

Following volcanism and the upper Tertiary sedimentation, further warping, folding, and faulting created a terrain of varied relief which has been strongly modified by erosion of uplifted blocks and deposition of the resulting detritus as alluvial fill in broad intervening basins and valleys. The surface area of alluvial valley fill exceeds the area of exposed bedrock throughout the province. Tectonic activity and volcanism have continued into recent times. Eastern Mojave is not a region of high seismicity, but historical earthquakes and related ground disruption are on record. Volcanism at Pisgah, Amboy, and in an extensive volcanic field southeast of Baker certainly extended well into the Pleistocene, and almost certainly into the Holocene at Amboy and Pisgah. The Lenwood anticline just south of Barstow is, at oldest, a Pleistocene feature, and even more recent deformation may have played a role in the disruption of drainages within this desert region. The western part of the region was affected by the Palmdale bulge of the early 1960's.

The southwestern part of the eastern Mojave has a strong northwest structural grain reflecting the influence of a series of parallel, subequally spaced northwest trending faults, some 20 in all, that cut the country like a loaf of sliced bread. Along some of these faults fresh scarps in alluvium indicate recent activity, and evidences of right-lateral displacement are found on some. The structural grain in much of the rest of the eastern Mojave is more haphazard, except to the north approaching Garlock fault where an east-west trend is discernible. East of Baker northerly trends suggestive of a Great Basin influence are perceptible but hardly dominant.

Two large, wide topographic troughs with an anomalous southeasterly trend cross part of the eastern Mojave. The first, and larger, extends from Barstow to Bristol Playa and the second from Victorville to Dale Playa, east of Twentynine Palms. This latter trough ends in a *cul de sac* at Dale Playa. Although regarded by some workers as the product of former drainage to the Colorado River, these troughs may well be largely structural in nature.

Many playa lakes dot the alluvial surfaces of this region. Most are dry playas with hard, smooth surfaces, except when temporarily wetted by rain or flood. A few are so-called wet playas with a punky, soft, hummocky surface created by crystallization of alkali salts through evaporation from the capillary fringe of a near-surface water table.

Mojave River drains north out of the relatively well-watered San Bernardino Mountains and then flows east to Soda Playa and Cronese lakes. It is the only through-flowing stream course of any consequence. In wet years its floods can reach as far as Silver Lake Playa, north of Baker, and given enough sustenance, floods could reach Death Valley along the course of pluvial Mojave River. Lake Manix with its shoreline features, including a huge and spectacular beach ridge near Afton, was formed by ponding of Mojave River waters in a pluvial epoch. Lake Mojave occupied the now separate basins of Soda and Silver lakes, respectively south and north of Baker, in at least late pluvial times.

SOME GEOLOGICAL ASPECTS OF THE SALTON TROUGH

Salton Trough is one of the more unusual geological provinces of southern California, more because of its substructure than its surface characteristics and configuration. However, even the latter are distinctive as the trough includes the largest land area below sea level in the Western Hemisphere, covering 5200 km^2. Death Valley is a bit lower, −86.3 m compared to −83.5 m but is not comparable in area.

As viewed from the southeast by satellite, Salton Trough is clearly a landward extension of the narrow depression of the Gulf of California, and it continues as a well-defined topographic and structural feature 225 km northwest from the Gulf to San Gorgonio Pass at the west end of Coachella Valley. It is now recognized from the principles of plate tectonics, as well as from geophysical and geological relationships, that the peninsula of Baja California has been split from the west coast of Mexico and shifted west-northwest by the processes of sea-floor spreading and transform faulting. Salton Trough presumably represents the landward effects of these same processes, and it displays characteristics compatible with that interpretation.

The continental crust is abnormally thin under the southern part of Salton Trough, and the underlying mantle displays a corresponding upward bulge. The area is riven with faults, many of which are currently active. The trough is one of the most active seismic areas in North America with several historical quakes of notable size, a high flux of current micro-seismic activity, and secular creep occurring on several faults. It is also the site of relatively recent volcanic activity, as expressed by the volcanic buttes at the southeast corner of Salton Sea, and by high temperature geothermal brines. The Salton Trough has been active in the immediate geological past, and there is every reason to believe such activity will continue into the future, perhaps ultimately resulting in the separation of coastal southern California from mainland North America.

Salton Trough is bounded on both sides by relatively high rugged mountain masses composed principally of Precambrian to Mesozoic crystalline igneous and metamorphic rocks. The trough itself is filled with over 6000 m of soft, relatively unconsolidated Cenozoic sedimentary materials, mostly non-marine, but containing interfingerings of marine beds, and impressively coarse deposits near the margins. The most notable marine unit is the late Miocene (10-12 m.y.) Imperial Formation, which contains abundant marine fossils more closely related to Gulf of California fauna than to the open Pacific coastal assemblages. These Cenozoic beds are deformed, both by faulting and folding, and locally the deformation is severe. An example can be seen in Painted Canyon in the Mecca Hills along the central eastern edge of Salton Trough, where sharp anticlines within late Cenozoic beds have cores of old metamorphic rocks squeezed up into the folds.

Three of the largest strike-slip fault zones of southern California, the San Andreas, San Jacinto, and Elsinore, extend southeast into the Salton Trough where they splay out into a sequence of parallel and *en echelon* fractures. Imperial Fault, of the San Jacinto family, has been particularly active, causing large earthquakes in 1915 and 1940 and offsetting the U. S. – Mexican border by about 15 feet in 1940. It also displays signs of current creep; geodetic measurements suggest a right lateral drift of 3 to 5 cm per year along this structure.

The floor of Salton Trough is thinly mantled by lacustrine clays deposited by predecessors of the present Salton Sea. Just as the present sea is known to be the product of diversion of the Colorado River into the Salton Trough, some of these earlier and much larger water bodies are regarded as probably of a similar origin. Marine waters from the Gulf of California are currently barred from Salton Trough by the Colorado River delta with a crest 12 to 13 m above sea level, but in earlier times, marine waters from the Gulf also invaded Salton Trough.

Shorelines of some of these older water bodies are prominent around the edges of the trough, like rings on a bath tub, particularly on the northwest side near the north end of the current Salton Sea. The most recent high water level with the strongest shoreline features, at about 12 to 13 m above sea level, is thought to have been attained within the last few hundred years.

Three areas of noteworthy aeolian-sand accumulation lie within Salton Trough. By far, the largest is Algodones Dunes along the southeast margin of Imperial Valley. This remarkably linear mass of dunes, 6 to 13 km wide, extends for more than 70 km to south of the Mexican border.

Large, subequally spaced intradune flats are a notable feature within the southern one-third of the chain. Owing to sand accumulation on a steep lee face on the northwest edge and sand removal from a gentler slope along the southeast edge, these flats show apparent motion along the axis of the dune chain at a rate of 15 to 25 cm per year. The All American Canal and Interstate 8 use one of these flats to cross the dune chain.

Farther north along the west shore of Salton Sea, some 16 km south of Salton City, is a group of about 50 active barchan (crescent-shaped) dunes moving eastward into Salton Sea at rates averaging about 20 m per year. The third area of sand accumulation is in northern Coachella Valley between Palm Springs and Indio. The dunes found here are not particularly large or unusual, as considerable vegetation and works of man obscure their pattern, but economically and socially, they are the most disruptive of all Salton Trough sand accumulations.

2. AEOLIAN ACTIVITY IN WESTERNMOST COACHELLA VALLEY AND AT GARNET HILL

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COACHELLA VALLEY

The westernmost end of Coachella Valley (Fig. 2-1), north and west of Palm Springs, provides a splendid natural laboratory for observations of and experiments with the behavior of sand moving by traction and saltation under a powerful unidirectional wind regime of high frequency. Ancient ventifacts (sand blasted rocks) on Garnet Hill (Fig. 2-2), just east of Indian Avenue and south of Interstate Highway I-10, indicate that similar activity has characterized this area in past millennia. Current conditions will be treated before the spectacular sand blasting of stones of Garnet Hill is described.

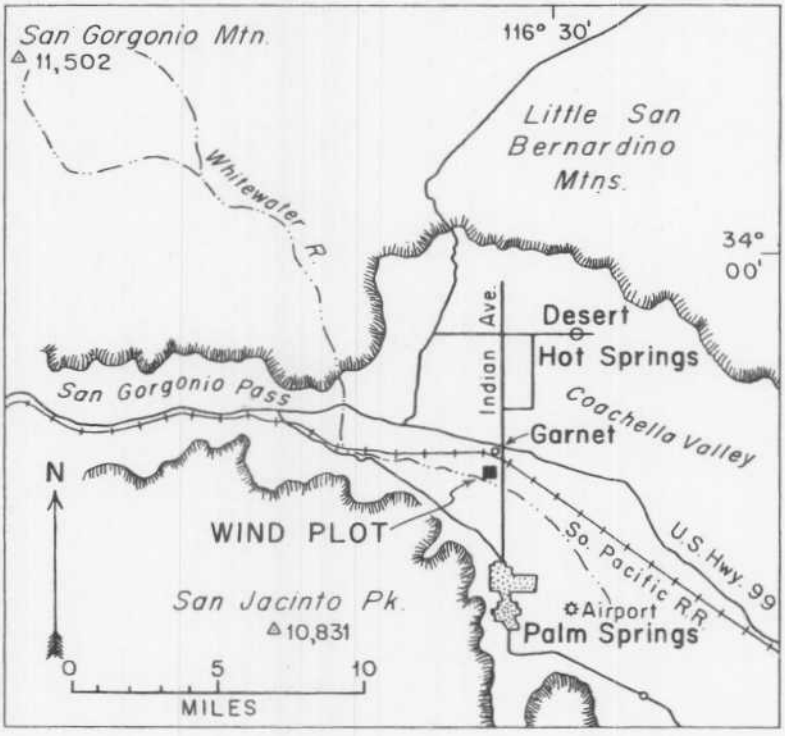

FIGURE 2-1. Location map of Garnet and aeolian erosion study area (from Sharp, 1964).

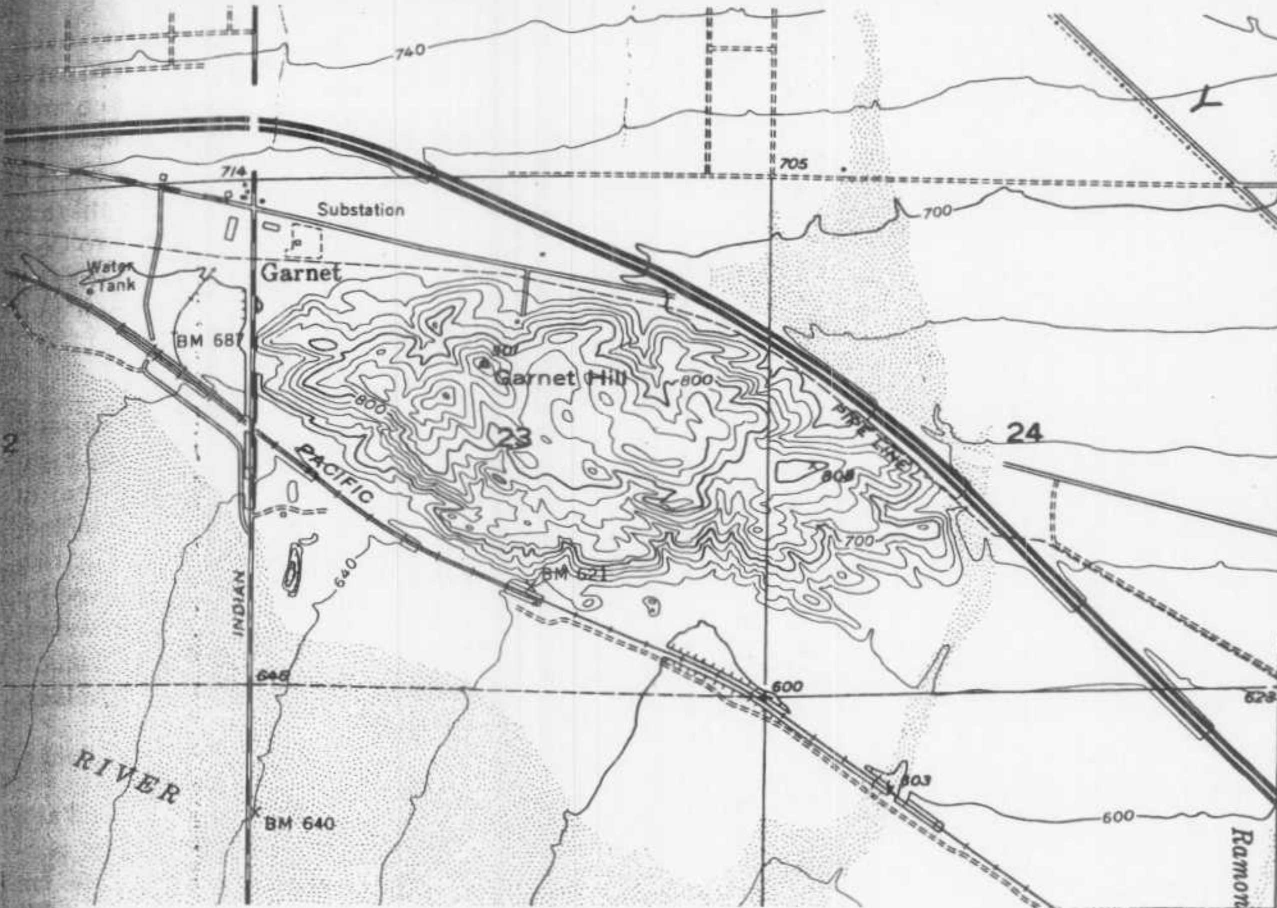

FIGURE 2-2. Enlargement of U. S. Geological Survey topographic map showing location of Garnet Hill.

The area currently has a high flux of aeolian sand transport derived from the barren active alluvial plain of Whitewater River. This stream, and its principal tributary, San Gorgonio wash, are ephemeral and only occasionally inundate the alluvial plain during wet winters. The plain slopes less than 1° eastward, is scarred by braided channels mostly 0.3 to 0.6 m deep, consists largely of coarse sand and gravel with largest boulders at 0.5 to 1 m, and in its active parts, is only sparsely dotted with low perennial bushes. Most stones on the surface of this plain, except those in recently active channels, show evidence of sand blasting as do other materials such as beer cans and chunks of wood.

The orographic setting is unusual in being at the east end of narrow San Gorgonio Pass between the two highest peaks in southern California, San Gorgonio (3508 m) to the north and San Jacinto (3303 m) to the south (Fig. 2-1). The pass serves as a funnel through which winds of high velocity blow from the coastal region to the Colorado Desert. Wind frequency is high in all seasons, becoming almost daily from May through July. These winds are almost entirely from N 75° W; only occasionally does air move from other directions and then only as gentle breezes with the exception of very rare strong storm winds from the north.

The alluvial plain created by the Whitewater River at the west end of Coachella Valley is the source for the windblown sand that inundates parts of the valley floor farther east, principally between Palm Springs and Indio. The flux of windborne sand carried into this accumulation area varies in direct relation to the amount of flooding of the alluvial plain west of Indian Avenue. Only a year or two is required for the wind to remove most of the transportable grains from the alluvial plain, leaving a residual armor of coarse material that prevents further significant removal until that armor is disturbed, or a new supply of debris is brought by flood waters. The flux of sand into Coachella Valley thus varies with fluctuations in climatic conditions, being greater following wet years than in time of drought. The solution to control of windblown sand here lies more with flood control than with wind control, as now attempted by means of hedges and other barriers.

When sand has been made available by floods, and wind action is strong, the flux of sand moving across the barren westernmost part of the Coachella Valley alluvial plain is extremely high. Sand movement occurs by traction, saltation, and impact creep. Traction refers to movement in which the particle is continuously on the ground surface, saltation is a hopping process, and impact creep is a form of traction in which material is moved by the impact of fast traveling saltating grains. Impact creep results in transport of grains many diameters larger than could be moved by wind drag alone, and its effects are probably underrated. However, the greatest volume and weight of sand moves by saltation, and it is the saltating grains which produce much of the mechanical wear on fixed objects and also launch into the air much of the material that ultimately travels by suspension.

Collection and mechanical analysis of the saltating sand curtain over an eleven year period at a station 1070 m west of Indian Avenue not far from Garnet Hill (Fig. 2-1) shows that, on the average, 50 percent by weight of the saltating grains travel within 13 cm and 90 percent within 64 cm of the ground surface. Saltating grains up to 2 mm diameter occasionally rebound to heights of at least 6 m in this environment. Both the amount of saltating material and mean grain size decrease with height, as would be expected, but many departures from this generalization occur within the saltation curtain with respect to materials of specific grain diameter, as expressed in terms of weight percentages. Particles smaller than 0.062 mm are essentially universally distributed, indicating they probably move in suspension, and particles up to 0.125 mm behave in a manner suggesting that they are strongly influenced by wind turbulence. The amount of larger grains, expressed in weight percentage relative to other grain sizes, peak at heights increasing with grain size under some wind regimes (Fig. 2-3).

Erosion of objects by windblown particles was also studied in the field (Sharp, 1964). Wear was measured largely on objects artifically placed in the wind plot, but a recording of cutting on natural rocks was also attempted. Maximum wear on a vertical lucite rod anchored in the experimental plot occurred at a level 23 cm above the ground (Fig. 2-4). This is thought to represent the level at which grain size, grain number, and grain velocity combine to give the greatest impact energy, and hence erosion, upon the rod. The amount of wear was essentially 1 mm in ten years. Cutting on common red bricks and cubes of hydrocal (a gypsum compound) of various dimensions and orientations was impressive (Figs. 2-5 and 2-6). Nearly 1 mm of cutting occurred in fifteen years on the face of a gneissic granitic boulder in the plot, most of it within the last two or three years of the experiment, when sand flux was abnormally heavy, owing to extensive and repeated floodings of the alluvial plain farther west. The station was destroyed in its fifteenth year by a flood of unusual magnitude.

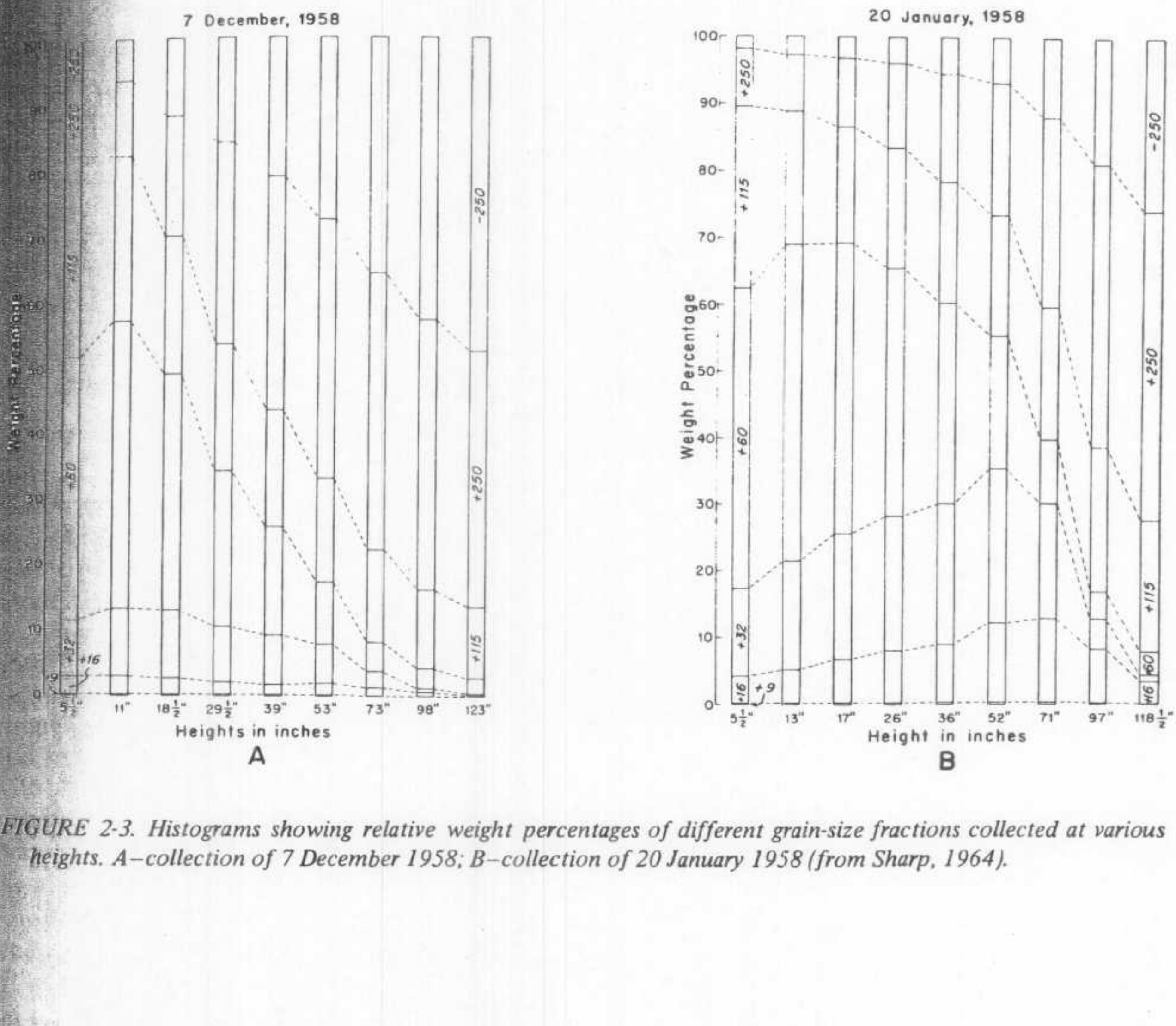

FIGURE 2-3. Histograms showing relative weight percentages of different grain-size fractions collected at various heights. A–collection of 7 December 1958; B–collection of 20 January 1958 (from Sharp, 1964).

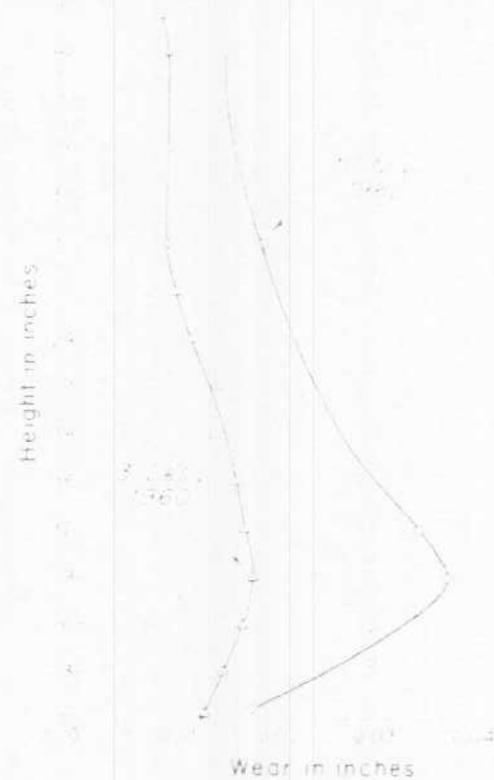

FIGURE 2-4. Wear by sand blast on a lucite rod anchored in the experimental plot (from Sharp, 1964).

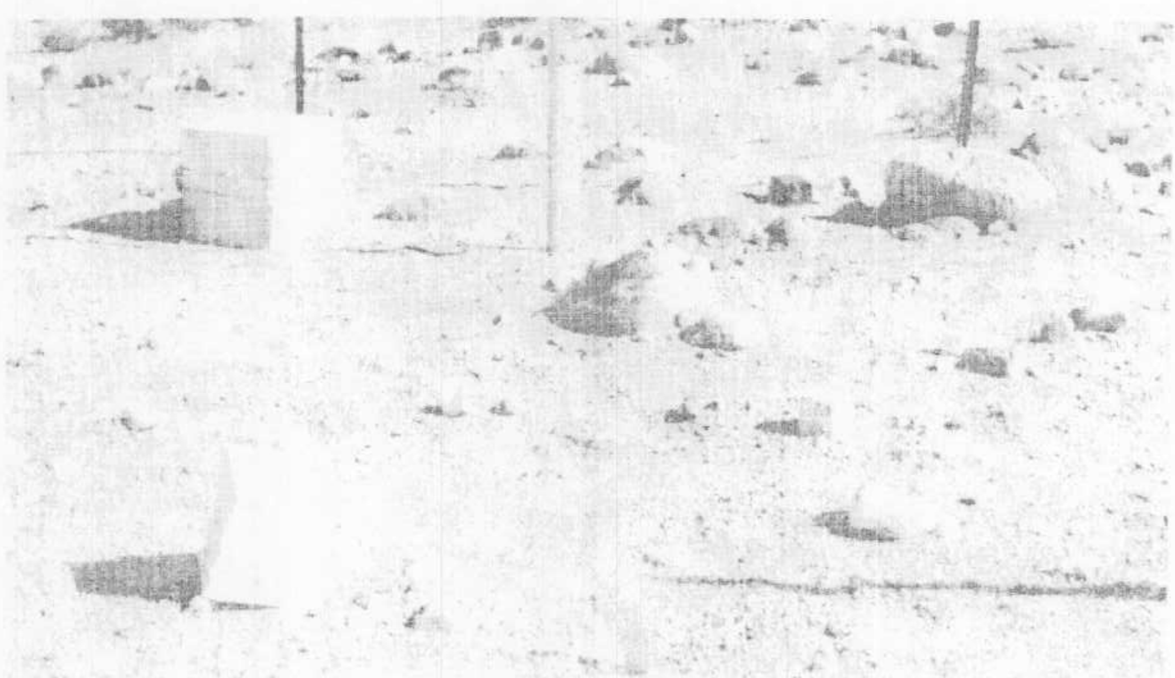

FIGURE 2-5. Stub of broken lucite rod center foreground. Overturned 1-inch cube (left) and overturned 2-inch cubes right and left center. Three-inch cube (right) and 12-inch cube (left) rear, undisturbed but worn. View northeasterly, 27 January 1964 (from Sharp, 1964).

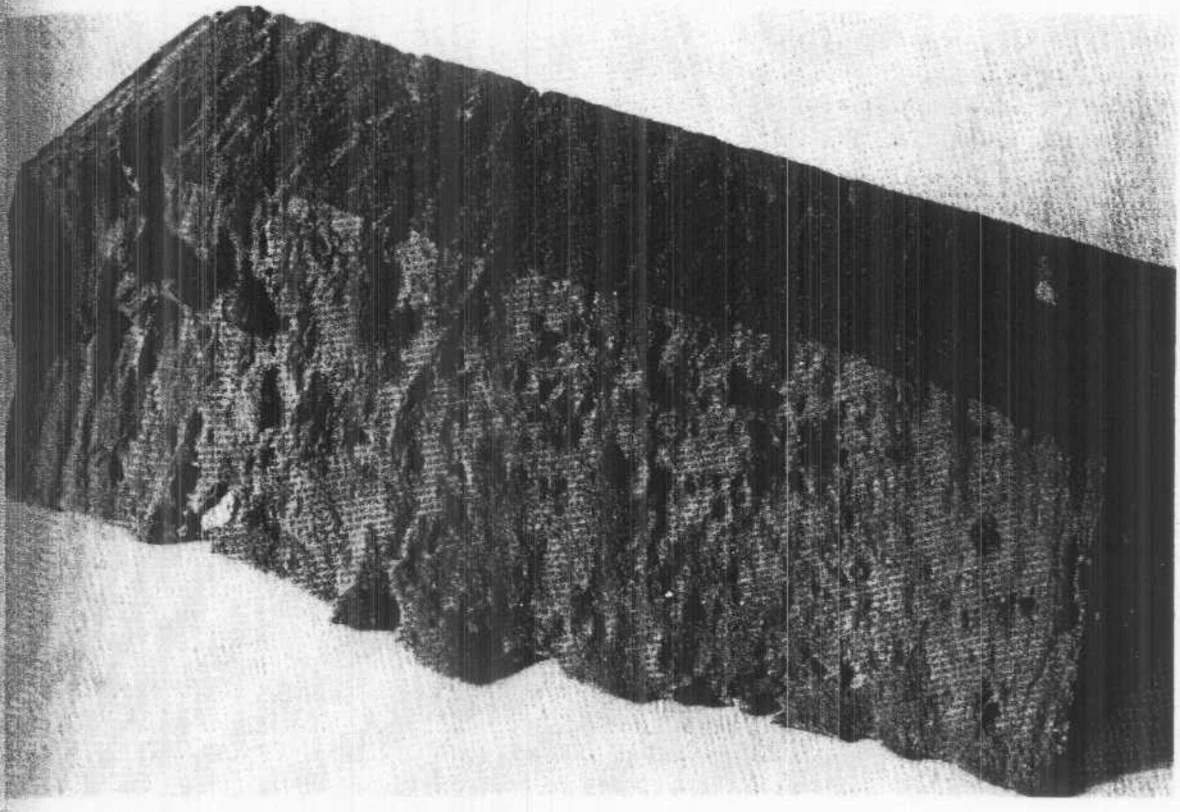

FIGURE 2-6. Common brick after six years of sand blasting (from Sharpe, 1964).

AEOLIAN PROCESSES AT GARNET HILL

Garnet Hill (Figs. 2-2 and 2-7) is about 2.5 km long, parallel to Interstate Highway I-10 on the north and Southern Pacific Railroad on the south. The hill is formed from an eroded anticline in Cenozoic sedimentary rocks and is bounded on the south by Garnet Hill fault. The uppermost stratigraphic unit, the Cabezon Fanglomerate, is of late Pleistocene age, deposited between 100,000 and 1 million years ago. This unit consists of poorly sorted pebbly and bouldery arkosic sandstone with about fifty percent gneiss clasts, forty-five percent granitic and pegmatitic rocks, and a minor amount of basalt. The lithologic character of the clasts indicates the sediment source was the San Bernardino Mountains, drained by the ancestral Whitewater River. On Garnet Hill, however, there are boulders of siliceous limestone and a predominance of diorite and granodiorite. These are rock types found in the San Jacinto Mountains and suggest this area as a contributing sediment source. The Cabezon Fanglomerate has been exposed at Garnet Hill by upwarping and subsequent erosion of overlying alluvium. The fanglomerate is the source of the abundant cobbles and boulders, some up to 3 m across, that dot the hillslopes.

Underlying the Cabezon Fanglomerate, and revealed primarily in scattered exposures on the south margin of Garnet Hill, is the marine Imperial Formation of late Pliocene age (more than two million years old). The Cabezon Fanglomerate rests unconformably on the Imperial Formation at Garnet Hill; elsewhere this gap is occupied by terrestrial conglomerates in which early horse and

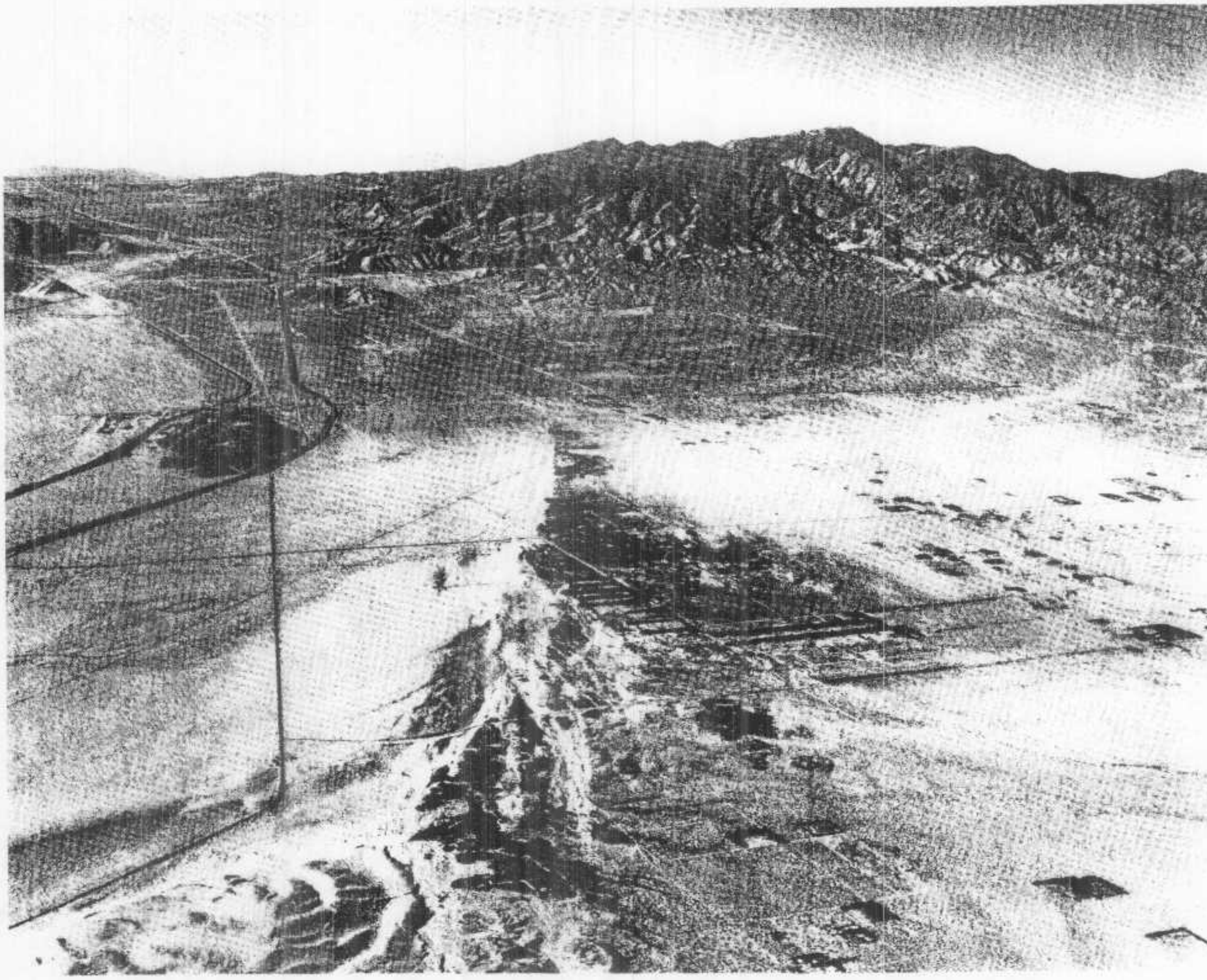

FIGURE 2-7. Oblique aerial view of Garnet Hill (left side) looking west. Trace of San Andreas fault is visible in middle foreground. (Photograph by J.S. Shelton).

camel teeth have been found. The Imperial Formation records an early invasion of the Salton Trough by the Gulf of California. This marine transgression filled the area with warm shallow water in which oysters and scallops thrived, evidenced by fossils that are common in the sandy facies. Garnet Hill has been discussed briefly by several authors that are referred to in Sharp (1964, 1972) and additional details of the local stratigraphy and structure may be found in Proctor (1968).

There are few places in the United States where large ventifacts deeply scoured, polished, faceted, and engraved by wind blasting are better displayed than on the slopes of Garnet Hill. These are fossil ventifacts in the sense that active blasting no longer occurs on most of them. Their antiquity is demonstrated by fractured and displaced wind-cut facets on individual stones, by shifting of wind-cut features on large, usually immobile stones, to an orientation incompatible with the local unidirectional wind regime, and by extensive solution of wind-cut facets on carbonate stones as well as oxidation and staining of wind-cut surfaces on stones of other compositions.

Why the slopes of Garnet Hill should have at one time, presumably centuries to millennia ago, have been subject to such intensive wind blasting, but now are almost totally spared such activity, is a matter of inference and interpretation. The area currently upwind from Garnet Hill is largely stabilized by armoring and a cover of creosote bushes. At earlier times and under possibly different climatic conditions, the area may have been barren alluvium and hence a rich source of windblown sand for Garnet Hill. This seems the most likely explanation, but the lithology of the fanglomerates composing Garnet Hill indicates that they have been derived from the north face of San Jacinto Mountain 6 to 8 km to the west. From this relationship, an argument could be made for several km of right-lateral displacement along Garnet Hill fault. The ventifacts are clearly fossil with respect to the present relationships controlling sandblasting. Active cutting is currently limited to the west end and to the lowermost flanks of Garnet Hill. Although the rocks of Garnet Hill may have been laterally displaced by strike-slip faulting, fault movement has probably not played a role in determining the effectiveness of sand blasting on Garnet Hill ventifacts. It may be that the Whitewater River was dumping alluvial material more directly upwind from Garnet Hill at some time than at present. At such a time, the hill may have lain directly in the path of maximum sand flux and climatic conditions may have created both a greater flux and stronger winds.

The ventifacts merit brief description. Stones of all sizes from pebbles only a few centimeters in diameter to huge boulders several meters across bear evidence of severe wind blasting (Figs. 2-8 and 2-9). Those of fine grain and relatively high silica content show a considerable degree of polish. Nearly all display pitting, fluting, and grooving on wind-cut faces and facets. Small stones susceptible to shifting may be cut on several sides (Fig. 2-10), but larger, stable stones show only the effects of wind blasting from the N 75°W direction. Some large boulders with a semi-radial arrangement of deep grooves look like they have been blasted by a permanently set fire hose (Fig. 2-11). Grooving often transects structure (foliation or lamination) in a stone (Figs. 2-12, 2-13, and 2-14)

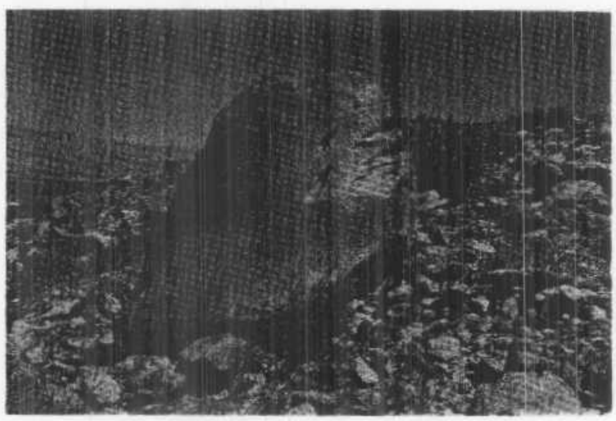

FIGURE 2-8. Large ventifact on Garnet Hill. Note smaller ventifact in foreground. (Photograph by W. A. Hunter, 1977.)

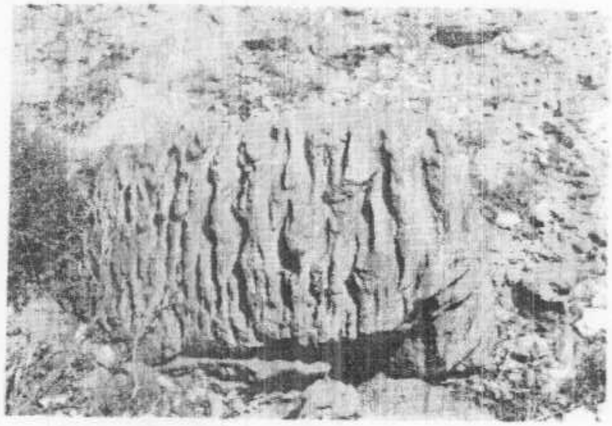

FIGURE 2-9. Multiple fluted ventifact on Garnet Hill. (Photograph by W. A. Hunter, 1977.)

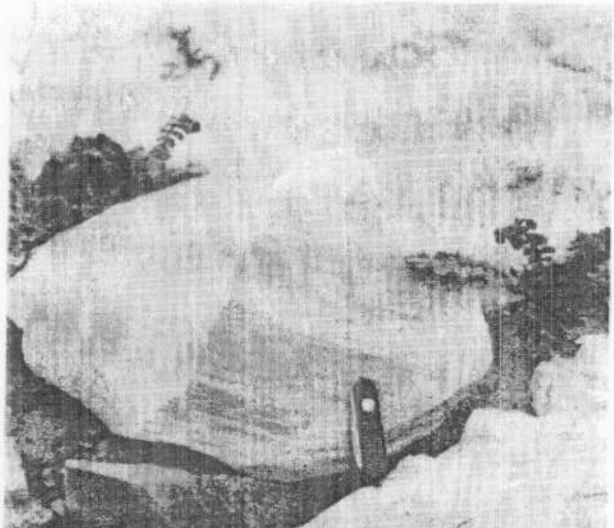

FIGURE 2-10. Ventifact on Garnet Hill. (Photograph by R. Greeley.)

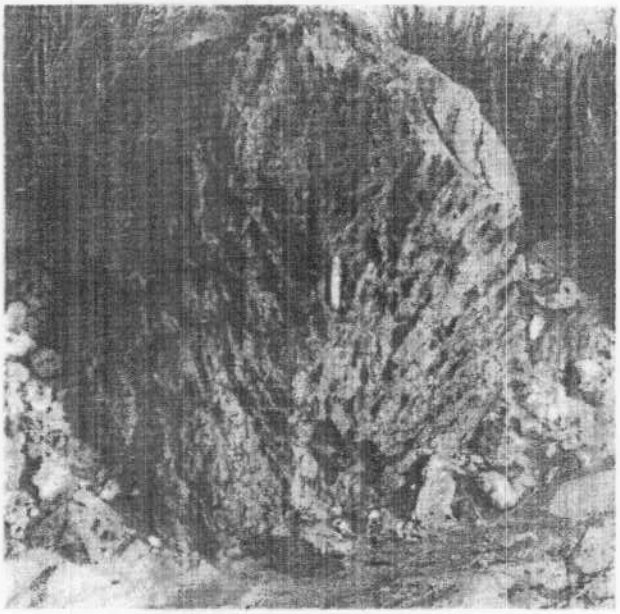

FIGURE 2-11. Large grooved ventifact on Garnet Hill displaying radial arrangement of pits, grooves, and flutes. Rock is a coarse, crystalline igneous variety, and cutting is old. (Photograph by R. P. Sharp.)

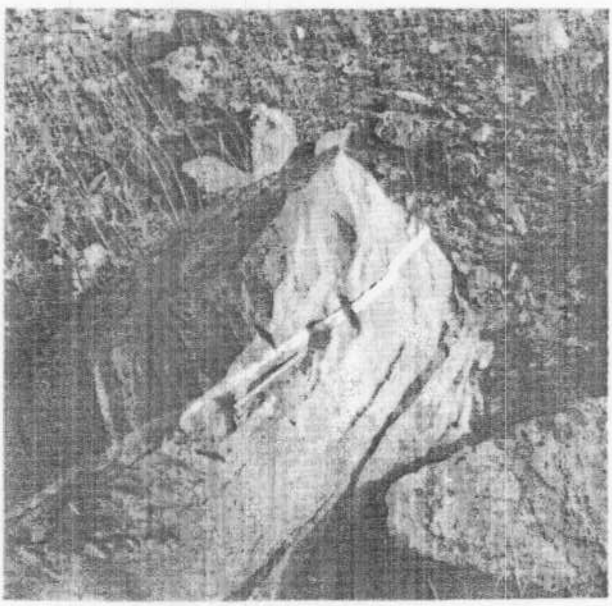

FIGURE 2-12. Grooved ventifact with foliation perpendicular to grooving. (Photograph by R. Greeley.)

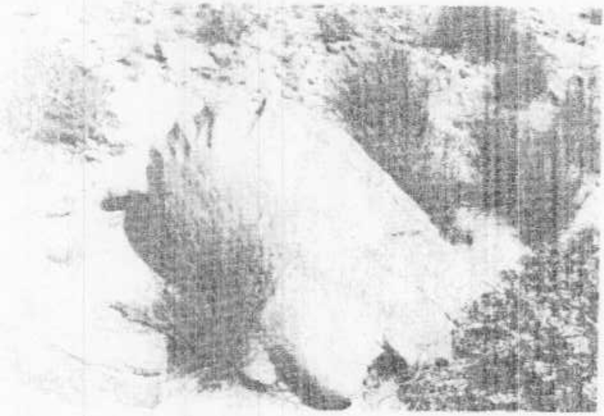

FIGURE 2.13. Fluted contact boulder on Garnet Hill. (Photograph by W. A. Hoover, 1977.)

FIGURE 2.14. Close-up view of grooves cutting rock structure on Garnet Hill contact.

unless the structure happens to be parallel to wind direction (Fig. 2-15). Hard parts or resistant mineral grains stand in positive relief (Fig. 2-16), spectacularly so in the instance of carbonate stones. In some instances, the shape and, roughly, the size of the original unmodified stone can be inferred from the wind blasted remnant, and it is apparent that up to 70 to 80 percent of some rocks have been worn away. One can easily spend many hours wandering over the slopes of Garnet Hill admiring the surprising variety and character of wind blasted rocks.

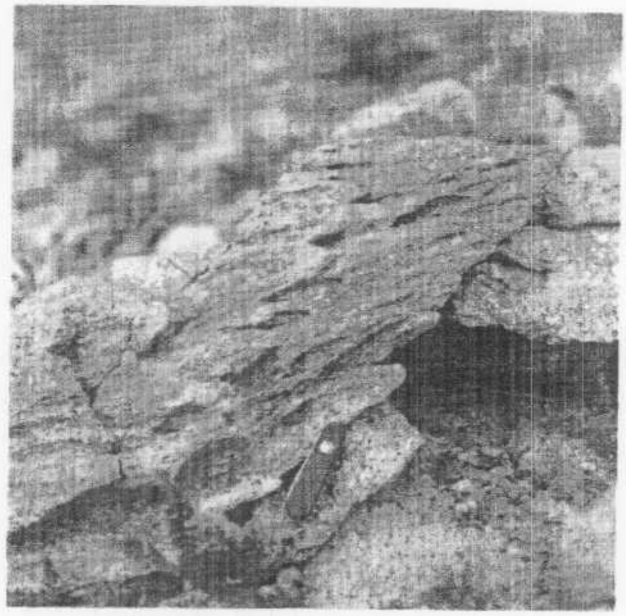

FIGURE 2-15. Ventifact grooving parallel to rock foliation. (Photograph by R. Greeley.)

FIGURE 2-16. Differential aeolian erosion in Garnet Hill ventifact. (Photograph by R. Greeley.)

REFERENCES

Proctor, R. J., 1968. Geology of the Desert Hot Springs–Upper Coachella Valley Area, California: Special Report 94, Calif. Div. Mines and Geology.

Sharp, R. P., 1964. Wind-driven sand in Coachella Valley, California: Bull. Geol. Soc. Am., vol. 75, pp. 785-804.

Sharp, R. P., 1972. Geology Field Guide to Southern California: Wm. C. Brown Co., Publishers, Dubuque, Iowa, 181 p.