In This Issue

GEOLOGY OF JOSHUA TREE NATIONAL PARK .............. 3
MINES IN JOSHUA TREE NATIONAL PARK .............. 17
LITERARY PROSPECTS ........................................ 18
TEACHER FEATURE—GEOSCIENCE CAREERS ............. 20
PARTIAL LIST OF PUBLICATIONS ORDER FORM .......... 23
CALIFORNIA GEOLOGY SUBSCRIPTION, ORDER, AND
CHANGE OF ADDRESS FORM .................................. 25
CALIFORNIA GEOLOGY SELECTED BACK ISSUES .......... 26
DMG RELEASES NEW AND REVISED OFFICIAL MAPS
OF EARTHQUAKE FAULT ZONES OF MAY 1, 1998 .......... 27

Cover Photo: Cretaceous White Tank monzogranite exposed in Joshua Tree National Park in the Wonderland of Rocks area of the park. These masses of rock have been sculpted through a combination of rock jointing, and chemical and physical weathering. ©1998, John Karachewski, Walnut Creek, California.
INTRODUCTION

Joshua Tree National Park, one of the nation’s newest national parks, preserves a typical area of California desert landscape that includes parts of two deserts; the lower elevation Colorado Desert and the higher elevation Mojave Desert. The first-known inhabitants were the Pinto Basin people, an early culture whose artifacts have been found along the shorelines of an ancient lake that once occupied the Pinto Basin in the Park’s eastern Wilderness Area. The dating of these artifacts suggests that the Pinto Basin people lived here from about 7,000 to 5,000 years ago. More recent Native American populations included the hunters and gatherers who are the ancestors of the modern Cahuilla, Chemehuevi, and Serano people. The Oasis of Mara, at the site of the Oasis Visitor Center and Park Headquarters at Twentynine Palms, was the home of Chemehuevi until the early 1900s.

In the late nineteenth century, the Oasis of Mara was a popular watering stop for miners on their way to and from the gold mines in the surrounding region. Today, within the park boundaries, are the remains of more than 2,000 abandoned mines and mining prospects. Among the more productive mines were the Lost Horse, Silver Bell, El Dorado, and Desert Queen. Estimates of the total gold production from

With the passage of the Desert Protection Act in 1994, Joshua Tree National Park gained the southern portion of the Little San Bernardino Mountains, the Eagle and Coxcomb mountains and part of the Pinto Mountains. These areas add to what the park is widely known for—outstanding examples of relict erosional features, recent tectonic activity and desert landforms (Photo 1). Recent studies have revised earlier interpretations of the geology of this region. This article, updated from the original published in the April 1984 issue of CALIFORNIA GEOLOGY, reflects these studies. It is reproduced with special permission from Geology of National Parks, 5th Edition by Harris and others, copyright 1997 by Kendall/Hunt Publishing Company*...editor.

*Geology of National Parks can be ordered directly from Kendall/Hunt Publishing Company by calling (800) 228-0810, or faxing (800) 772-9165, or see their website www.kendallhunt.com
these mines range from $40,000 to $40,000,000.

Cattle raising went on at about the same time as the mining activity as cattlemen found the grasses in the high desert suitable for their stock. Grazing continued within what is now the park until 1945.

Beginning in the early 1920s, homesteaders began taking up land in the Twentynine Palms area. The reasons for this were the availability of water at the Oasis of Mara and the desert climate. Disabled veterans of World War I were encouraged to settle in the area in hope that the dry air would help cure their ailments. Many of the health-seekers found that an out-of-doors desert lifestyle did indeed have therapeutic value. Gradually the area became more popular, bringing new housing, more roads, an influx of land developers, and cactus poachers.

A dedicated lady from Pasadena, Mrs. Minerva H. Hoyt, who had a passion for the desert, agonized over the removal of cacti and other desert plants from the Joshua Tree area to the backyard rock gardens of Los Angeles. Her efforts to protect the desert environment culminated in the creation of Joshua Tree National Monument proclaimed by President Franklin D. Roosevelt in 1936.

**LOCATION AND GEOGRAPHY**

Joshua Tree National Park is on the eastern end of the broad mountainous belt called the Transverse Ranges, that stretch from Point Arguello, 50 miles west of Santa Barbara, eastward for nearly 300 miles to the Eagle Mountains in the Mojave Desert (Figure 1).

The park region includes several distinct mountain ranges, the Little San Bernardino, Cottonwood, Hexie, Pinto, Eagle, and Coxcomb mountains (Figure 2). Both the southern and the northern margins of the park are marked by steep escarpments that rise abruptly from the lower desert areas. Elevations within the park range from 1,000 feet in Pinto Basin to 5,814 feet at the summit of Quail Mountain. Valleys lying between the mountain ranges are of two types: 1) structural basins formed by the down-dropping of a block between two faults and 2) erosional valleys. Pleasant Valley, between the Little San Bernardino and Hexie mountains, is an example of the structural type; Queen Valley, in the central part of the park, is an example of the eroded type.

**CLIMATE**

The climate of the high desert of the Joshua Tree region is that of a mid-latitude desert with relatively moderate temperatures. For example, the average temperature at Twentynine Palms, elevation 1960 feet, is only 67.3 degrees Fahrenheit (F) and at Hidden Valley Campground, 4,200 feet, the average temperature is about 7 to 12 degrees F cooler. Two factors cause eastern California to be a desert: 1) the rain shadow effect produced by the high mountains on the west, and 2) the existence during summer months of a semi-permanent high-pressure air mass, the Hawaiian High, which builds up over the northeastern Pacific Ocean and blocks the passage of frontal storm systems over California. Occasionally, during the summer and fall, the Hawaiian High weakens and moist air from the Gulf of Mexico slips into the region across Arizona, bringing thunderstorms. For this reason, August has the highest rainfall (Table 1) which, curiously enough, is usually the driest month for the more humid regions of the state.

The Hawaiian High usually dissipates during the winter months and southern California is subjected to an average of four or five frontal storms that originate in the northeastern Pacific. Consequently, it is in December and January that the desert’s second rainy season occurs (Table 1). The average rainfall at Twentynine Palms is only a little over 4 inches but at higher elevations the average rainfall is greater.

**TYPES OF ROCK EXPOSED IN THE JOSHUA TREE REGION**

Metamorphic Rocks

The earliest events in the geologic history of Joshua Tree National Park are recorded in rocks of early and middle Proterozoic (Precambrian) age that were formed by the metamorphism of preexisting sedimentary and igneous rocks. These rocks, formerly named the Pinto gneiss, are now recognized as fragments of a widespread metamorphic complex that was caught up in the
Table 1. Joshua Tree National Park weather records taken at the Oasis Visitor Center at Twentynine Palms at an elevation 1,960 feet. The averages were compiled from data collected from 1936 through 1991. Temperatures average approximately 7 to 10 degrees F cooler at higher elevations in the park. Higher elevations also average about 3.5 inches more precipitation annually. Courtesy of National Park Service, 1992. From Trent (1997).

<table>
<thead>
<tr>
<th>Month</th>
<th>Average Maximum Temperature*</th>
<th>Average Minimum Temperature*</th>
<th>Average Precipitation (inches)</th>
<th>Average Humidity (percent)</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>62.8</td>
<td>31.5</td>
<td>0.38</td>
<td>28.2</td>
</tr>
<tr>
<td>February</td>
<td>67.7</td>
<td>38.2</td>
<td>0.35</td>
<td>24.1</td>
</tr>
<tr>
<td>March</td>
<td>74.8</td>
<td>42.9</td>
<td>0.30</td>
<td>19.2</td>
</tr>
<tr>
<td>April</td>
<td>83.1</td>
<td>50.1</td>
<td>0.10</td>
<td>16.5</td>
</tr>
<tr>
<td>May</td>
<td>90.3</td>
<td>55.9</td>
<td>0.06</td>
<td>14.0</td>
</tr>
<tr>
<td>June</td>
<td>100.6</td>
<td>64.8</td>
<td>0.02</td>
<td>12.3</td>
</tr>
<tr>
<td>July</td>
<td>105.2</td>
<td>70.6</td>
<td>0.62</td>
<td>17.0</td>
</tr>
<tr>
<td>August</td>
<td>103.0</td>
<td>69.5</td>
<td>0.68</td>
<td>20.8</td>
</tr>
<tr>
<td>September</td>
<td>96.4</td>
<td>62.4</td>
<td>0.31</td>
<td>16.4</td>
</tr>
<tr>
<td>October</td>
<td>85.7</td>
<td>52.6</td>
<td>0.32</td>
<td>19.5</td>
</tr>
<tr>
<td>November</td>
<td>71.5</td>
<td>41.4</td>
<td>0.27</td>
<td>25.7</td>
</tr>
<tr>
<td>December</td>
<td>62.3</td>
<td>31.6</td>
<td>0.46</td>
<td>28.4</td>
</tr>
</tbody>
</table>

* degrees Fahrenheit
Mesozoic tectonic arc along the Pacific margin of North America, became fragmented, and was widely distributed throughout the Transverse Ranges and vicinity. Four subunits of this complex are recognized within Joshua Tree National Park: the Joshua Tree augen gneiss, a granitic augen gneiss that crops out in the Chuckwalla, central Eagle, and south-central Pinto Mountains; the metasedimentary suite of Placer Canyon, composed of quartzite and dolomite, which unconformably overlies the Joshua Tree augen gneiss; the distinctive augen gneiss of Monument Mountain, a dark colored porphyritic granodiorite-monzogranite,* in the Hexie Mountains; and the metasedimentary suite of Pinkham Canyon in the Chuckwalla, Eagle, Hexie, and Pinto mountains (Table 2). The Pinkham Canyon rocks include quartzite, schist, very fine-grained granofels, and dolomite, a suite identical to strata in the northeastern-most Mojave Desert near Baker that offers a tentative link between the Proterozoic rocks of the North American craton and the Transverse Ranges of California. Radiometric age dating of these Proterozoic rocks yields ages of 1.65 to 1.70 billion years before present (ybp) for the augen gneiss of Joshua Tree and 1.65 to 1.68 billion ybp for the augen gneiss of Monument Mountain, making these some of the oldest rocks known in California.

Igneous Rocks

At least five different major plutons, ranging in age from middle Proterozoic to Cretaceous, have intruded the metamorphic complex described above (Photo 2). The oldest are a succession of intrusions of the igneous protoliths (parent rocks) of foliated metamorphosed hornblende gabbro, diorite and amphibolite, laminated granodioritic to monzogranitic orthogneiss, and various leucocratic granite orthogneiss (commonly gneissiferous) that intruded the metasedimentary rocks of Pinkham Canyon. The amphibolite and the leucocratic granitic orthogneiss have yielded isotopic ages of 1.71 billion ybp and 1.68 billion ybp respectively. A younger Proterozoic suite of plutonic rocks is an anorthosite-syenite intrusive complex in the southeastern section of the park, which yields a radiometric age of about 1.2 billion ybp.

The Triassic and Cretaceous plutons in Joshua Tree National Park, in common with the granitic rocks of the Sierra Nevada, the Peninsular Ranges, the Klamath Mountains, and the White-Inyo Mountains, are believed to have been generated in an oceanic-continental convergence zone. Examples of the intrusive contacts of these rocks with the Proterozoic gneiss country rocks are well exposed along the trail to FortyNine Palms Oasis and along the east side of Lost Horse Valley (Photo 3).

The oldest Mesozoic intrusion, the TwentyNine Palms porphyritic quartz monzonite, consists of a matrix of small mineral grains that enclose large phenocrysts of potassium feldspar that attain lengths up to 2 inches. The pluton is of Triassic age, yielding a preliminary radiometric age of 245 million ybp. It is part of a widespread belt of Permo-Triassic plutonic rocks exposed in southern California. This belt of rocks is significant because its intrusion signals the onset of an ocean-continent tectonic convergence and subduction plutonism along the continental margin. The TwentyNine Palms pluton crops out along the trail to FortyNine Palms Oasis and along the arroyo on the east side of Indian Cove campground.

The principal plutons of Cretaceous age include the Queen Mountain monzogranite, the Gold Park diorite, the White Tank monzogranite, and the Oasis monzogranite (Table 2). These rocks appear to be part of the late Cretaceous intrusive events recognized in the eastern Mojave Desert, Peninsular Ranges, and the Sierra Nevada.

The oldest of the Cretaceous plutons in Joshua Tree National Park is the Queen Mountain monzogranite. It is coarse-grained, consisting of plagioclase, potassium feldspar, quartz, and either biotite or hornblende. The Queen Mountain has yielded a radiometric age date of 104 million ybp.

The light-colored Cretaceous White Tank monzogranite predominates in the more accessible parts of the park. The White Tank pluton resembles the Queen Mountain monzogranite but differs by being finer-grained, and by containing small amounts of biotite and/

* The igneous rock terminology used here follows the modified Streckeisen (1973) classification.
or muscovite but no hornblende. What are perhaps the most scenic areas of the park underlain by the White Tank monzo-granite are Indian Cove, the Wonderland of rocks, Jumbo Rocks, White Tank, and Lost Horse Valley (Photo 4).

The youngest of the Cretaceous plutons, the Oasis monzogranite, is a garnet-muscovite-bearing pluton exposed in the area around Fortynine Palms Oasis. The garnets are blood-red and small, but large enough, nevertheless, to be visible without magnification. The muscovite grains impart a distinct glitter to the rock on sunny days.

In addition to the large monzogranite and quartz monzonite plutons already described, there are smaller masses of a similar rock, granodiorite, and small dark plutons named the Gold Park diorite. Cutting across all of these rock masses, and thus being younger in age, are dikes of felsite, aplite, pegmatite, andesite, and diorite. Pegmatite dikes in the park consist mainly of quartz and potassium feldspar with a composition close to that of granite. Making them distinctive is the very large size attained by the mineral grains, often 3 to 4 inches long.

Even younger than these dikes are veins of milky quartz that, over the years, have been prospected for gold. The quartz is sometimes stained reddish brown from the weathering of pyrite (fool's gold). Pyrite is a common mineral in quartz veins and is sometimes associated with gold or other valuable minerals. Chemical alteration of the pyrite...
produces reddish iron oxides that stain the rocks and serve prospectors as clues that gold, silver, copper, lead, or other important ores may be present.

Basalt occurs at three places within the easily accessible parts of the park: 1) near Pinto Basin, where the basalt probably originated as extrusive flows, 2) at Malapai Hill on the Geology Tour Road (Photos 5 and 6), and in the Lost Horse Mountains. These exposures show much in common with other basalt bodies in the eastern San Bernardino Mountains and the Mojave Desert that have been age-dated at between 8 to 10 million ybp. In addition to basalt, another mafic rock, lherzolite, occurs as inclusions within the basalt at Malapai Hill and in the Lost Horse Mountains. Lherzolite is an olivine-rich peridotite that is derived from the mantle; thus, the basalt has risen some 30 to 50 miles in order to carry the inclusions to the surface.

**STRUCTURAL GEOLOGY**

**Faults**

Joshua Tree National Park is surrounded by active or recently active faults. The Pinto Mountain Fault, trending nearly east-west along the north side of the Pinto Mountains, is one of the most prominent. The fault zone is followed closely by Twentynine Palms Highway (State Highway 62) between Morongo Valley and Twentynine Palms.

Between Morongo Valley and Yuca Valley, the fault is marked by side hill benches, triangular faceted spurs, and a probable left-lateral stream offset. Quaternary basin-fill buries much of the geomorphic evidence of the fault from Yuca Valley to Copper Mountain, but just west of Copper Mountain the fault is marked by a line of vegetation. A prominent escarpment is formed by the main trace of the fault along a 1.2 mile-long shutter ridge at Copper Mountain. (A shutter ridge is formed by displacement on a fault traversing ridge-and-valley topography. The displaced part of a ridge “shuts in” an adjacent canyon.) In Twentynine Palms, the fault at the Oasis of Mara, immediately west of the Oasis Visitor Center, is marked by a line of vegetation about 1.5 miles long and by a scarp about a half-mile long and 3 to 6 feet high.

The Blue Cut Fault extends east-west through the Little San Bernardino Mountains, about a half-mile south of Keys View, under Pleasant Valley and into the Pinto Basin. The Blue Cut Fault branches from the Dillon Fault, which is even farther south and trends southeastward through the Little San Bernardino Mountains. The Blue Cut and Pinto Mountain faults are both left-lateral faults. They appear to belong to a system of faults, all about the same age.
Joints

These small fissures cutting rocks may occur in sets of parallel joints and in systems of two or more intersecting sets. The White Tank monzogranite has a system of rectangular joints that is primarily responsible for the spectacular landforms in the park. One set, oriented roughly horizontally, results from the erosional removal of the overburden stress of many miles of rock that once overlay the monzogranite. These joints, sometimes called lift joints, cause exfoliation. Lift joints (or pressure release joints) are due to expansion from the release of overburden stress, somewhat analogous to that of a seat cushion resuming its shape after a person sitting on it arises. Where vertical joints are lacking or widely spaced, lift joints form domelike landforms (Photo 4).

That include the many north-northwest-trending right-lateral faults of the Mojave Desert. Included in this fault system are the Johnson Valley, Camp Rock, and Emerson northwest-trending right-lateral faults that ruptured in the 1992 Landers earthquake (M=7.3), the epicenter of which was about 22 miles northwest of Twenty-nine Palms. This right-lateral fault set appears to extend southeastward from the central Mojave Desert into the western part of Joshua Tree National Park in the region of Black Rock Canyon campground.

South of the Dillon and Blue Cut faults lies the San Andreas Fault Zone. The trace of the San Andreas Fault is clearly visible from Keys View (Photo 7). Along this portion of the San Andreas, the fault divides into two main branches, the Banning and Mission Creek faults. The traces of these faults are marked by the Indio Hills, an uplifted block wedged between the faults, and by a number of palm oases that are aligned along the faults.

In addition to the major faults are many minor faults throughout the region of the park. Such fault zones are often important in localizing springs. Movement by faults causes impervious zones composed of pulverized rock fragments that form subsurface barriers and may force ground water to rise. The oasis at Cottonwood Spring, for example, appears to be localized by a fault zone that has provided the fissures along which ground water reaches the surface. The Oasis of Mara at the Twenty-nine Palms Visitor Center has been formed in a similar manner along the Pinto Mountain Fault.
Photo 7. The northern end of the Salton Trough as seen from Keys View in Joshua Tree National Park. The high peak in the distance is Mount San Jacinto, 10,786 feet in elevation. Palm Springs and Cathedral City are at the base of the mountains. The Indio Hills, running from left to right in the middle distance, mark an uplifted block wedged between two branches of the San Andreas Fault. Photo by D.D. Trent.

Another set of joints is oriented vertically, roughly paralleling the contact of the White Tank monzogranite with its surrounding rocks. The third set is also vertical but cuts the second set at high angles. The resulting system of joints tends to develop rectangular blocks. Especially good examples of the joint system may be seen at Jumbo Rocks, Wonderland of Rocks, and Split Rock (Photo 1).

SCULPTURING THE LANDSCAPE

Weathering

Perhaps the most impressive aspect of the landforms at Joshua Tree National Park are the strange and picturesque shapes assumed by the bold granitic rock masses at the Jumbo Rocks, Wonderland of Rocks, Split Rock, and elsewhere (Photos 1 and 8). The sculpturing of these rock masses is the result of the combined action of rock jointing, and chemical and physical (mechanical) weathering. The combination of these processes results in spheroidal weathering, the peeling-off of thin concentric shells of rock that form spherical rock masses. Spheroidal weathering results from slight pressures that have been built up in the outer portions of the rock from chemical decomposition of the aluminum silicate minerals into clay minerals. For example, when potassium feldspar comes into contact with hydrogen ions and water, the following chemical reaction, called hydrolysis, takes place:

\[
2\text{KAlSi}_3\text{O}_8 + 2\text{H}^+ + \text{H}_2\text{O} \rightarrow \text{Al}_2\text{Si}_2\text{O}_5(\text{OH})_4 + 2\text{K}^+ + 4\text{SiO}_2
\]

Kaolinite, a clay mineral formed by hydrolysis in an arid environment, occupies a greater volume than the original

Photo 8. View of Lost Horse Valley from the Lost Horse Mountains. The flat surface is a pediment and the rocky knobs are inselbergs, remains of the corestones that were isolated in ages past by deep chemical weathering of the White Tank monzogranite. The foreground hills are underlain by Proterozoic gneiss. Photo by D.D. Trent.
feldspar. The expansion is especially great at the edges and corners of the jointed granitic rocks, resulting in the jointed blocks of rock losing their sharp edges and corners to eventually assume rounded or spheroidal shapes.

The stresses, in addition to popping off thin shells of rock, cause the mineral grains of the rock to disintegrate physically and form a loose mineral soil called grus. Furthermore, frost-wedging and root-wedging also contribute to the breakdown of rocks by physical action.

Subsoil Weathering

The concave hollows or pits that pockmark granitic rock surfaces in Joshua Tree National Park are called tafoni. Although a rather common phenomenon, the process explaining the formation of tafoni is not clearly understood. The most common explanations included hydrolysis and hydration, thermal differences due to freezing and thawing or insolation, recrystallization of salts on exposed rock faces, and wind erosion.

In many areas of tafoni, nearly all of the declivities are aligned parallel to the outcrop-soil contact. This implies that the tafoni may have originated several centimeters beneath the surface of the soil by a two-step process of chemical and mechanical weathering. The first step involves the episodic wetting and drying that caused local chemical weathering of bedrock beneath the soil surface. In the second step, climate change and soil erosion forced removal of the soil cover, exposing the chemically altered sites that became pits when exposed to the atmosphere. Because of lower evaporation rates in the declivities, they weathered more rapidly than the surrounding rock, enlarging and sometimes merging into larger pits, with Skull Rock being an especially good example (Photo 9).

Nearly vertical surfaces, commonly on the shady sides of rock outcroppings throughout the park, have been formed by subsoil weathering. The action of moisture trapped in the soil at the base of the vertical surface causes undercutting and accounts for many of the steep cliff faces because the process of wearing back and rounding off higher on the cliff cannot keep up with the undercutting at the base.

Erosion

Of the dynamic processes that carry away surficial rock material, running water, even in arid environments, is by far the most important erosional agent. Wind action is important in the desert, but the long-range effects of the wind are small when compared to the action of water.

Erosional and weathering processes presently operating in the arid climate conditions in the region of Joshua Tree National Park, however, are not entirely responsible for the spectacular sculpturing of the rocks. The present Joshua Tree landscape, and that of much of the Mojave Desert, is essentially a collection of relict features inherited from earlier times of higher rainfall and lower temperatures. Thus, the desert landscape we see now is a "fossil" landscape. For example, Fortynine Palms Canyon could not have formed in the present rainfall regime. Such deep canyons must be attributed to former pluvial conditions during an epoch when the area of the southwestern United States received much greater precipitation than at present, when evaporation was considerably less, and the mean annual temperature was several degrees cooler.

LANDFORMS OF THE DESERT

The landforms encountered in Joshua Tree National Park are typical of those found in the arid portions of the southwestern United States:

1. arroyos, or dry washes—deep, flat-floored stream courses that contain water only a few hours or perhaps a few days each year;
2. playas—lakes that may contain water a few weeks a year during the rainy season;
3. alluvial fans—fan-shaped deposits of sediment formed at the base of mountains in arid regions;
4. bajadas—broad sloping aprons of rock debris that form by the coalescing of several alluvial fans;
5. pediments—gently sloping bedrock surfaces that are erosional surfaces carved along the base of desert mountains.

Photo 9. Skull Rock at Jumbo Rocks campground illustrates cavernous weathering and undercutting by subsoil notching. Photo by D.D. Trent.
Pediments are a curious desert landform typical of the southwestern United States and many other desert regions. Superficially, pediments look like bajadas (depositional features) rather than products of the bedrock erosion. The slopes of pediments are slight, from 1/2 to about 6 degrees, and they are usually carved on homogeneous crystalline rock, such as granite. Pediments may be covered with a thin mantle of gravel, but if overlain by more than 10 feet of gravel cover, the resulting landform is considered depositional and is called a bajada. In order to determine whether a gently sloping desert surface is a pediment or a bajada, the observer must look at thickness of the gravel veneer, exposed along the drainage channels.

Apparently a pediment is formed by the retreat of a mountain front leaving an extensive planed bedrock surface that records the path of the retreating front. Rill wash, sheetfloods, winds, and lateral planation by streams tend to sweep the pediment clean of debris except for local accumulations of alluvium or gravel.

A pediment may be seen at Malapai Hill (Stop 7 on the Geology Tour Road).* Large expanses of bare granite pavement and bold dikes weathered out of the granite are exposed on the surface of the pediment (Photo 10).

Some investigators regard pediments as the only true desert landforms that can be attributed solely to arid conditions operating at present. Others regard pediments as features that have evolved in a sequential manner over a period of years. At issue are the relative roles of past and present processes in explaining the development of these arid region landforms.

The origin of pediments may be closely linked to the origin of another characteristic desert landform, inselbergs, prominent, steep-sided residual hills and mountains rising abruptly from erosional plains (Figures 3 and 4). Studies in Uganda conclude that inselbergs are residuals of deep chemical weathering during the more humid environments of the late Tertiary and Quaternary periods (Figure 3A). Inasmuch as subsurface weathering is more intense

---

**How arid region landforms differ from landforms in humid regions.**

1. The internal drainage basins in deserts provide base levels of erosion that may lie well above, or even below, sea level. In humid regions, however, the ocean surface provides the base level of erosion.

2. Base levels of erosion in most deserts, and clearly in the Mojave Desert, are constantly rising as the products of erosion accumulate within the internal basins; in humid regions, the ocean provides a relatively constant base level.

3. Products of erosion in humid regions are carried great distances, eventually to the ocean. But erosion products in the desert are carried only short distances resulting in the conspicuous accumulation of loose debris in the form of sand dunes, talus, alluvial fans, and bajadas.
in areas of closely spaced joints, but less so in areas of widely spaced joints, pediments form by the removal of the deeply weathered rock materials, leaving behind the sparsely jointed rock residuals as inselbergs.

The origin of inselbergs in Uganda is not totally applicable to the deserts of the southwestern United States where, unlike Uganda, tectonism has been active for millions of years and continues up to the present. Tectonism has created fault-block mountain ranges and down-dropped basins. The internal drainage of the basins results in the gradual filling of the basins with rock debris derived from the adjacent uplands, which cause a slow rise of local base levels. Stream erosion, accompanied by rising base levels, is important in forming pediments in the Mojave Desert (Figure 3B).

Climatic conditions during the late Tertiary and the Quaternary periods surely were significant in the development of pediments and inselbergs. The present climate of this region is relatively new, having been established during the Quaternary Period, which began only about 2 million years ago. Botanical evidence indicates that progressive deterioration of vegetative cover took place throughout the Mojave Desert during the Miocene and Pliocene epochs (from about 25 million to about 2 million ybp). The change in climate and the corresponding change in plant cover left increasing areas of surface unprotected by vegetation, which promoted accelerated denudation of the soil. Furthermore, the renewal of soil during the Quaternary was slowed by decreased rainfall causing the rate of soil erosion to exceed the rate of soil formation.

Eight million years ago, the landscape of the Mojave Desert was one of rolling hills covered with a soil mantle that had developed in a hot, semi-arid to humid climate. At that time, the rates of soil formation and soil erosion were closely balanced. The climate and the vegetative cover then were similar to that existing today along Interstate Highway 15 between Temecula and Escondido, California. Increased erosion removed the residual soils from the steeper hillsides leaving behind the subangular and spheroidal boulders that formerly had been the subsurface corestones that had been isolated by chemical decomposition along joint planes. Good examples of these corestone features, called "boulder-mantled slopes," may be seen along the road between the northwest entrance to Joshua Tree National Park and Hidden Valley campground (Photo 11).

 Eventually, the boulder mantles crumble into grus leaving only the inselbergs that form the spectacular prominences at Hidden Valley, Cap

![Figure 3. Two hypotheses of pediment and inselberg development. A. Pediment and inselberg development in Uganda (after Ollier, 1975): 1) Subsurface jointing in the original substrate. (2-4) Deep and complete weathering of the rock with closely spaced joints, but unconsumed rectangular blocks in regions of widely spaced joints. 5) Removal of weathered rock leaves pediments and inselberg remnants. B. Pediment and inselberg development in the southwestern United States resulting from a combination of deep weathering of horst upland, stream erosion, and rising base levels in the adjacent down-faulted basins. After Garner, 1974; Bradshaw and others, 1978).](image)

![Photo 11. Boulder mantled slopes along the road between the town of Joshua Tree and Hidden Valley. Photo by D.D. Trent.](image)
The presence of these masses of undecomposed rock is evidence that the renewal of boulder mantles by present-day weathering processes is not taking place. Thus, the granitic landscape of Joshua Tree National Park, and elsewhere in the Mojave Desert, may be thought of as a fossil (relict) landscape that has evolved over a time span of several million years.

Evidence for this interpretation comes from sites in the Mojave Desert such as at Old Woman Springs, about 43 miles northwest of Twenty-nine Palms, where reddish iron oxide and calcite-rich soils, and corestones in a grus matrix have been preserved beneath remnants of a basalt lava flow. The lava flow at Old Woman Springs yields a radiometric age of 8 million years. Similar soils are forming today but in warm regions under the cover of heavy brush where the average rainfall exceeds 10 inches annually. Continuity between these relict soils, corestones, and grus beneath the basalt remnants, and the present-day boulder-mantled slopes in the park, establishes the boulder mantles as features inherited from a time of deep subsurface chemical weathering in the late Tertiary Period (Figure 5).

The Final Polish

Nearly all of the rock surfaces in the region of the park show some degree of desert varnish, a thin patina of insoluble clay, plus iron and manganese oxides. In some cases the surface impregnation of varnish is deep enough into the partially decomposed rock that it binds the material together and produces a dark-brown, metallic-looking rind called "case hardening." The Proterozoic gneiss and the monzogranite cropping out at Indian Cove and along the Fortynine Palms Oasis Trail reveal especially good examples of desert varnish.

Varnish is not unique to the desert, but it is best revealed there. Varnish forms today wherever water seeps into rock surfaces. In humid regions, it forms in tunnels and along railroad cuts; in the southwest, it forms where there are seeps along canyon walls. Apparently water is needed to transport the iron and manganese onto rock surfaces. The principal hypotheses for the origin of desert varnish are 1) a microbial origin in which bacteria concentrate iron and manganese oxides, and 2) an inorganic origin in which clay and iron and manganese oxides that are derived from airborne dust and other sources form thin layers on rock surfaces. Regardless of the mechanism of formation, the varnish formed long ago when the climate was different from that of today. Abundant archeological evidence from the Old World and the southwestern United States (Photo 12) indicates that varnish on today's dry surfaces must have been deposited more than 2,000 years ago. Examination of the pyramids and other stone mountains in Egypt indicates that...
there has been essentially no deposition of desert varnish for the last 2,000 years, some deposition in the last 5,000 years, but considerable deposition on even older stoneworks.

Figure 5. Diagrammatic sketch of geologic relationships at Old Woman Springs. After Oberlander, 1972.

D.D. "Dee" Trent

Now semi-retired, Dee taught geology for 28 years at Citrus Community College in Glendora, California. Along the way he worked with the National Park Service, earned a Ph.D. at the University of Arizona, did field research on glaciers in Alaska and California, and mapped in the deserts of California and Arizona. He is co-author of Geology and the Environment, a college textbook; writes a regular column "Have You Read...?" in the Journal of Geoscience Education; and appears in the PBS telecourse, The Earth Revealed.
REFERENCES


Trent, D.D., 1984, Geology of the Joshua Tree National Monument, Riverside and San Bernardino counties: CALIFORNIA GEOLOGY, v. 37, no. 4, p. 75-86.


CLARENCE A. HALL IS AWARDED 1998 DIBBLEE MEDAL

Clarence A. Hall, professor and dean emeritus at the University of California, Los Angeles, has received the 1998 Dibblee Medal for 1998.

Hall produced more than a dozen quadrangle maps in the west central Coast Ranges and the White-Inyo Mountains of California. He also mapped along the North Pyrenean Fault in southern France. Hall’s careful mapping and synthesis of complex country in coastal California from the Monterey Bay region to the Transverse Ranges resulted in landmark papers supporting large-scale strike slip on some of California’s major faults and enabled identification of the southern California allochthon.

The Dibblee Medal honors the extraordinary geologic mapping achievements of Tom Dibblee, and underscores the importance of geologic mapping to help solve complex geological problems.

For more information about the Thomas W. Dibblee Geologic Foundation, visit the web site at http://dibblee.geol.ucsb.edu/
Mines in Joshua Tree National Park

D.D. TRENT, Professor Emeritus, Citrus College, Glendora, California

The lost Horse Mine was discovered in 1893 by four men, George Lang, John Lang, Ed Holland and James Fife. Development began early in 1894 when rich ore was hand cobbled from rich ore-shoots on the Lost Horse vein. Rich outcroppings and float of this gold ore were also found, some of this rich ore was sold as "jewelry gold" or specimen gold (Fife and Fife, 1982). The high-grade milling ore was sent to the small mill at Pinyon Wells, southwest of Pleasant Valley in Joshua Tree National Park. The richest known specimen of float found near the mine was picked up by Jim Fife. It was a mass of gold the size of a man's fist; the grade was estimated to be 4,000 ounces per ton (Fife and Fife, 1982). Pieces of this gold-quartz nugget are still in the family. Some of the purest portions of this nugget were carved out and made into a wedding band for Jim Fife's wife (Fife and Fife, 1982).

Sites of other mining activity in the park may be observed by hiking the Winona Mill trail that starts at loop A in the campground at Cottonwood Spring. One half mile along the trail are the remains of the Winona (or Cottonwood Spring) Mill. The concrete foundations that remain supported the mill's jaw crusher, ball mill, classifier, concentrator, and flotation tanks. The mill was here because of an assured supply of water, this being one of only two springs between Mecca and Dale; water is a critical element in milling ore. The concentrate from this mill was produced from the ore of the Mastodon Mine and from some of the smaller mines in the Hexie Mountains (Moore, date unknown).

Along the trail for another mile is the site of the Mastodon Mine. The mine was active from 1919 to 1932. Little of the mine remains today, but the reddish-brown, iron oxide-stained quartz vein, the inclined shaft, a few timbers and fragments of mining machinery clearly mark the site.

About one-half mile south of Cottonwood Spring, along Cottonwood Canyon, a trail leads to the site of Moorton's Mill. A five-stamp mill was built at this site by "Cactus" Slim Moorton, a prospector who frequented the area in the 1930s. His operation was abandoned in 1939 and little remains of his cabin and mill (Moore, date unknown).

REFERENCES


Moore, Terry A., date unknown, A day at Cottonwood Spring: Joshua Tree National Monument Trail guide, 8 p.

Tucker, W.B. and Sampson, R.J., 1945, Mineral resources of Riverside County: California Journal of Mines and Geology, v. 41, no. 3, p. 121-144.
Fire-blackened fan palms, Fortynine Palms Oasis, Joshua Tree National Park. © 1998, John Karachewski, Walnut Creek, California.