CALIFORNIA GEOLOGY

April 1984

CALIFORNIA DEPARTMENT OF CONSERVATION

GEOLOGY OF THE JOSHUA TREE NATIONAL MONUMENT

Riverside and San Bernardino Counties

By

D.D. TRENT, Geologist
Citrus College
Azusa, California

Reprinted with permission by the Joshua Tree Natural History Association, 1990.

GEOLOGY OF

THE JOSHUA TREE NATIONAL MONUMENT

Riverside and San Bernardino Counties

By

D.D. TRENT, Geologist
Citrus College
Azusa, California

> Go my sons, buy stout shoes, climb the mountains, search the valleys, the deserts, the sea shores, and the deep recesses of the earth...for in this way and in no other will you arrive at a knowledge of the nature and properties of things.
>
> *P. Severinus (Circa 1778)*

GEOGRAPHY

Location and Physiography

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

The Monument region is made up of several distinct mountain ranges, the Little San Bernardino Mountains in the southwestern part, the Cottonwood, Hexie, and Pinto Mountains in the center, and the Eagle and Coxcomb Mountains in the eastern part. Both the southern and northern margins of the Monument are marked by steep escarpments that rise abruptly from the lower desert areas. Much of the Monument lies at elevations above 4,000 feet.

Valleys lying between these mountain ranges are of two types, those that have been formed by downdropping along faults (*grabens* or *structural basins*), and those that have been carved by erosion. 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 Monument, is an example of the eroded type.

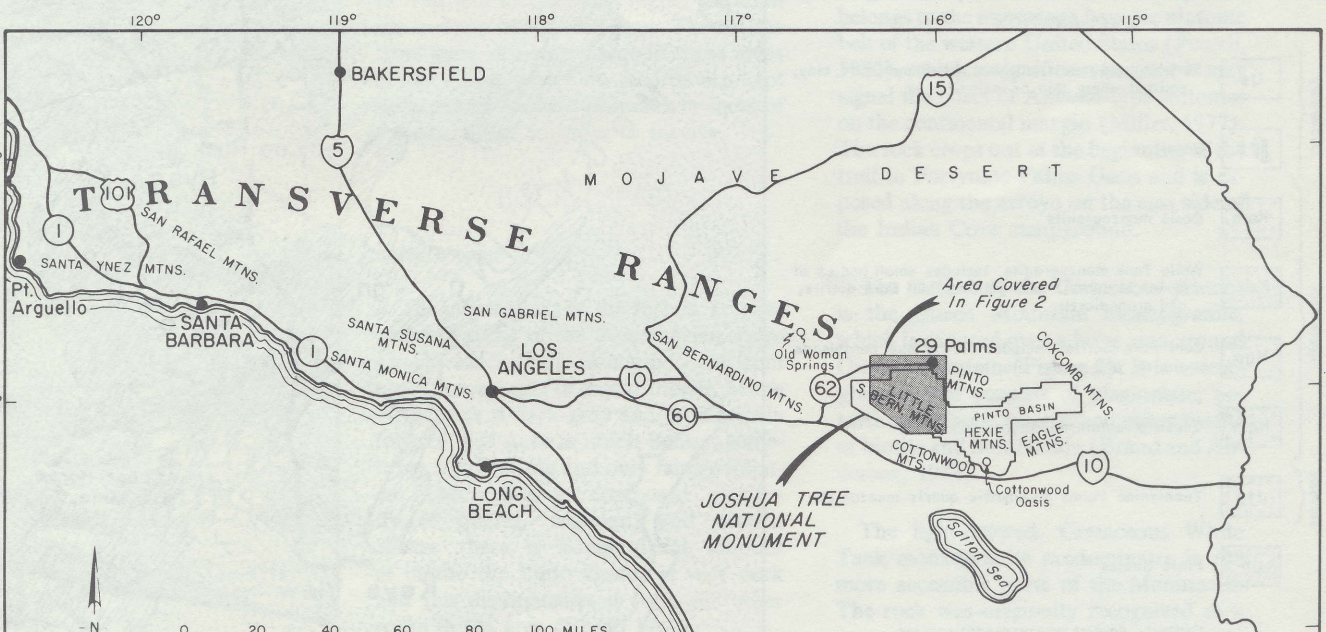
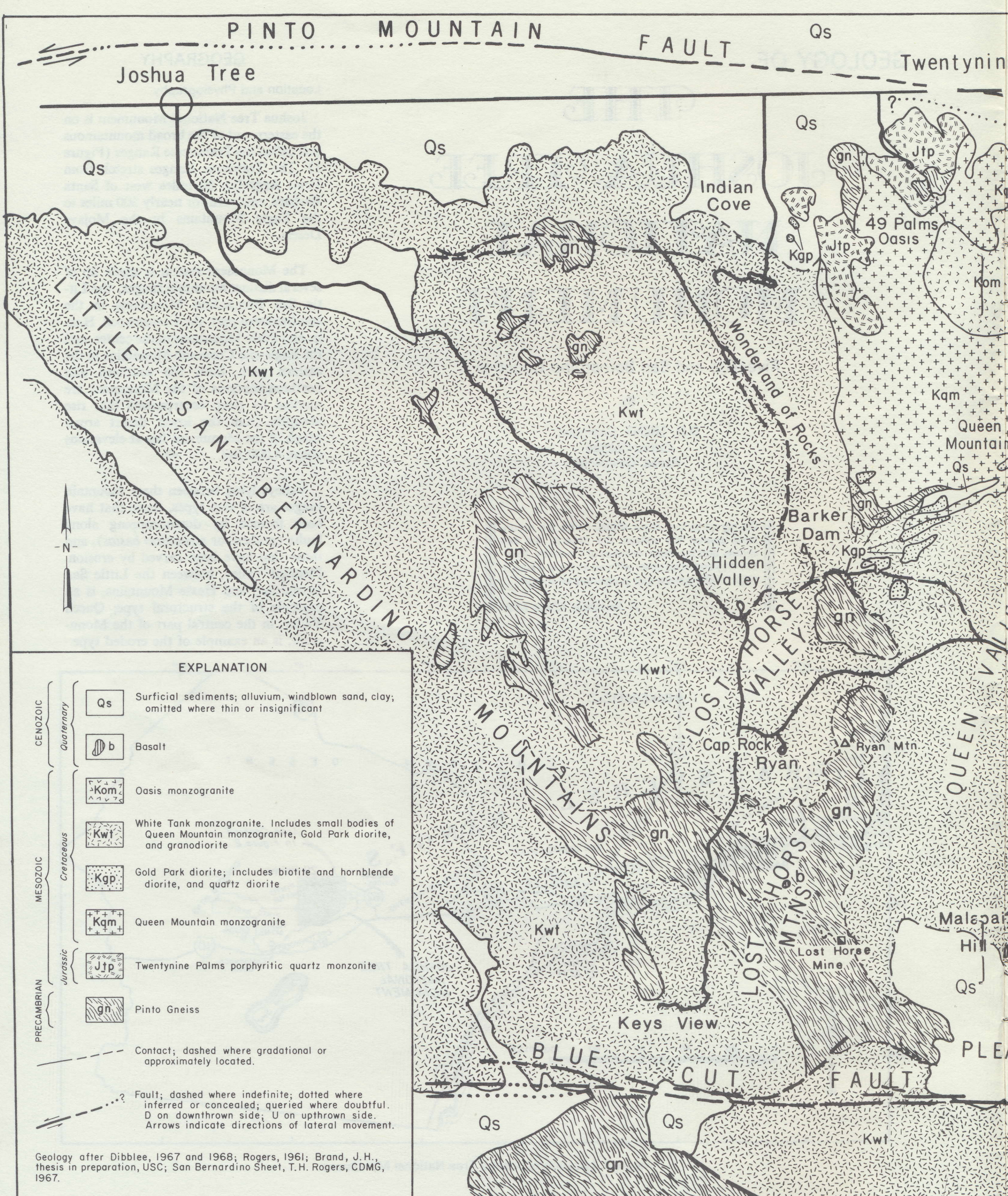
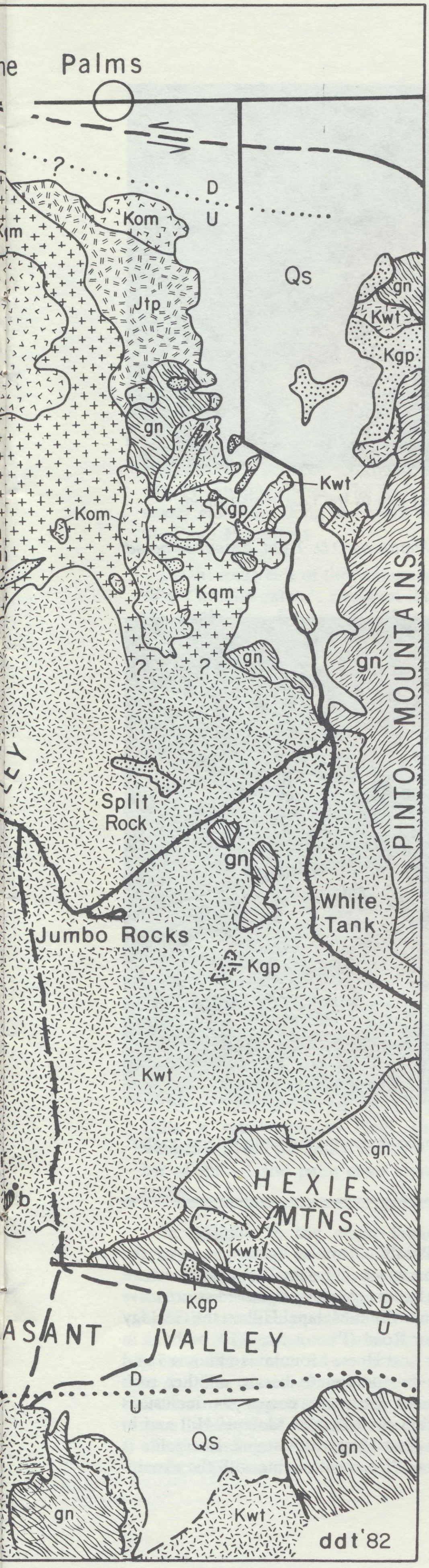


Figure 1. Location of Joshua Tree National Monument.



PINTO MOUNTAIN FAULT
Qs
Twentynin
Joshua Tree
Qs
Qs
Qs
Indian Cove
gn
Jtp
49 Palms Oasis
Kgp
Jtp
Kom
Kg
gn
gn
LITTLE SAN BERNARDINO MOUNTAINS
Kwt
Kwt
Wonderland of Rocks
Kqm
Queen Mountain
Qs
N
gn
Barker Dam
gn
Kgp
Hidden Valley
LOST HORSE VALLEY
gn
Kwt
QUEEN VAL
Cap Rock
Ryan
Ryan Mtn.
gn
gn
LOST HORSE MTNS.
b
Kwt
Lost Horse Mine
Malapai Hill
Qs
Keys View
BLUE CUT FAULT
PLEA
Qs
Qs
Kwt
gn
EXPLANATION
CENOZOIC
Quaternary
Qs
Surficial sediments; alluvium, windblown sand, clay; omitted where thin or insignificant
b
Basalt
MESOZOIC
Cretaceous
Kom
Oasis monzogranite
Kwt
White Tank monzogranite. Includes small bodies of Queen Mountain monzogranite, Gold Park diorite, and granodiorite
Kgp
Gold Park diorite; includes biotite and hornblende diorite, and quartz diorite
Kqm
Queen Mountain monzogranite
Jurassic
Jtp
Twentynine Palms porphyritic quartz monzonite
PRECAMBRIAN
gn
Pinto Gneiss
Contact; dashed where gradational or approximately located.
?
Fault; dashed where indefinite; dotted where inferred or concealed; queried where doubtful. D on downthrown side; U on upthrown side. Arrows indicate directions of lateral movement.
Geology after Dibblee, 1967 and 1968; Rogers, 1961; Brand, J.H., thesis in preparation, USC; San Bernardino Sheet, T.H. Rogers, CDMG, 1967.
0 1 2 3 4 MILES



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 2000 feet, is only 67.3°F (19.6°C), and at Hidden Valley Campground the average temperature is about 62°F (17°C). There are two factors causing 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 slips into the region across Arizona from the Gulf of Mexico bringing thunderstorms. For this reason August has the highest rainfall (Table 1) which, curiously enough, is usually the driest month for the more humid portions of the state.

In the winter months the Hawaiian High usually dissipates and southern California receives an average of four or five frontal storms that originate in the northern Pacific. At this time the second rainy season in the desert occurs in December and January (see Table 1). The average rainfall at Twentynine Palms is only a little over four inches but at higher elevation the average rainfall increases. The Joshua trees serve as a rain gauge in those areas of the desert where no records are kept because they require 10 inches or more of annual rainfall in order to survive.

ROCK TYPES

Metamorphic Rocks

The oldest rocks of the Joshua Tree region are those of the Precambrian *Pinto Gneiss* which range in composition from quartz monzonite to quartz diorite. Much of the rock is dark-gray and prominently foliated, but some is much lighter, sometimes nearly white and only faintly foliated. The gneiss is composed primarily of quartz, feldspar, and biotite. Where there is a significant amount of biotite the Pinto Gneiss is very dark and this distinguishes it from the other rocks in the area (Photo 1).

The Pinto Gneiss, which is exposed in much of the high desert of Joshua Tree National Monument, formed from the metamorphism of pre-existing sedimentary and igneous rocks. Radiometric dates give two ages of metamorphism, 1650 million years and 1400 million years (Powell, 1982, p. 120-121).

The Pinto Gneiss served as the host rock into which the younger plutonic rocks intruded. Examples of the intrusive contact can be seen along the trail to Fortynine Palms Oasis and northeast of Sheep Pass (Photo 2).

Igneous Rocks

At least four different major plutons have intruded the Pinto Gneiss (Figure 2). The oldest are Jurassic, and the youngest are Cretaceous. The exact dates of these Mesozoic intrusions, however, are poorly known. Isotopic ages of Jurassic plutons in California fall generally between 186 and 155 million years, and the ages of the Cretaceous plutons are mainly between 155 and 125 million years (Bateman, 1981). The Mesozoic plutons in Joshua Tree National Monument, in common with the granitic plutons of the Sierra Nevada, the Peninsular Ranges, the Klamath Mountains, and the White-Inyo Mountains, are generally believed to have originated in an Andean-type tectonic environment (Ernst, 1981).

The oldest pluton is the Twentynine Palms porphyritic quartz monzonite (Brand and Anderson, 1982). It consists of a matrix of small mineral grains which enclose large spectacular phenocrysts of potassium feldspar crystals that attain lengths of up to two inches. This pluton belongs to the important Jurassic plutonic belt of the western United States (Powell, 1982), which is significant because it may signal the onset of Andean-type tectonics on the continental margin (Miller, 1977). The rock crops out at the beginning of the trail to Fortynine Palms Oasis and is exposed along the arroyo on the east side of the Indian Cove campground.

The earliest of the Cretaceous plutons is the Queen Mountain monzogranite, which is exposed over a large area around Queen Mountain (Figure 2). It is coarse-grained, and consists of plagioclase, potassium feldspar, quartz, and either biotite or biotite and hornblende (Brand and Anderson, 1982).

The light-colored, Cretaceous White Tank monzogranite predominates in the more accessible parts of the Monument. The rock was originally recognized as a monzonite by Miller (1938), later as a quartz monzonite by Rogers (1954, 1961) and Dibblee (1968), but is now named a monzogranite (Brand and Anderson, 1982; Powell, 1982) in accordance with the modified version of Streckeisen's classification (1973) of igneous rocks. It resembles the Queen Mountain monzogranite but differs by being finer-grained, and by containing very small amounts of

Table 1. Twentynine Palms Oasis weather record. The averages were compiled from the 44-year record (1936 through 1979). *U.S. National Park Service, 1980.*

MONTH	AVERAGE MAXIMUM TEMP (F)	AVERAGE MINIMUM TEMP (F)	AVERAGE PRECIPITATION (inches)
JANUARY	61.7	34.7	.48
FEBRUARY	66.9	38.3	.27
MARCH	72.5	41.9	.28
APRIL	80.6	48.8	.11
MAY	89.7	56.6	.05
JUNE	98.8	64.2	.02
JULY	104.7	71.7	.59
AUGUST	102.8	70.3	.66
SEPTEMBER	96.8	63.4	.42
OCTOBER	84.7	52.9	.38
NOVEMBER	71.2	41.6	.31
DECEMBER	62.9	35.9	.47

These weather readings are taken at Twentynine Palms Oasis at an elevation of 1960 feet. At the higher elevations in Joshua Tree National Monument, temperatures will average approximately eleven degrees lower. Higher altitudes average about 3.5 inches more of precipitation annually.

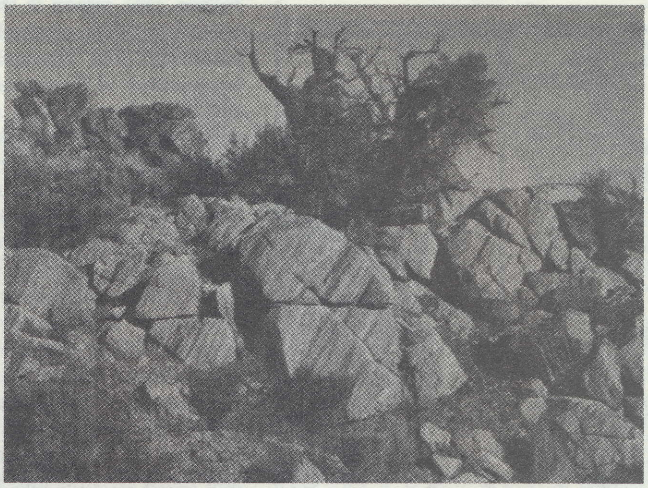


Photo 1. Pinto Gneiss on the trail to the Lost Horse Mine.

Photos by D.D. Trent, except as noted.

biotite and/or muscovite but no hornblende (Brand, personal communication). Areas underlain by the White Tank monzogranite include Indian Cove, the Wonderland of Rocks, Jumbo Rocks, White Tank, and Lost Horse Valley (Photo 3).

The youngest of the Cretaceous plutons, the Oasis monzogranite, is a distinctive garnet-muscovite-bearing pluton that is exposed in the area of Fortynine Palms Oasis (Brand and Anderson, 1982). The garnets are blood red and small, but large enough, nevertheless, to be visible without magnification. The muscovite grains impart a glittery appearance to the rock on sunny days, even in shadows.

In addition to large monzogranite and quartz monzonite plutons, there are masses of a similar granitic rock called *granodiorite,* and small dark plutons called the Gold Park diorite (Rogers, 1954, 1961; Brand and Anderson, 1982). Cutting across all of these rock masses, and thus being younger in age, are dikes of *felsite, aplite, pegmatite, andesite,* and *diorite* (Photo 4).

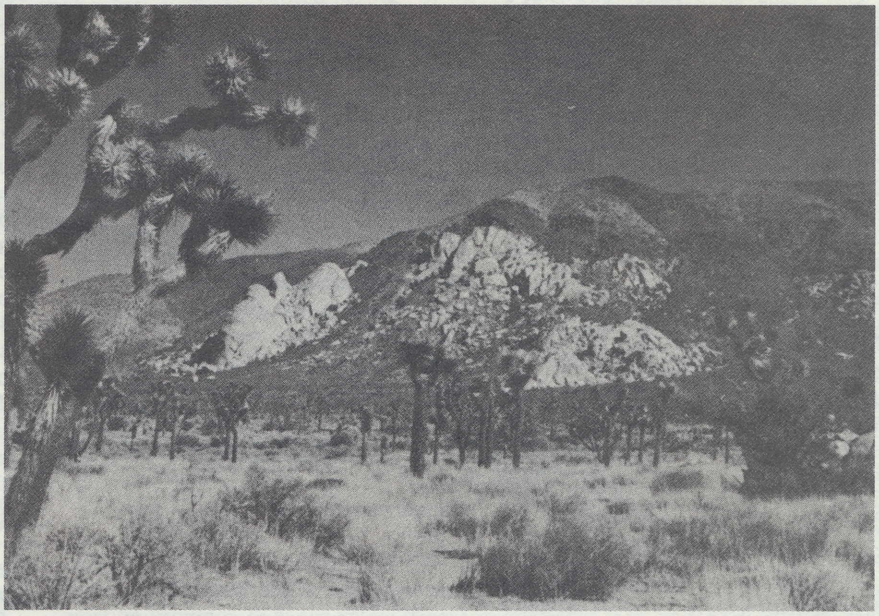


Photo 2. The contact between the White Tank monzogranite and the Pinto Gneiss on the east side of Lost Horse Valley.

Even younger than these dikes are veins of milky quartz which over the years have been prospected for gold. The quartz is sometimes stained reddish brown from the weathering of pyrite, or fools 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 rock and serve the prospector as a clue that gold, silver, copper, and other metals may be present.

The pegmatite dikes are mainly quartz and potassium feldspar and have a composition close to that of granite. What makes them distinctive is the very large size attained by the mineral grains, often three or four inches long. Pegmatites may have large books of biotite and muscovite mica (isinglass).

Basalt occurs at three places in the Monument: (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 (3) in the Lost Horse Mountains (Photos 7 and 8). In addition to basalt, another rock named *lherzolite* occurs as inclusions within the basalt at Malapai Hill and in the Lost Horse Mountains. Lherzolite is about 75 percent olivine with the remainder being mostly **bronzite** and **diopside**. It is considered to be derived from the mantle; thus the basalt has risen some 35 to 50 miles to carry the lherzolite inclusions to the surface.

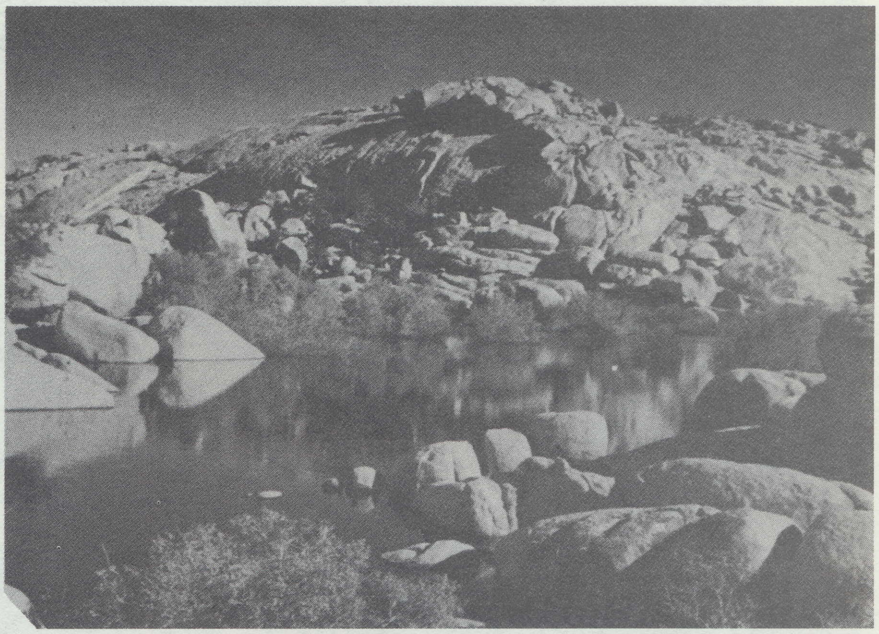


Photo 3. Rock sheeting in the White Tank monzogranite forming a dome-like landform at Barker Dam in the Wonderland of Rocks. *Photo by Walter R. Stephens.*

STRUCTURAL GEOLOGY

Faults

Uplifting and downdropping, and horizontal slipping of crustal blocks in the Joshua Tree region has occurred along fractures (faults) in the earth's crust. The *Pinto Mountain fault* is one of the most prominent. The topographic break marking the fault zone is closely followed by the Twentynine Palms Highway (State Highway 62) between Morongo Valley and Twentynine Palms. The fault trends nearly east-west along the north side of the Pinto Mountains.

On the south side of the Monument the *Blue Cut fault* extends east-west through the Little San Bernardino Mountains, about one-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 further south and trends southeastward through the Little San Bernardino Mountains. The Blue Cut and Pinto Mountain faults are both left-lateral faults. They may belong to a conjugate fault set that includes the north-northwest trending right-lateral faults of the Mojave Desert (Powell, 1982, p. 109). Pleasant Valley is a graben formed by the Blue Cut fault and one of its branches (Photo 9).

South of the Dillon and Blue Cut faults is the *San Andreas fault zone.* The trace of the San Andreas fault is clearly visible from Keys View (Photo 10). The San Andreas fault south of the Monument is divided into two main branches, the *Banning* and *Mission Creek faults.* The trace of these faults is marked by the Indio Hills, a small uplifted block that is wedged between the faults, and by a number of springs and palm oases along the faults.

In addition to the major faults are many hundreds of minor faults throughout the region. Fault zones are important factors in localizing springs. Movement by faults causes impervious zones of shattered rock fragments to form an underground dam, which forces ground water to rise. The oasis at Cottonwood Springs, for example, appears to be due to a fault zone which has provided the fissures along which ground water reaches the surface. The oasis at the Visitor Center at Twentynine Palms marks the Pinto Mountain fault.

Rock Jointing

Joints are simply small fissures cutting rocks. They may occur in *sets* of parallel joints and *systems* of two or more intersecting sets. The White Tank monzogranite has a system of joints that is primarily responsible for the spectacular landforms in the Monument. The joint system in the White Tank monzogranite consists of three dominant joint sets. One set oriented horizontally has been caused by the release of pressure due to the removal of overlying rocks by erosion. These joints, sometimes called *lift joints*, cause *rock sheeting* and are caused by expansion and the release of stress in rocks, somewhat analogous to a seat cushion resuming its shape after the person sitting on it arises. Lift joints form dome-like outcroppings where vertical joints are widely spaced (Photo 3).

Another set of joints is oriented vertically, and roughly parallels the contact of the White Tank monzogranite with its surrounding rocks. The third set is also vertical, but it is approximately perpendicular to the other vertical set. The resulting system of joints forms rectangular blocks. Especially good examples of the joint system are at Jumbo Rocks, Wonderland of Rocks, and Split Rock (Photos 4 and 11).

Joints are often closely spaced along fault zones, where either there may be no apparent order to their pattern, or the major joint set may closely parallel the orientation of the fault.

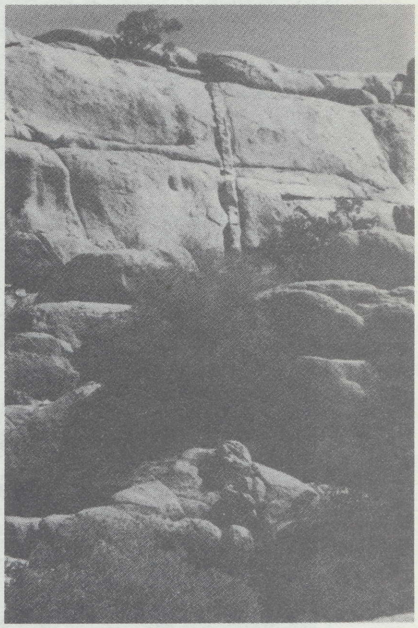


Photo 4. Aplite dike cutting White Tank monzogranite on the Barker Dam trail. The horizontal shelf-like development of the cliff is from thick slabs of monzogranite blocked out by rock sheeting.

Photo 5. Malapai Hill, an eroded endogenous volcanic dome, rises above the pediment of southern Queen Valley. The Hexie Mountains, behind Malapai Hill, reveal the contact between the Pinto Gneiss (dark rocks) and the White Tank monzogranite.

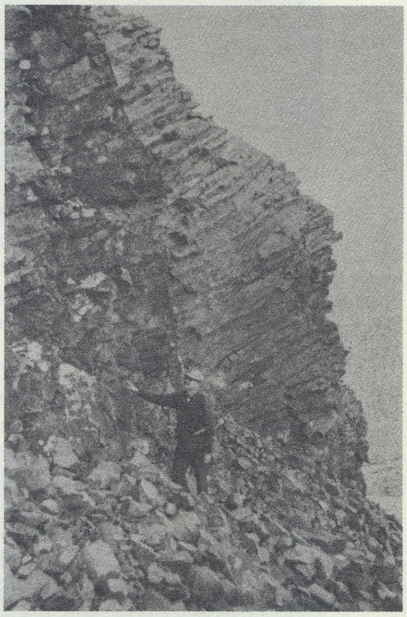


Photo 6. Columnar jointing in the basalt at Malapai Hill.

Photo 7. Columnar jointing in the endogenous volcanic dome in the Lost Horse Mountains. Columns are 10 to 12 inches in diameter. The white encrusting material has formed by "wicking" of water from the joints and evaporation leaving a thin coating of calcium carbonate. *Photo by Walter R. Stephens.*

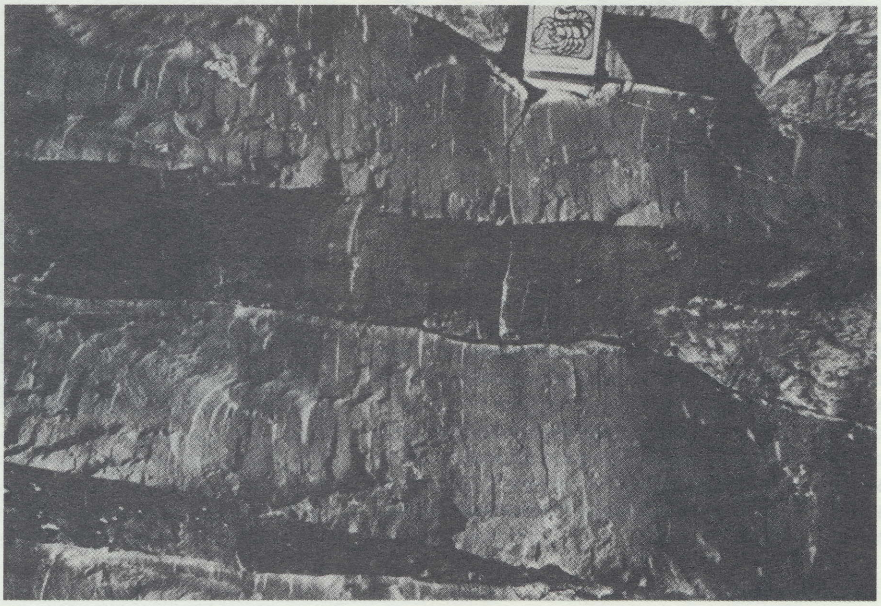


Photo 8. Detail of the sides of the basalt columns in the Lost Horse Mountains. The step-like pattern marks the incremental progress of the crack during the cooling of the basalt.

Photo 9. A branch of the Blue Cut fault forms the steep, straight, southern edge of the Hexie Mountains where they border the playa of Pleasant Valley on the Geology Tour Road.

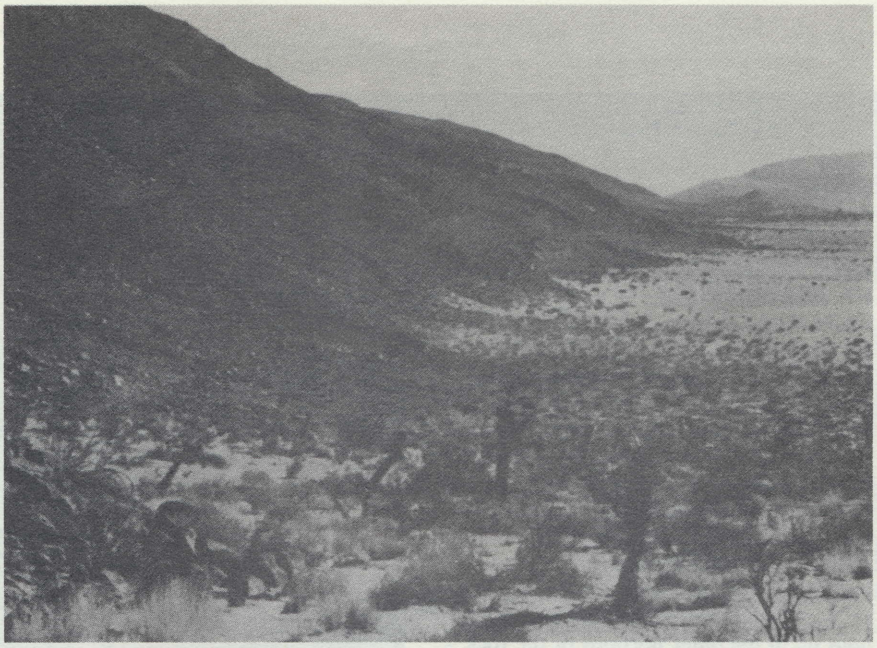
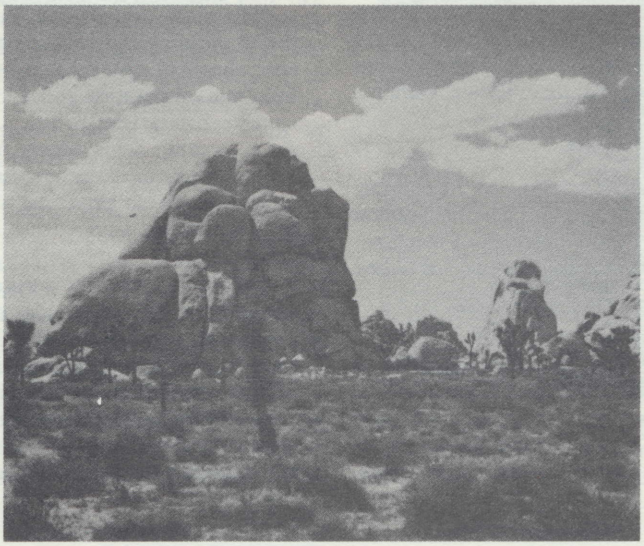


Photo 10. The northern end of the Salton Trough from Keys View. The high peak in the distance is Mt. San Jacinto, 10,786 feet (3287 m) elevation. Palm Springs and Cathedral City are at the base of the mountains. The Indio Hills, running from left to right in the middle distance, mark an uplifted block wedged between two branches of the San Andreas fault.

Photo 11. Inselbergs at Hidden Valley Campground display the joint system that is prevalent in the White Tank quartz monzogranite.



SCULPTURING THE LANDSCAPE

Weathering

One of the most impressive aspects of the landforms in the Joshua Tree region is the strange and picturesque shapes assumed by the bold granitic rock masses at the Wonderland of Rocks, Ryan Campground, Split Rock, and elsewhere in the area (Photos 11, 12). The sculpturing of these rock masses results from the combined action of rock jointing and *chemical* and *mechanical weathering.* The combination of these processes is called *spheroidal weathering,* the spalling-off of thin concentric shells of rock to 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 along joint surfaces. It is the chemical decomposition of the aluminum silicate minerals that is primarily responsible for these pressures. For example, when potassium feldspar comes into contact with hydrogen ions and water, the following chemical reaction takes place:

potassium feldspar + hydrogen ions + water → kaolinite + potassium ions + silica

$$2KAlSi_3O_8 + 2H^+ + H_2O \rightarrow Al_2Si_2O_5(OH)_4 + 2K^+ + 4SiO_2$$

The potassium ions and silica are dissolved in water and eventually carried away by surface runoff or by ground water, leaving behind the clay. The clay mineral that has been formed is called *kaolinite,* and it occupies a greater volume than the original feldspar. This increase in volume is responsible for the pressure that causes the outer part of the cuboidal blocks of rock to expand. The expansion is especially great at the edges and corners so that gradually the blocks of rock lose their sharp edges and eventually assume a rounded or spheroidal shape.

The stresses, in addition to the popping off of thin shells of rock, cause the mineral grains of the rock to disintegrate mechanically and form a loose mineral soil called *grus.*

Frost and *root wedging* contribute to the breakdown of rocks by mechanical action. When water seeping into cracks and joints in the winter months freezes, it expands by 10 percent and breaks the rocks.

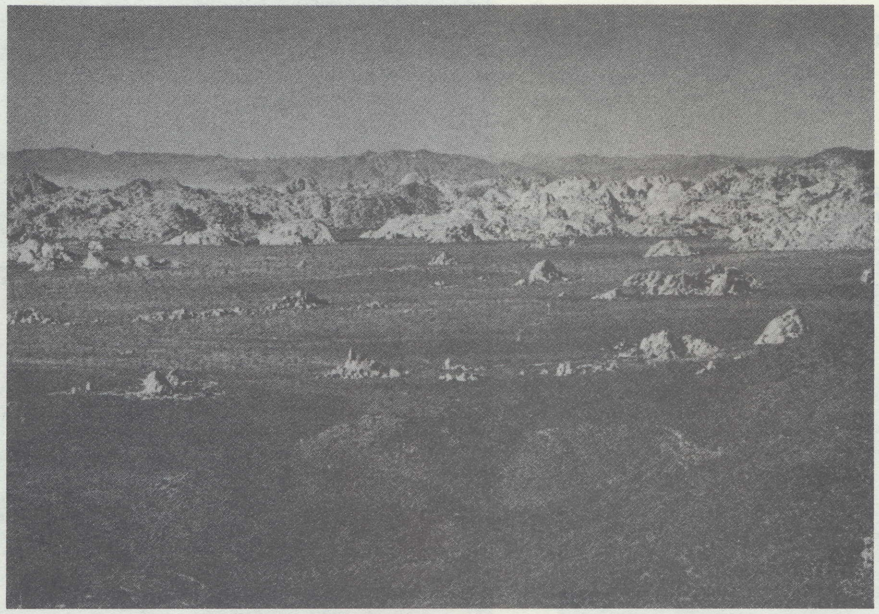


Photo 12. View of Lost Horse Valley from the Lost Horse Mountains. The flat surface is a pediment and the rocky knobs are inselbergs, remains of the corestones which were isolated in ages past by deep chemical weathering of the White Tank quartz monzogranite. The foreground hills are underlain by the dark Pinto Gneiss.

Plant roots, anchored in a hairline crack or a joint, will slowly expand and enlarge the crack as the plant grows.

The concave hollows and pits that are common on joint surfaces in crystalline rocks form by a process called *cavernous weathering.* This process begins with local irregularities or perhaps temporary accumulations of mineral fragments that hold water on the rock surface. The additional moisture locally promotes kaolinization of feldspars and other aluminum silicate minerals on the surface. Once a concavity begins to develop it perpetuates itself by ponding water from rainfall, melting snow, or even dew. Furthermore, the shade provided by the concavity assists chemical decay by reducing water loss from evaporation and also provides a suitable habitat for lichen. Lichen produces organic acids which furthers the process of chemical decomposition. Loose mineral grains so produced are removed by rainwash or wind.

The undercutting of vertical surfaces, common on the shady sides of rock outcroppings throughout the Monument, have formed in a similar manner to cavernous weathering by the action of moisture trapped in the soil at the base of the vertical surface. Such undercutting probably accounts for many of the steep cliff faces as the processes of wearing back and rounding off higher up on the cliff cannot keep up with the undercutting at the base.

Good examples of cavernous weathering and undercutting exist at many places in the Monument. Skull Rock is an example of undercutting and cavernous weathering (Photo 13).

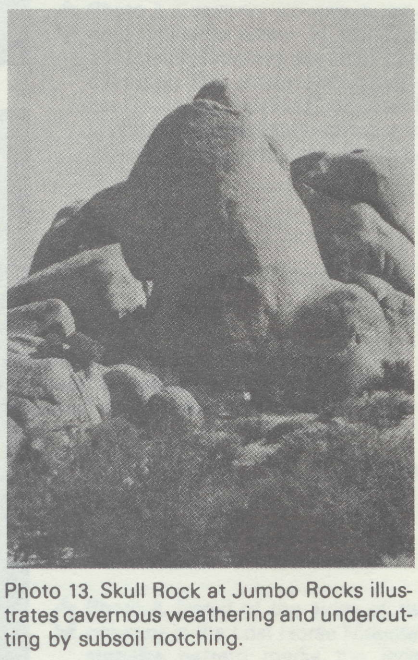


Photo 13. Skull Rock at Jumbo Rocks illustrates cavernous weathering and undercutting by subsoil notching.

Erosion

Erosion is the dynamic process that lifts up, carries away, and deposits 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 running water.

However, weathering and erosional processes presently operating in the arid conditions of the Joshua Tree region apparently are not entirely responsible for the spectacular sculpturing of the rocks of the region. 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 is dominantly a "fossil" landscape. For example, Forty-nine Palms Canyon could not have formed in the present rainfall regime. Such deep canyons are attributed to former pluvial conditions (Bradshaw and others, 1978, p. 305) during an epoch when the area of the southwestern United States received approximately eighty percent greater precipitation than at present, the evaporation was about thirty percent less, and the mean annual temperature was 5°-8°C cooler (Flint, 1971, p. 442-451).

LANDFORMS OF THE DESERT

There are major differences between the landforms in arid and in humid regions. This is because:

1. The internal basins in the desert 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 the Mojave Desert are constantly rising as the products of erosion accumulate in the internal basins, whereas for humid regions, the ocean provides a relatively constant base level.

3. Products from 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.

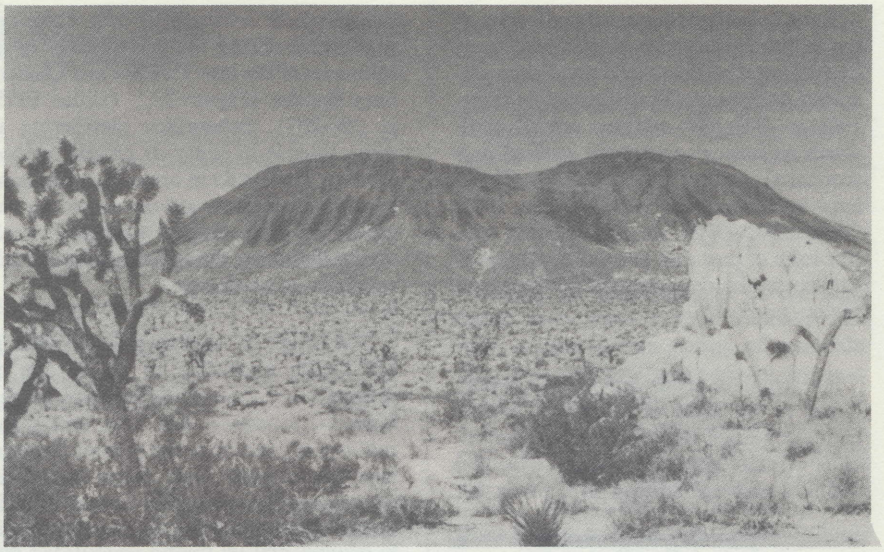


Photo 14. Pediment on the Geology Tour Road through Joshua Tree Monument. The pediment is eroded on the White Tank monzogranite. Malapai Hill is in the distance.

Typical arid landforms encountered in the high desert are:
(1) *arroyos* or dry washes, stream courses that contain water only a few hours or perhaps a few days per 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,* the broad sloping aprons of sediment that result from the coalescing of many alluvial fans;
(5) *pediments,* erosional features on gently sloping bedrock surfaces that have been carved along the base of desert mountains.

Pediments are a curious desert landform, typical of the southwestern United States and many other desert areas of the world. Superficially, pediments look like bajadas (depositional features) rather than products of erosion of bedrock. The slopes of pediments are slight, from ½° to about 6°, and they are usually carved on homogeneous crystalline rock such as granite. Pediments may be covered with a thin mantle of gravel, but if more than ten feet of gravel cover a pediment the resulting landform is considered depositional and is called a bajada. In order to determine whether the sloping surface is a pediment or a bajada the thickness of the gravel veneer in the drainage channels must be observed.

Apparently pediments are formed by the retreat of the mountain front leaving an extensive bedrock surface that marks the path of the retreating foot of the slope. Rill wash, sheetfloods, winds, and lateral planation by streams sweep the pediment clean of debris except for local accumulations of gravel.

A pediment can be seen at Malapai Hill (Stop 6 on the "Geology Tour Road" through the Monument*). Large expanses of bare granite pavement and bold dikes weathered out of the granite are exposed on the surface of the pediment (Photo 14 and 15).

*See road guide available at the Monument headquarters.

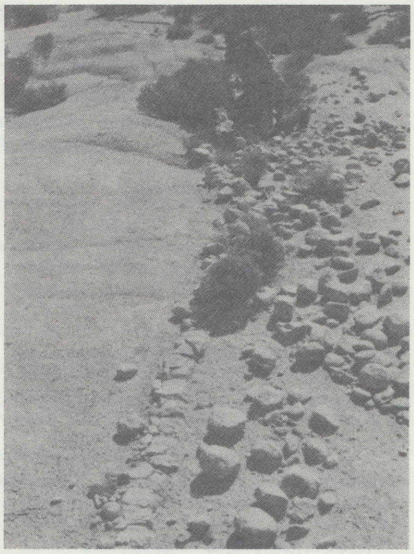


Photo 15. Remnants of an aplite dike exposed in monzogranite on the pediment near Malapai Hill.

Some investigators regard pediments as the only true desert landforms which can be attributed solely to arid conditions operative at present (Bradshaw and others, 1978, p. 307-308). Others regard pediments as features that have evolved in a sequential manner over a period of perhaps several million years (Ollier, 1975; Oberlander, 1972). 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 *inselbergs,* prominent steep-sided residual hills and mountains rising abruptly from erosional plains. Inselbergs studied in Uganda are thought to be residuals of deep chemical weathering during the more humid environments of the late Tertiary and Quaternary Epochs (Figure 3A) (Ollier 1975, p. 206-207). Subsurface weathering is more intense in areas of closely spaced jointing but less so in areas of wider joint spacing. Pediments are developed by removal of these deeply weathered rock materials leaving the sparsely jointed rock residuals as inselbergs.

The origin of inselbergs in Uganda is not totally applicable to the deserts of southwestern United States where, unlike Uganda, tectonism has been active for millions of years up to the present. Tectonism has created fault block mountain ranges and downdropped basins. The internal drainage of the basins causes the basins to fill gradually with sediments derived from the adjacent uplands. As a result the local base level of erosion slowly rises. Possibly stream erosion with rising local base levels is important in forming pediments in the Mojave Desert (Figure 3) (Garner, 1974; Bradshaw and others, 1978).

Climatic conditions during the late Tertiary and the Pleistocene must have been significant in the development of pediments and inselbergs. The present climate of this region is relatively new, having been established during the Pleistocene Epoch which began only about 2.5 to 3 million years ago. Botanical evidence indicates that progressive deterioration of vegetative cover took place throughout the Mojave Desert during the Miocene and Pliocene (from about 25 million to about 3 million years ago) (Axelrod, 1950; 1958).

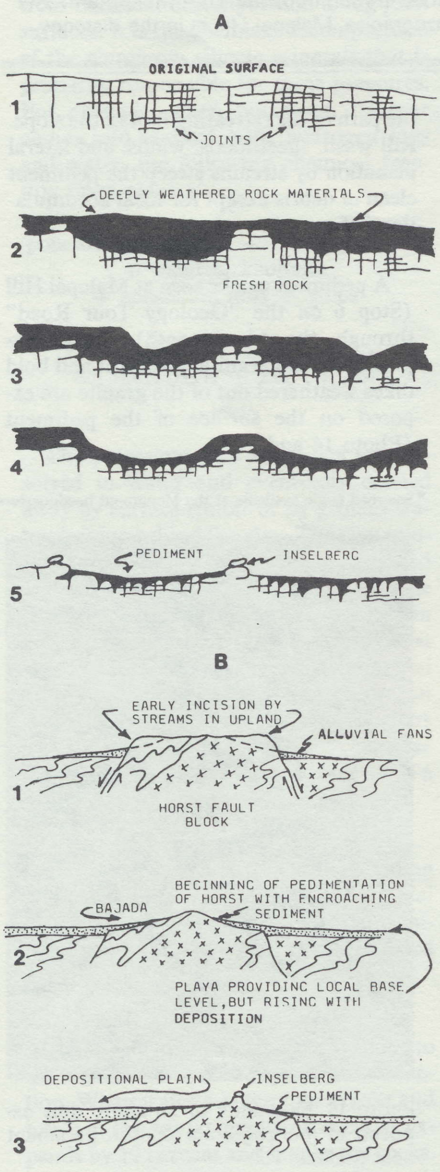


Figure 3. Two theories of pediment and inselberg development.

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 cuboidal 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 from a combination of deep weathering of a horst upland, stream erosion, and rising base level in the adjacent down-faulted basins (*after Garner, 1974, and Bradshaw and others, 1978*).

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 Pleistocene Epoch 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 amount of vegetative cover then were similar to that existing today along U.S. Highway 395 between Temecula and Escondido (Oberlander, 1972).

Increased erosion removed the residual soils from the steeper hillsides leaving behind the subangular and spheroidal boulders that formerly had been the subsurface corestones which had been isolated by chemical decomposition along joint planes (Figure 4). These corestone features, called *boulder mantled slopes* (Oberlander, 1972), can be seen along the road between the northwest entrance to Joshua Tree National Monument and Hidden Valley Campground (Photo 16).

The boulder mantles gradually crumble away in the present arid climate leaving inselbergs, the cores of relatively unweathered, sparsely jointed granite that form the spectacular prominences at Hidden Valley, Cap Rock, Jumbo Rocks, and along the Geology Tour Road (Photos 9 and 10). 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 in Joshua Tree National Monument, and elsewhere in the Mojave Desert, is a fossil landscape which has evolved over a time span of several million years (Figure 4).

Evidence for this interpretation comes from sites in the Mojave Desert such as at Old Woman Springs where reddish iron oxide and calcite-rich soils and corestones in a grus matrix have been preserved beneath remnants of lava flows. The lava flow at Old Woman Spring has a radiometric age of eight million years. Similar soils form today in warm regions under the cover of heavy brush where the average rainfall exceeds 10 inches annually.

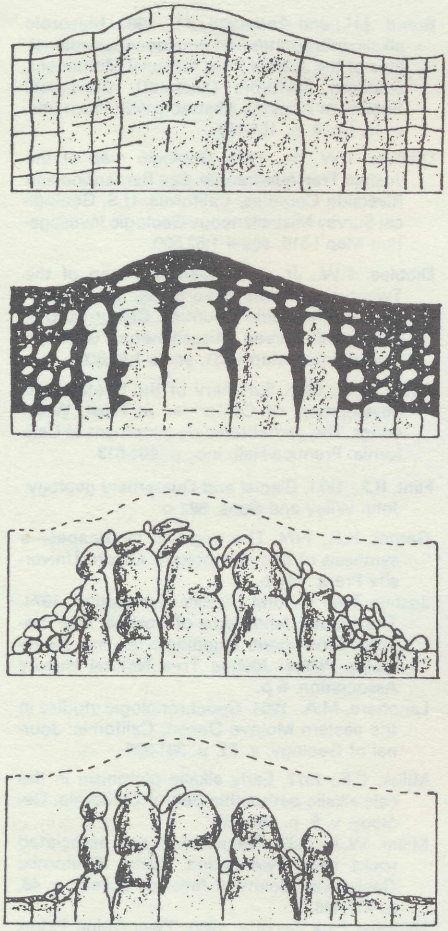


Figure 4. Schematic diagram illustrating the formation of inselbergs at Joshua Tree National Monument.

A. Vertical section through granitic rocks with a varied spacing of joints some 20 million years ago.

B. During the Pliocene after a period of sub-humid climate and decomposition of the rock by ground water that percolated downward along joints to the water table. Rotted and decomposed rock is shown in black.

C. Boulder-mantled slopes developed in the past few tens of thousands of years of the Pleistocene Epoch by the removal of the decomposed rock under arid conditions. Present day examples: along the Fortynine Palms Oasis trail and along the highway between the town of Joshua Tree and Hidden Valley Campground.

D. The present. In higher elevations with longer exposure to conditions of arid weathering, the boulder mantle has been largely decomposed leaving steep-sided bold outcrops rising abruptly above the surrounding surface. A thin veneer of grus covers the horizontal surface. Examples are at Hidden Valley, Caprock, Ryan Campground, and Jumbo Rocks.

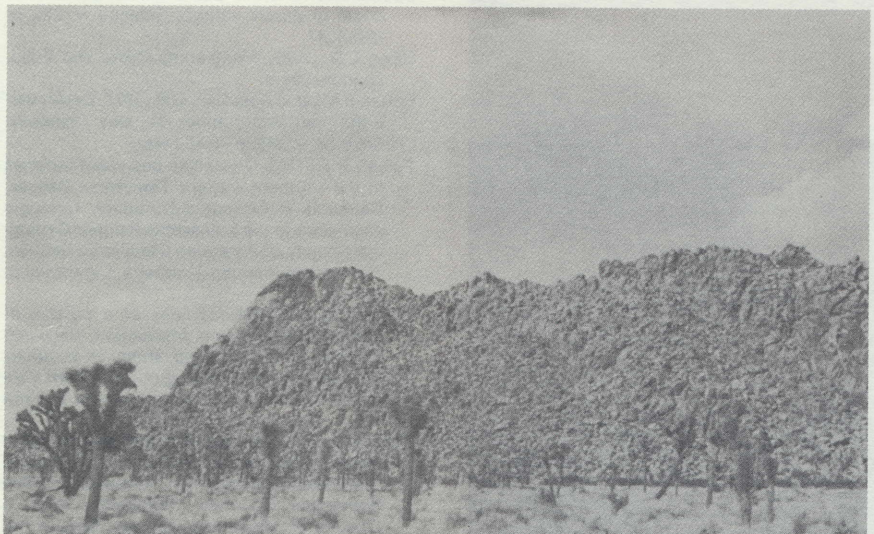


Photo 16. Boulder mantled slopes along the road between Joshua Tree City and Hidden Valley.

Continuity between these relict soils, corestones, and grus beneath the basalt remnants and the present boulder-mantled slopes clearly establishes the boulder mantle as a feature inherited from a time of deep weathering in the late Tertiary Period (Figure 5).

THE FINAL POLISH

Nearly all rock surfaces in the high desert show some degree of *desert varnish,* a usually thin patina of insoluble clay, iron, and manganese oxides. In some cases the surface impregnation of varnish is so deep into the partially decomposed rock that it binds the material together and produces a dark-brown, metallic-looking rind called *case hardening.* The Pinto Gneiss and the monzogranite which crops out at Indian Cove and along the Fortynine Palms Oasis trail have good examples of desert varnish (Photo 17).

Varnish is not unique to the desert, but is best revealed there. Two current hypotheses for the origin of desert varnish are: (1) a microbial origin in which bacteria concentrate manganese oxides (Oberlander and Dorn, 1981), and (2) an inorganic origin in which clay and iron and manganese oxides that are derived from air borne dust and other sources form thin layers on the rock surfaces (Potter and Rossman, 1977; Allen, 1978).

ACKNOWLEDGMENTS

My appreciation is extended to hundreds of students who over the years have accompanied me on field trips to Joshua Tree National Monument. Their comments and questions have sharpened my perception and improved my explanations. Thanks are due also to my field assistants, my wife Patricia, and Walter R. Stephens.

REFERENCES

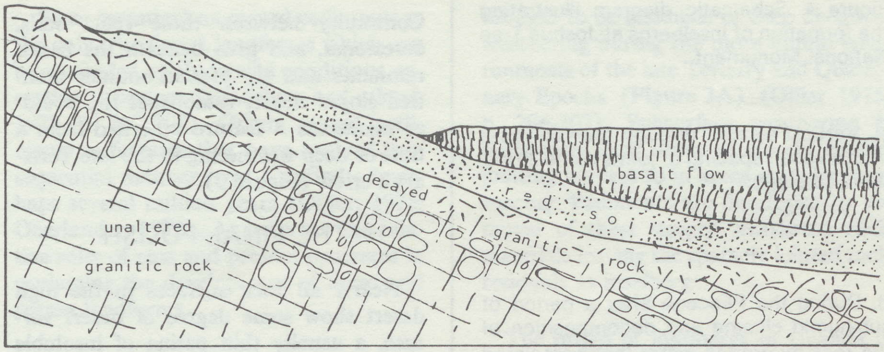
Allen, C.C., 1978, Desert varnish of the Sonoran Desert—optical and election probe micro analysis: Journal of Geology, v. 86, no. 6, p. 743-752.

Axelrod, D.I., 1950, Studies in late Tertiary paleobotany: Carnegie Institution of Washington, Publication 590, Washington, D.C., 323 p.

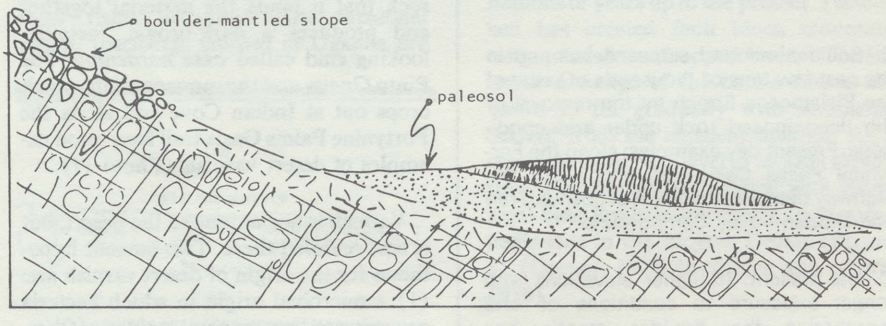
Axelrod, D.I., 1958, Evolution of the macro-Tertiary geoflora: Botanical Review, v. 24, no. 7, p. 433-509.

Bateman, P., 1981, Geologic and geophysical constraints on models for the origin of the Sierra Nevada batholith, California, *in* Ernst, W.G., editor, The geotectonic development of California: Prentice-Hall, Inc., p. 71-86.

Bradshaw, M.J., Abbott, A.J., and Gelthorpe, A.P., 1978, The Earth's changing surface: Halsted Press, John Wiley and Sons, 336 p.



A. Immediately after the Pliocene episode of volcanism about 8 million years ago.



B. Present conditions showing the paleosol (ancient soil) protected from erosion by the remnant of the 8 million-year old basalt flow, and the boulder-mantled slope of corestones that formed beneath the ancient soil.

Figure 5. Diagrammatic sketch of soil conditions at Old Woman Spring. *After Oberlander, 1972.*

Photo 17. Inselberg with desert varnish and old soil line (arrow) revealing geologically recent exhumation of the pediment by rejuvenation of drainage across the pediment. The inselberg is located on the nature trail at the west end of the Indian Cove Group Campground.

Brand, J.H., and Anderson, J.L., 1982, Mesozoic alkalic monzonites and peraluminous adamellites of the Joshua Tree National Monument, southern California (abstract): Geological Society of America Abstracts with Programs, v. 14, no. 4, p. 151-152.

Dibblee, T.W., Jr., 1967, Geologic map of the Joshua Tree quadrangle, San Bernardino and Riverside Counties, California: U.S. Geological Survey Miscellaneous Geologic Investigation Map I-516, scale 1:62,500.

Dibblee, T.W., Jr., 1968, Geologic map of the Twentynine Palms quadrangle, San Bernardino and Riverside Counties, California: U.S. Geological Survey Miscellaneous Geologic Investigation Map I-561, scale 1:62,500.

Ernst, W.G., 1981, Summary of the geotectonic development of California,, *in* Ernst, W.G., editor, The geotectonic development of California: Prentice-Hall, Inc., p. 601-613

Flint, R.F., 1971, Glacial and Quaternary geology: John Wiley and Sons, 892 p.

Garner, H.F., 1974, The origin of landscapes—a synthesis of geomorphology: Oxford University Press, 734 p.

Joshua Tree Natural History Association, 1974, The natural landscape of Joshua Tree National Monument, a geologic resume: Twentynine Palms, Joshua Tree Natural History Association, 8 p.

Lanphere, M.A., 1964, Geochronologic studies in the eastern Mojave Desert, California: Journal of Geology, v. 72, p. 381-399.

Miller, C.F., 1977, Early alkalic plutonism in the calc-alkalic batholithic belt of California: Geology, v. 5, p. 685-688.

Miller, W.J., 1938, Precambrian and associated rocks near Twentynine Palms, California: Geological Society of America Bulletin, v. 49, p. 417-446.

National Park Service, 1980, Twentynine Palms Weather, typed M.S., 1 p.

Oberlander, T.M., 1972, Morphogenesis of granitic boulder slopes in the Mojave Desert, California: Journal of Geology, v. 80, no. 1, p. 1-20.

Oberlander, T.M., and Dorn, R.I., 1981, Microbial origin of desert varnish: Science, v. 213, p. 1245-1247.

Ollier, C.D., 1975, Weathering: Oliver and Boyd, London, 384 p.

Potter, R.M., and Rossman, G.R., 1977, Desert varnish: the importance of clay minerals: Science, v. 196, p. 1446-1448.

Powell, R.E., 1982, Crystalline basement terranes in the southern eastern Transverse Ranges, California *in* Cooper, J.D., editor, Geologic excursions in the Transverse Ranges: Geological Society of American Cordilleran Section, 78th annual meeting, Anaheim, California, p. 109-136.

Rogers, J.J.W., 1954, Geology of a portion of Joshua Tree National Monument, Riverside County, California: Map Sheet 24 *in* Jahns, R.H., editor, 1954, Geology of Southern California: California Division of Mines, Bulletin 170.

Rogers, J.J.W., 1961, Igneous and metamorphic rocks of the western portion of the Joshua Tree National Monument, Riverside and San Bernardino Counties, California: California Division of Mines and Geology, Special Report 68, 26 p.

Small, R.J., 1972, The study of landforms: Cambridge University Press, 486 p.

Streckeisen, A.L., 1973, Classification and nomenclature recommended by the I.U.G.S. Subcommission on systematics: Geotimes, v. 18, p. 26-30.

$1.00

CALIFORNIA GEOLOGY

A PUBLICATION OF THE DEPARTMENT OF CONSERVATION DIVISION OF MINES AND GEOLOGY

State of California	GEORGE DEUKMEJIAN *Governor*
The Resources Agency	GORDON K. VAN VLECK *Secretary for Resources*
Department of Conservation	RANDALL M. WARD *Director*
Division of Mines & Geology	JAMES F. DAVIS *State Geologist*

CALIFORNIA GEOLOGY staff

Editor-in-Chief:	Mary C. Woods
Editor:	Don Dupras
Editorial Assistance:	Mary El-Bdour
Graphics and Design:	Louise Huckaby
Publications Supervisor:	Jeff Tambert

Divison Headquarters: 1416 Ninth Street, Room 1341, Sacramento, CA 95814 (Telephone: 916-445-1825)

Publications and Information Office: 660 Bercut Drive, Sacramento, CA 95814-0131 CALIFORNIA GEOLOGY: 916-445-0514; Public Information: 916-445-5716

Los Angeles Office: 107 South Broadway, Room 1065, Los Angeles, CA 90012-4402 (Telephone: 213-620-3560)

Pleasant Hill Office: 380 Civic Drive, Suite 100, Pleasant Hill, CA 94523-1921 (Telephone: 415-646-5920)

CALIFORNIA GEOLOGY (ISSN 0026 4555) is published monthly by the Department of Conservation, Division of Mines and Geology. The Records Office is at 1721-20th Street, Sacramento, CA 95814. Second class postage is paid at Sacramento, CA. Postmaster: Send address changes to CALIFORNIA GEOLOGY (USPS 350 840), Box 2980, Sacramento, CA 95812-2980.

Reports concerning Division of Mines and Geology projects and articles and news items related to the earth sciences in California are included in the magazine. Contributed articles, photographs, news items, and geological meeting announcements are welcome.

THE CONCLUSIONS AND OPINIONS EXPRESSED IN ARTICLES ARE SOLELY THOSE OF THE AUTHORS AND ARE NOT NECESSARILY ENDORSED BY THE DEPARTMENT OF CONSERVATION.

Correspondence should be addressed to Editor, CALIFORNIA GEOLOGY, 660 Bercut Drive, Sacramento, CA 95814 (916) 445-0514.

Subscriptions: $10.00 per year. Single copies: $1.00 each. Send subscription orders and change of address information to CALIFORNIA GEOLOGY, P.O. Box 2980, Sacramento, CA 95812-2980.

The Joshua Tree Natural History Association is a private, non-profit organization dedicated to supporting the historical, scientific, educational, and interpretive activities of Joshua Tree National Monument.

For membership information or to receive a mail order list, write to:

Joshua Tree Natural History Association
74485 National Monument Drive
Twentynine Palms, CA 92277