The Water Supply of El Morro National Monument

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Prepared in cooperation with the National Park Service

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This report was prepared in response to a request from the National Park Service for assistance from the U.S. Geological Survey in appraising possible sources of water supply for El Morro National Monument. The fieldwork was done intermittently from July 1959 to April 1, 1961. Mr. John Kell, Regional Chief of Lands, or Mr. Bill Fields, engineer, National Park Service, accompanied the senior author during the well tests. Mr. Irving McNeil, Jr., superintendent, El Morro National Monument, other members of his staff, and land owners in the area provided valuable information on wells in the vicinity of the monument.

The Pool by Inscription Rock

In the land of enchantment, between Gallup and Grants, N. Mex., near the Zuni Mountains, a huge sandstone bluff rises abruptly 200 feet above the plain. The Spaniards called it "El Morro," which means "the headland" or "bluff." Around it are other mesas and canyons and stands of piñon and ponderosa pine. Other great rocks are nearby, but none are as popular as El Morro, and none have been as important to the traveler.

For at El Morro there is water.

In that country, water is scarce and precious. In the old days, travelers from Santa Fe would tell each other about the pool of clear, refreshing water at the base of the huge rock. This is the story of the great bluff, its water supply, and the rocks around it.

In the late summer of 1849, an American lieutenant of the Topographical Engineers, James H. Simpson, accompanied infantry and artillery troops on a reconnaissance march from Santa Fe into the Navajo Country. On September 18, at the urging of one Mr. Lewis, an Indian trader, Lieutenant Simpson left the main party in order to see "half an acre of inscriptions" [1] upon a huge rock (fig. 1). Although somewhat dubious, the Lieutenant had allowed himself to be persuaded by Lewis that the trip was worthwhile. Taking with him an artist named R. H. Kern, another man by the name of Bird, and Mr. Lewis as guide, he set off through miles of desert country, filled with huge red and white sandstone rocks, "some of them looking like steamboats, and others presenting very much the appearance of façades of heavy Egyptian architecture." [2]

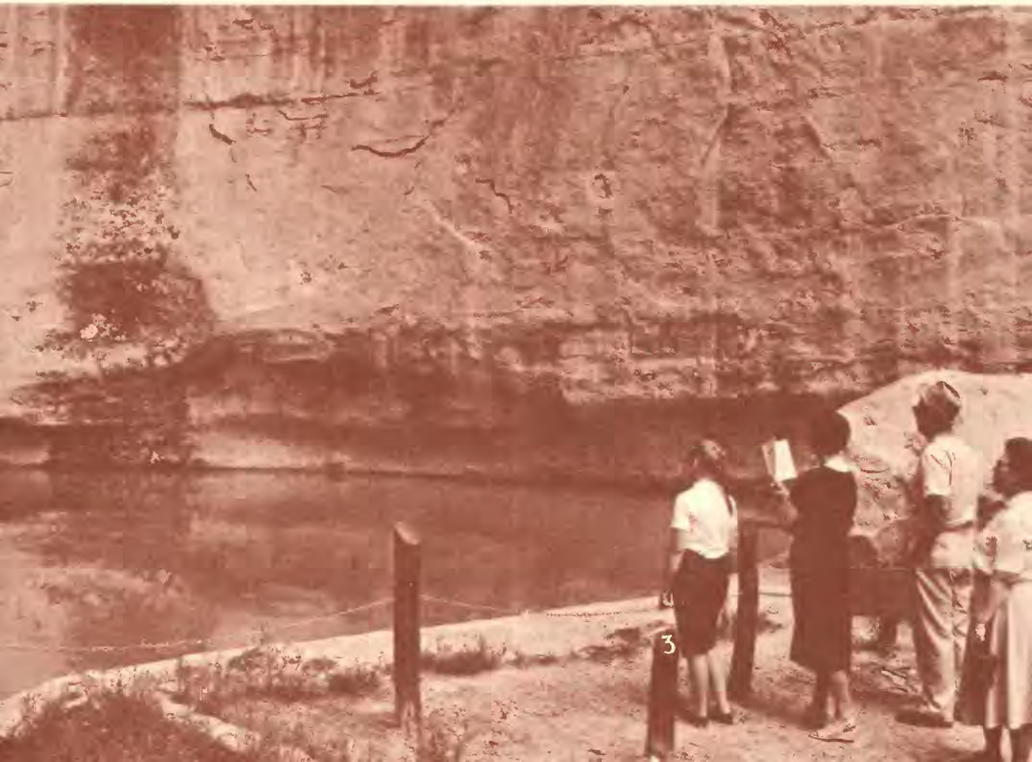
As they drew near the huge mass of rock, they dismounted and went up close. There were the inscriptions. "Perhaps not half an acre," wrote Lieutenant Simpson, cautiously. But there were enough to be an exciting find: "One of them dating as far back as 1606, all of them very ancient, and several of them very deeply as well as beautifully engraven." [3] Simpson tried to remain objective, but excitement and interest kept breaking through. He knew he had found something of enormous interest to historians and to Americans generally.

He and his friends decided to stay overnight, in order to copy the inscriptions. Simpson knew that without facsimiles their report might not be believed—just as he himself had been doubtful of Lewis' story.

[1] Simpson, 1852, p. 98. [2] Op. cit., p. 99.

[3] Simpson, 1852, p. 99. Some inscriptions date further back than 1606.

▼ *Figure 2. The pool at El Morro as it is today. National Park Service photograph, by Jack E. Boucher.*



◀ *Figure 1. Inscription Rock, El Morro National Monument, New Mexico.*

Looking for water and a place to camp, they rounded a corner of the rock and came upon the pool, "canopied by some magnificent rocks, and shaded by a few pine trees, the whole forming an exquisite picture." [4] Kern has left us a charming sketch of it. This lonely little scene had the wild and primitive beauty which Europeans looked for in the novels of Fenimore Cooper, and which Americans were learning to love and recognize as their own.

Lieutenant Simpson thought the water came from springs, but actually the pool is fed by rains and melted snow. After improvements, it is 12 feet deep when it is full, and holds about 200,000 gallons of water (fig. 2).

Lieutenant Simpson was the first American official to visit El Morro. Although it is a military report, his account is delightful to read, full of personal touches and expressions of a sense of beauty and wonder not characteristic of official reports. With Bird and Kern, he copied all the inscriptions they could find, carefully noting that there was not a single inscription in English upon the rock. Then they too left their names inscribed on the rock (fig. 3), and set off to rejoin the troops and tell the story of their discovery.

[4] Simpson, 1852, p. 100.

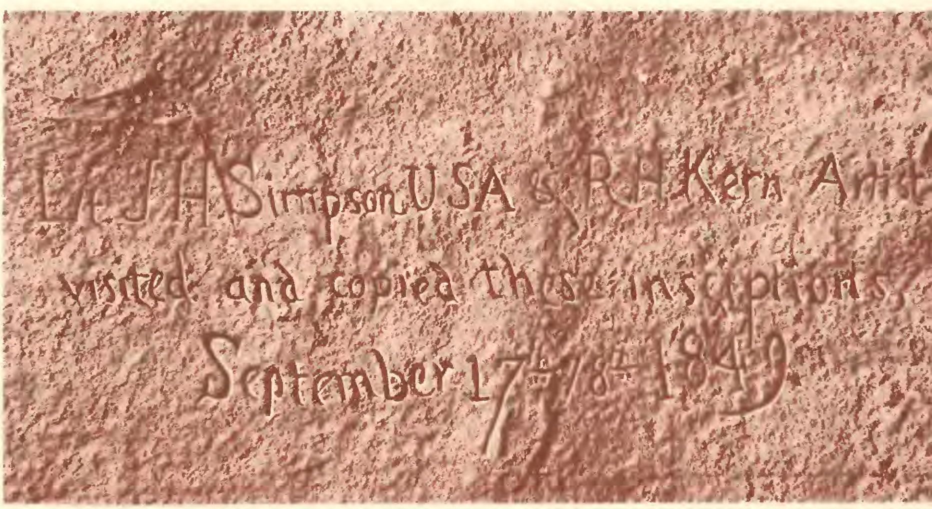


Figure 3. Facsimile of Simpson-Kern inscription.

From that day to this, Americans have been visiting El Morro. A few years after Simpson's visit to El Morro, a Captain Sitgreaves passed by the rock on an expedition down the Zuni River. It is briefly mentioned by his surgeon, Dr. Woodhouse, in a description of the natural history of the region.[5]

In 1858 Edward F. Beale, in the course of a survey of the wagon road from Fort Defiance to the Colorado River, stopped briefly at the rock:

When at 9 a.m., we reached Inscription Rock, I was tired of exclaiming, as every hundred yards opened up some new valley, "how beautiful." The rock itself seems to be a centre from which radiates valleys in all directions, and of marvelous beauty. It rises grandly from the valley, and the tall pines growing at its base give out long before they reach the top of its precipitous face. Inscriptions, names and hieroglyphics cover the base, and among the names are those of the adventurous and brave Spaniards who first penetrated and explored this country * * * the rock is some three or four hundred feet in height, and the spring almost hidden in the cavity of it * * * [6]

Beale's trip was especially interesting, because he commanded a caravan of camels that were imported as an experiment in transportation for the arid Southwest. However, the railway train soon made its appearance and put an end to camel trains.

Long before the Spaniards arrived, the Zuni Indians had constructed a village on top of the headland, and carved a path on the face of the cliff between the village and the waterhole. Ruins of this village, fragments of pottery, and interesting carvings on the face of the cliff gave one a glimpse into the lives of these prehistoric inhabitants (fig. 4).

For nearly 200 years, El Morro was the principal watering-point for Spanish travelers between the villages of Acoma and Zuni. Here they found shelter from the sun and from storms, and at the pool, fresh water for their horses, and for their own needs.

The first written record of El Morro dates from 1583. A Spanish visitor, Diego Perez de Luxan, mentions in his journal, "El estanque del penol,"—"The Pool by the Great Rock." [7]

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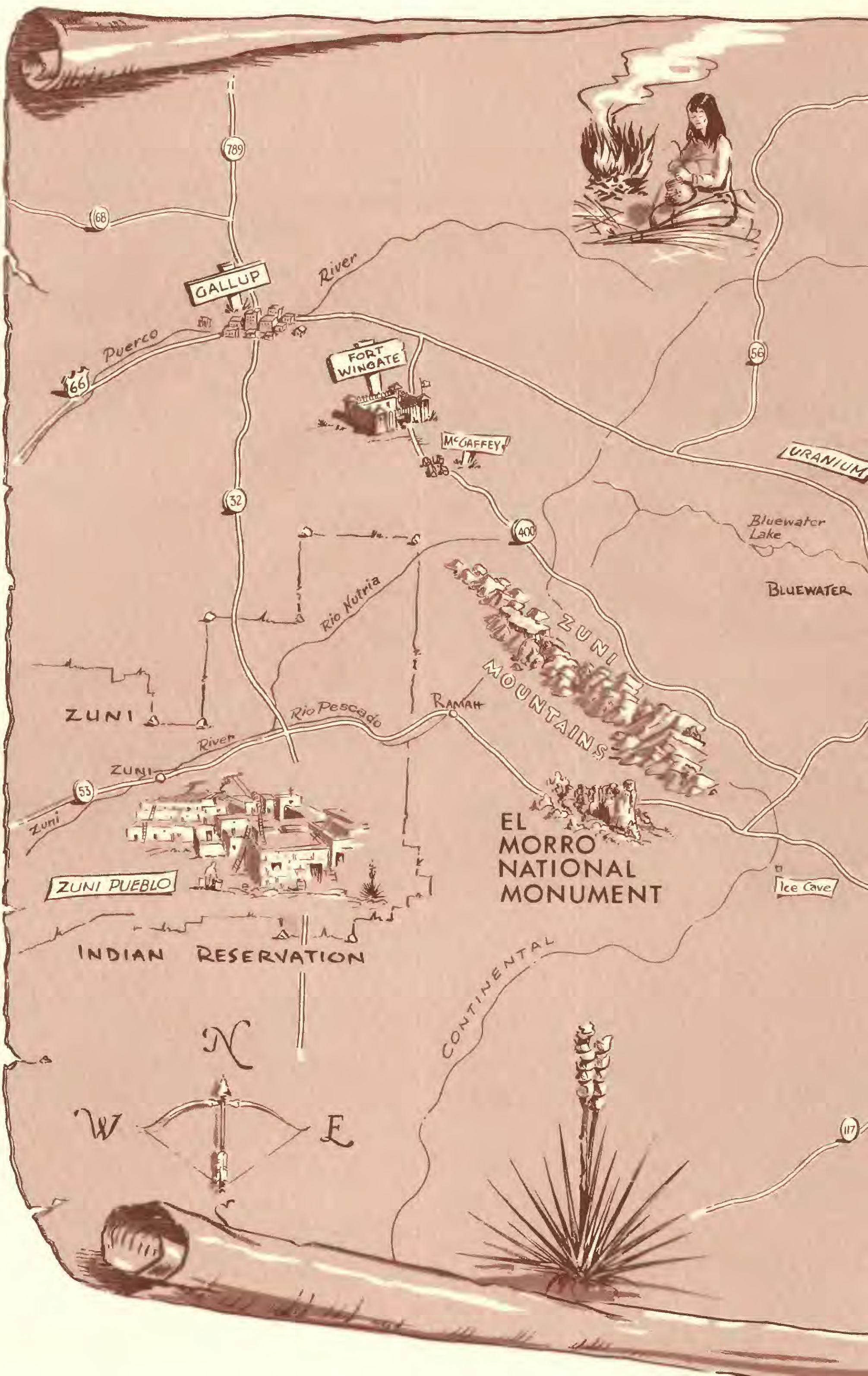
[5] Sitgreaves, 1853, p. 35.
[6] Beale, 1858, p. 85.
[7] El Morro National Monument: U.S. Dept. Interior Pamphlet.

The earliest inscription by the Spaniards was that of Don Juan de Oñate in April, 1605, who wrote, "Pasó por aquí el Adelantado Don Juan de Oñate del descubrimiento de la mar del sur a 16 de Abril de 1605." [8] (Passed by here the Governor Don

Figure 4. Prehistoric Indian village on top of Inscription Rock.

Juan de Oñate, from the discovery of the Sea of the South, on April 16, 1605). It is impressive to think that Oñate's name was inscribed on the rock 15 years before the pilgrims landed at Plymouth! We do not know whether other explorers preceded him and left no record inscribed on the rock. Many other Spanish travelers who visited the waterhole between Oñate's visit in 1605 and the last recorded Spanish visit in 1774, left inscriptions on the sandstone cliff.

[8] El Morro Trails: Southwestern Monuments Association, Globe, Ariz., p. 4–5.



789
68
GALLUP
River
Puerco
66
FORT WINGATE
56
McGAFFEY
URANIUM
32
400
Bluewater Lake
BLUEWATER
Rio Nutria
ZUNI MOUNTAINS
ZUNI
RAMAH
Rio Pescado
River
ZUNI
53
Zuni
EL MORRO NATIONAL MONUMENT
ZUNI PUEBLO
Ice Cave
INDIAN RESERVATION
CONTINENTAL
N
W
E
117

DIVIDE
Area of this map
SAN JUAN
RIO ARRIBA
McKINLEY
SANDOVAL
SANTA FE
El Morro
Albuquerque
VALENCIA
NEW MEXICO
Rio Grande
Carlsbad
LOCATION MAP
AMBROSIA LAKE
53
GRANTS
SAN RAFAEL
66
Rio San Jose
LAGUNA
LAGUNA PUEBLO
18 MILES TO ALBUQUERQUE
Puerco
Rio
6
53
ACOMA
0
10
20
Miles

Because fresh water was so important to all travelers in this area, the trail past El Morro became the principal road across the region. Names of wagon-train emigrants, traders, Indian agents, soldiers, surveyors and settlers, were inscribed on the rock in the years following 1850 (fig. 5).

After the transcontinental railroad and U.S. Highway 66 were constructed 25 miles to the north, the road by the watering place lost its prominence and became little used for a time. Improvement of the road past El Morro (State Highway 53) was begun in 1955, and by 1962 construction was almost complete.

El Morro National Monument was established by Presidential proclamation in 1906 to preserve the rock carvings and the pool of water that had contributed so much to the exploration and development of the Southwest. There were always some visitors to the monument, but after the improvement of the road, they began to come in greater numbers. In 1961, nearly 20,000 tourists visited El Morro. Ironically, the pool of fresh water that gave prominence to El Morro for 300 years is now inadequate to supply the large numbers of visitors, tourists, and the monument staff. Eventually, most of the water supply had to be hauled by truck from San Rafael, 38 miles northeast of the monument, and later from a well 3 miles to the south. Although its charm remains, Lieutenant Simpson's "exquisite" pool has outlived its usefulness as a water supply.

The waterhole, gouged by rain and snowmelt that cascaded off Inscription Rock through the centuries, is protected from the bright sunlight of this semiarid region. Precipitation in the area averages about 12 inches a year, according to records of the U.S. Weather Bureau. Streams do not exist in the area, except for a short spring-fed stream in Water Canyon, 6 to 7 miles northeast of the monument. Wells are scattered widely, and failures have been common.

It is often thought that this region was at one time green and verdant and that the present desertlike appearance is the result of overgrazing. However, the accounts of the expeditions of Simpson and Beale and those by other trustworthy travelers reveal that, although grass did grow well in certain areas, "there were also many areas * * * where grass was so poor that forage for a string of horses could hardly be obtained." [9] Rainfall tends

[9] Leopold, 1951, p. 295.

to run off the land or evaporate very quickly where there is not sufficient plant life to catch and hold it. Some of it, of course, does sink into the soil and eventually seep into the rocks under the soil cover. There, under the earth's surface, is the source of more water for the monument—what we call ground water.

Where the Water is Stored: The Geology of El Morro

View eastward from top of Inscription Rock. The steep southwest slope of the Zuni Mountains forms the distant skyline; the valley plain is underlain by volcanic flow rocks.

El Morro National Monument lies in a wild and beautiful region of sheer cliffs, high mesas, steep mountains, and narrow valleys and canyons. The altitude at the monument headquarters is 7,200 feet. North of El Morro, the forest-covered slopes of the Zuni Mountains rise higher, to altitudes of 8,000 or 9,000 feet. Many streams in the Zuni Mountains have carved deep canyons in the slopes. Unfortunately, none of these streams cross the lava plain to run near the monument because all the water sinks into the lava very quickly.

The inscriptions and Indian relics at El Morro are young in comparison with the rocks. The history they record is only an infinitesmal part of the millions of years of history that can be read in the rocks of the region. Through the billions of years of its history, the appearance of the earth has changed many times. The mountains and valleys that we recognize did not always exist where they are now. The crust of the earth has been pushed and pulled by subcrustal forces, which made the crust sink in some places, and rise in others. At places it has been ripped by earthquakes.

In ages past, many of the rocks which now are mountains were formed at the bottom of the sea. We know this because fossil remains of sea animals are found in the rocks on mountain tops. Then powerful forces from within the earth folded and raised these rocks to their present position. As soon as the mountains rose above the sea, however, streams, wind, and glaciers began tearing them down. Billions of tons of sediment (minute particles of rock) were eroded from the land by rivers and added to the oceans or the stream valleys along the way. Some of the particles were whisked about by the winds and accumulated in dunes on the land. As the ocean floor piled up with sedimentary material, subcrustal forces gradually lifted the sediments out of the water until they became mountains, and the process of erosion started all over again (fig. 6).

These movements of the earth's crust—the wearing down and the bulging up—have taken place during many million years. At El Morro, some of the sedimentary rocks are almost 300 million years old. The sedimentary rocks lie on a complex system of igneous and metamorphic rocks, which are more than 600 million years old.

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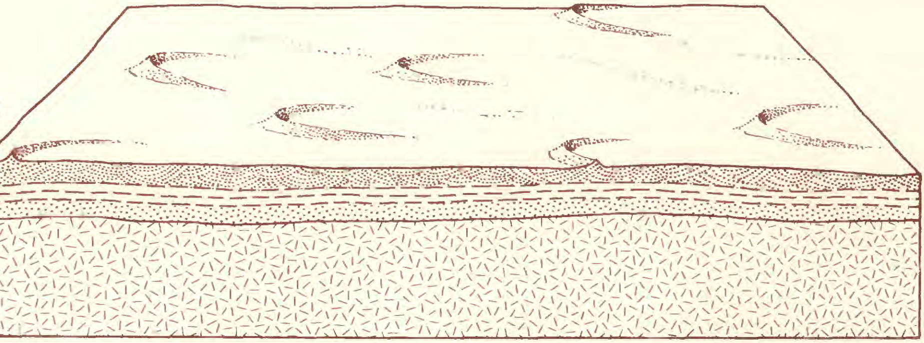
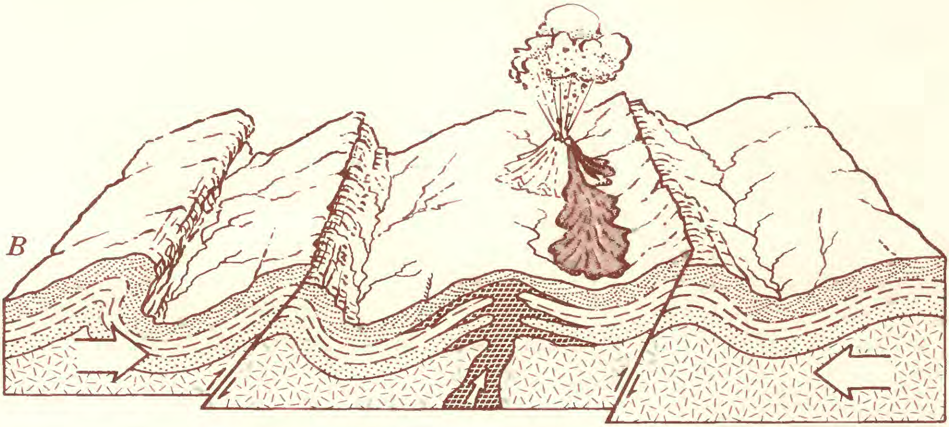
A



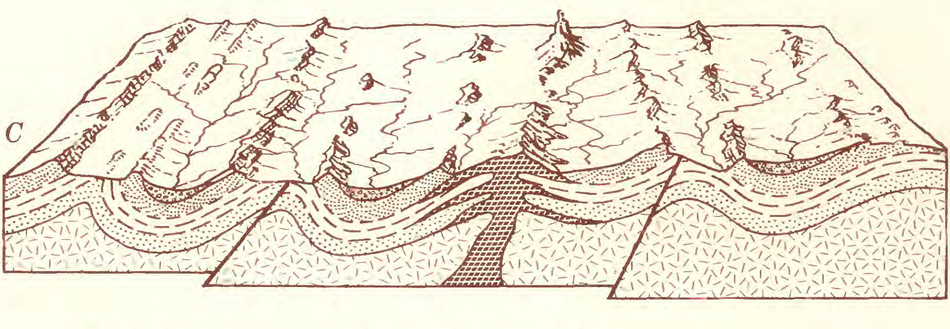
In Precambrian time layers of sediment accumulated and eventually formed rock.

B



The layers of rock were squeezed and crumpled into mountains. Molten rock from below moved upward through cracks and formed volcanoes.

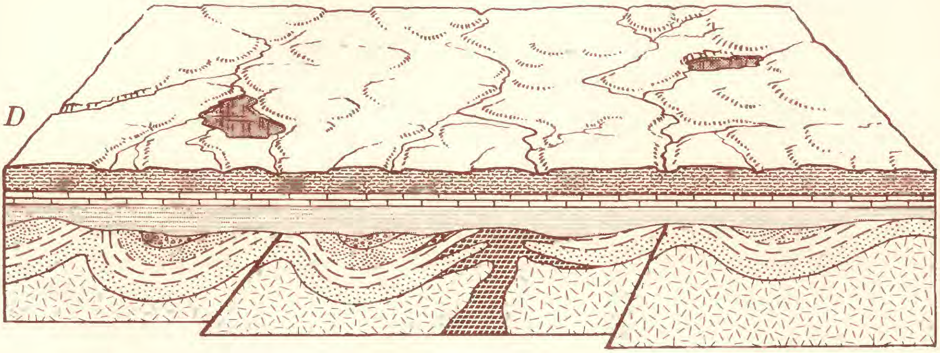
C



During many millions of years the mountains were worn down by erosion, and a nearly level plain little higher than the sea was left.

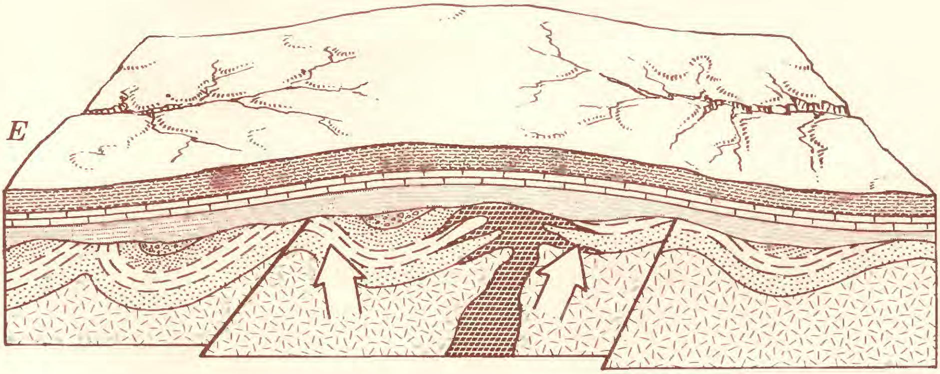
 Figure 6. The process of mountain building and erosion.

D



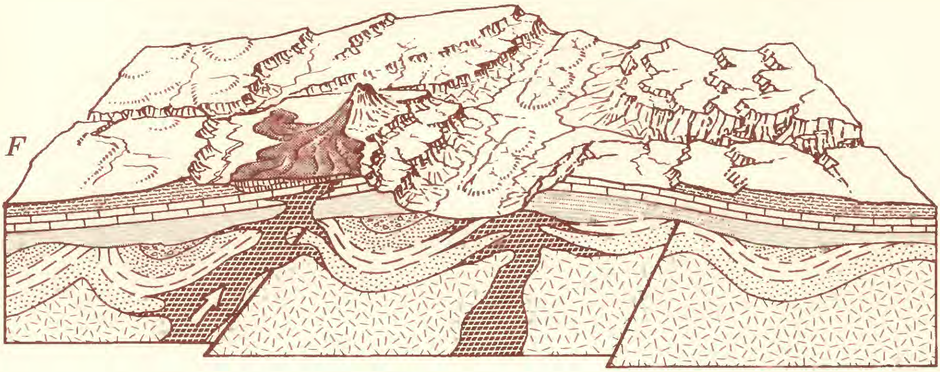
In Paleozoic and Mesozoic time, new layers of sediment accumulated in seas and streams and as sand dunes in broad expanses of deserts.

E



At the end of Mesozoic time the new layers of rocks were bowed upward above the seas in a broad arch that formed the Zuni Mountains.

F



In Cenozoic time, erosion sculptured the landscape as we see it today, modified slightly by new outpourings of lava.

The history of the earth can be read in these rocks as clearly as the writing on Inscription Rock. *Sedimentary* rock is made from materials that have been carried by water or wind to their place of rest and turned into rock. Rain and ice grind rocks into sand and mud, which settles into the bottoms of rivers, lakes, and seas. As this sand and dirt piles up into layers, it is squeezed and pressed into sedimentary rock. Some characteristic sedimentary rocks are sandstone, limestone (rocks made from sea shells), shale (rock made from clay and mud), and pudding stone or conglomerate (mass of different-sized pebbles cemented together).

The word *igneous* comes from the Latin word for fire. The inside of the earth contains molten rock, or *magma.* In some places, this magma is closer to the surface than in others, and the molten rocks push through crevices in the earth's crust. This rock, when solidified, is called igneous. Granite, basalt, pumice, and obsidian are igneous rocks. Nearly everyone knows what granite looks like. Basalt is hardened lava, and pumice is the hardened froth from volcanoes. Both basalt and pumice have bubbles or air holes in them. Obsidian looks like dark, heavy glass.

The word *metamorphic* comes from the Latin word meaning to change or be changed. Metamorphic rocks have been changed by heat and pressure from the way they were originally. They may have begun as igneous or sedimentary rocks, but heat, time, pressure, and sometimes water, have changed the rocks into other kinds. For instance, sandstone is metamorphosed into quartzite; limestone into marble; shale into slate.

All three of these main kinds of rock are present at El Morro. The layers of sedimentary rocks that once were horizontal, or nearly so, have been tilted from their original plane, as in the diagram. The layers of rock are tilted, as though bent by a giant hand (fig. 7). You will learn more about these rocks as you read further.

Geologists rarely think in terms of years or even hundreds of years; they usually reckon time in millions of years. To make their work easier, they have divided time into eras, and the eras into periods. Geologists tell us into which eras and periods the rocks belong, usually starting with the oldest and working up to modern times, as in other history books. If you will refer to figure 8 on geologic time divisions, as you read, the descriptions of the rocks will be easy to follow and understand.

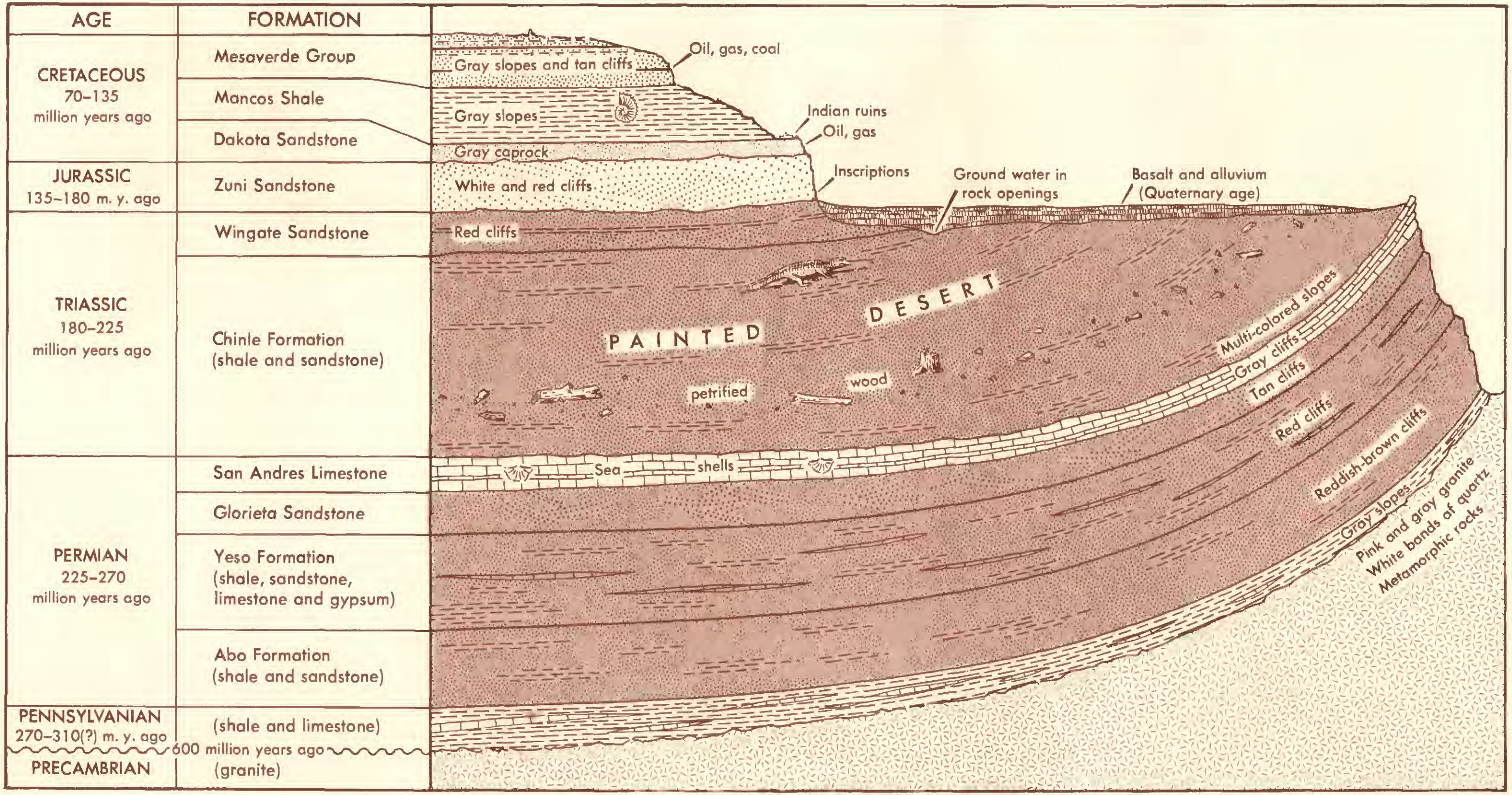


Figure 7. Tilted layers of rocks at El Morro.

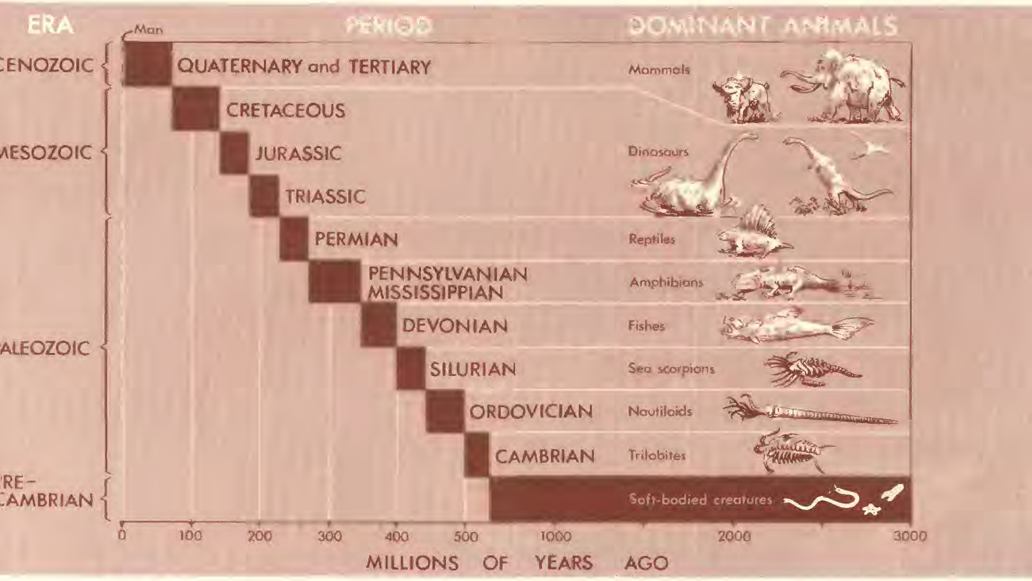


Figure 8. Division of geologic time.

How do geologists know how old different rocks are, or how old the earth is? Until recently, they had to guess, basing their guesses on physical and biological evidence. Geologists know roughly how long it takes for layers of sediments to be laid down. Remains of animals and plants are found at many levels, and study of these fossils can be correlated with the evidence of the rocks themselves. Such *dating,* however, only establishes the sequence of events; it does not tell how old the earth's rocks actually are.

In the present century a fairly reliable method of age determination has been developed. This method depends on measurements of radioactive minerals in rocks. The atoms which compose uranium, thorium, and other radioactive minerals decay or break up into smaller atoms at a regular rate, and gradually end up as atoms of lead. As the years go by, a rock that contains uranium will have less uranium and more lead in it. By comparing the amounts of lead and uranium, scientists can tell how old the rock is. Use of the radioactive method of dating has shown that the earth is more than 3 billion years old.

In using the table of geologic time, one must remember that these divisions and subdivisions are more or less arbitrary. We use them for convenience in dealing with such long periods of time. The divisions are based on the time estimated for accumulation of sediments and the building of mountains. The passage of time from one period to another was very long, and the changes which developed in the earth's surface were very gradual and overlapped from one period to another.

Ground water is the water stored in the rocks under the surface of the earth. If geologists know the kind of rock in a given area, they can usually tell approximately how much water the rocks are likely to yield. For this reason, all the rocks underlying the area have been carefully listed and described.

The person willing to leave the main roads may see all these rocks a short distance from El Morro.

Precambrian Rocks

The oldest rocks in the El Morro region are igneous and metamorphic rocks of the Precambrian Era. (See fig. 7.) These Precambrian rocks could be 600 million to 3 billion years old. They have had a turbulent history. They were squeezed, contorted, and torn, and great masses of magma and narrow bands of quartz from the interior of the earth were injected into them. Some of the magma spewed out on the surface as lava flows. The intense heat and pressure subsequently converted the sediments and lava into metamorphic rocks. Lofty mountains were built and then eroded away. No traces of primitive life are evident in these rocks, but that does not necessarily mean no life was ever present. Such traces may have been destroyed by the intense heat and pressure to which the rocks were subjected.

The bands of quartz are more resistant to erosion than the granitic rocks that enclose them, and several can be seen in low ridges along the road across the Zuni Mountains between Ice Cave and Grants. (See fig. 5.) They are easily discerned because of the large amount of white quartz fragments strewn over the ridges.

Rocks of Paleozoic Age

The Paleozoic Era of geologic time began about 510 million years ago and lasted about 330 million years. However, only a small part of this time is recorded by the rocks in the vicinity of El Morro. If rocks were deposited in the region during the first

300 million years of the Paleozoic Era, they must have been later completely removed by erosion, as there is no evidence of them now. However, rocks of one of the later subdivisions of the Paleozoic Era, the Pennsylvanian age, lie over the Precambrian rocks. (See fig. 7.)

The Pennsylvanian rocks range in age from about 235 to about 205 million years. The central interior of the United States was a vast lowland at the beginning of Pennsylvanian time, and part of the continent was submerged intermittently below the seas. During much of this time, El Morro region was a highland surrounded by seas, but the sea advanced temporarily into the area of the Zuni Mountains. We know this because marine fossils have been found in sedimentary beds of limestone and shale.

The brown and gray Pennsylvanian rocks are in areas of low relief bordering the central part of the Zuni Mountains on the southeast. The secondary road between Ice Cave and Grants (fig. 5) crosses some of these rocks about 10 miles north of Ice Cave. Pennsylvanian rocks do not exist beneath El Morro itself.

The latest subdivision of the Paleozoic Era is the Permian, which began about 205 million years ago and lasted roughly 25 million years (fig. 7). The central interior of the United States was a vast basin during Permian time. El Morro region remained above the seas during all of Early Permian time, but eventually it too was drowned by an advancing sea.

Rocks of Permian age in this region have been divided into four major sedimentary units, based on differences in the rocks that were deposited in the changing environment. These four units have been named, from bottom to top, the Abo Formation, the Yeso Formation, the Glorieta Sandstone, and the San Andres Limestone.

The Abo Formation consists of thin beds of brown to brownish-red sandstone, shale, and conglomerate. Fossils are sparse, except for a few species of small plants. These features indicate that the formation was deposited on the flood plains of streams on a nearly flat surface.

The formation is soft to very hard, and it forms alternating slopes and cliffs where it has been eroded. The best exposures of these rocks are in the lower parts of high escarpments and in areas of low relief bordering the central part of the Zuni Mountains. A few outcrops can be seen along the secondary road between Ice Cave and Grants, N. Mex. (fig. 5); better exposures can be seen along the road between Ice Cave and McGaffey.

The lower part of the Yeso Formation consists of pale-red sandstone. It is soft to hard and forms low rounded ridges or steep cliffs where it has been eroded. The physical character of the sandstone indicates that it was deposited by the wind as massive sand dunes in a wide expanse of desert.

The upper part of the Yeso Formation consists of red sandstone and shale and gray limestone. Gypsum, a soft white rock that formed on the bottom of shallow seas as the water evaporated, is also present as thin beds and a dispersed material in the sandstone and shale. Where eroded, the Yeso consists of nearly vertical cliffs. The beds of limestone contain the remains of marine shells, which show that the region was submerged below the sea during part of the time when the Yeso Formation was being deposited. The beds of shale record intervals during which the region was still submerged below the sea or was a little above the sea, and deposition was on broad mudflats or deltas.

The Yeso Formation is best exposed in the walls of deep canyons on the slopes of the Zuni Mountains and in high cliffs around the central part of the mountains. The lower part of the formation is best exposed in areas of low relief circling the central part of the mountains. The formation is well displayed along the roads between Ice Cave and Grants and McGaffey (fig. 5), and the striking red color of these rocks adds much to the scenic beauty of the Zuni Mountains.

The Glorieta Sandstone is light-gray to buff, and in some places it is red. The grains of sand are uniform in size, and they have been firmly cemented with minerals that make the rock very hard. This sandstone was deposited along the coast or in shallow water as the seas again covered the region.

The Glorieta is best exposed as the caprock on high cliffs and on timbered slopes in the Zuni Mountains. It can be seen in the canyon walls along the mountain road between Ice Cave and Grants. (See fig. 5.)

The San Andres Limestone is medium to dark-gray limestone and limy sandstone. Remains of seashells are common in the limestone. This marine limestone attests to the complete submergence of the region beneath the Permian seas.

The limestone is best exposed on broad slopes on the north, east, and south sides of the Zuni Mountains. The steep, southwest-facing mountain front that can be seen from El Morro is capped with the San Andres. The formation can be seen also along the road betwen Ice Cave and El Morro and in canyon walls between Ice Cave and Grants. (See fig. 5.)

The San Andres Limestone furnishes large supplies of water to irrigation, municipal, and industrial wells near Grants.

Rocks of Mesozoic Age

The Mesozoic Era is sometimes referred to as the age of reptiles, for it was during this time that the great dinosaurs roamed the earth. The era began about 180 million years ago and lasted about 120 million years. An incomplete record of its three geologic periods—Triassic, Jurassic, and Cretaceous—has been found near El Morro.

The Triassic Period began about 180 million years ago and lasted about 30 million years. (See fig. 7.) The Triassic rocks have been divided into two formations of sedimentary rocks in the vicinity of El Morro—the Chinle Formation (shale, sandstone, and limestone), and the Wingate Sandstone. These rocks were formed during a long interval in which the land rose above the seas again, and rivers and streams deposited material in the valleys and on broad plains.

The Chinle Formation consists of a colorful sequence of red, gray, and purple shale, pebbly sandstone, and, in the uppermost part, impure limestone. Gypsum is dispersed throughout the formation. The beds of sandstone are firmly cemented, and they form low cliffs and even slopes. Because most of the Chinle is easily eroded, it commonly is exposed in areas of low relief in broad valleys. Perhaps the most widely known of the Chinle exposures are those at the Painted Desert and Petrified Forest National Monuments in Arizona. Equally impressive exposures can be seen on the flanks of the Zuni Mountains.

Petrified wood (wood that has turned to stone) is common in the Chinle Formation. At the Petrified Forest National Monument, Ariz., the wood is brilliantly colored. However, at El Morro it is mostly drab in color. The grain of the wood can be distinctly seen in the rock.

The Wingate Sandstone on the north flank of the Zuni Mountains was deposited as dune sand in a desert. The Wingate south of the mountains, in contrast, was deposited as sand, clay, and pebbles on flood plains, and in lakes or inland basins. It consists of pale-red, very fine grained sandstone. The best exposures of the formation are in the lower parts of cliffs on the slopes of the Zuni Mountains and south of State Highway 53 from 5 to 10 miles east of Zuni. (See fig. 5.) The bright-red cliffs of Wingate Sandstone east of Zuni contrast sharply with the green of juniper and piñon trees. Many of the houses in Zuni are made of stone quarried from the Wingate Sandstone.

The Jurassic Period began roughly 150 million years ago and spanned 25 million years. (See fig. 7.) Rocks of the Jurassic age (also sedimentary) on the north flank of the Zuni Mountains have been divided into several units as follows (in ascending order): Entrada Sandstone, Todilto Limestone, Summerville Formation, Bluff Sandstone, Zuni Sandstone, and Morrison Formation.

A short distance south of U.S. Highway 66, the units lose their distinctive characteristics, and near El Morro they are all called simply Zuni Sandstone. This Jurassic-age unit is the sandstone on which the inscriptions are carved at El Morro.

The Zuni Sandstone consists of white, light-gray, and buff to pale-red very fine to fine-grained sandstone, containing some intermixed clay and silt. It also contains some coarse sand and fine gravel in the uppermost part, but in general the particles are uniform in size. This rock was formed from massive sand dunes and stream deposits in a broad expanse of desert. The Zuni is soft to hard and it stands in cliffs. The high red cliffs extending eastward from Gallup, N. Mex., for many miles just north of U.S. Highway 66 are Entrada Sandstone.

The Morrison Formation, another unit of the Jurassic rocks north of U.S. Highway 66 (fig. 5), contains about 65 percent of the uranium ore that is known to exist in the United States. Most of the ore is found north of Laguna and in the vicinity of Ambrosia Lake. Other important deposits are a few miles east and northeast of Gallup.

The Cretaceous Period began about 125 million years ago and spanned a time interval of 55 million years. (See fig. 7.) Only a part of the Cretaceous rocks are represented in the region. In the vicinity of El Morro, these rocks have been divided into three sedimentary units—the Dakota Sandstone, the Mancos Shale, and the Mesaverde Group (shale and sandstone), from bottom to top. These units reflect a marked change in the environment of the region from that of the Triassic and Jurassic Periods. Once again the seas gradually rose over the land and then receded. The Dakota Sandstone was deposited in streams, lagoons, and in the margin of an advancing sea. The Mancos Shale was deposited in a sea that covered the entire region, and the Mesaverde Group was deposited along the coast and in low swamplands as the land once again emerged from the sea.

As shown in figure 7, the Jurassic unit is the Morrison Formation, and the Cretaceous unit is the Dakota Sandstone. The change from one kind of rock to another was accompanied by a change in the environment, during which time the sea covered the land. In many places, the contact between the two formations is marked by the presence of kaolin, a white clay. In some areas the kaolin appears by itself; in others it is mixed with the sandstone as a cement. This whitened zone is very distinctive at Inscription Rock. The kaolinized cementing material probably came from weathering of other minerals during the long interval of time betwen the deposition of the Morrison and Dakota sediments. Where it appears almost pure, it may have been "formed by local concentration of the fine, white clay in small, shallow lakes on the old surface." [10] It indicates that a moist climate prevailed during a part, at least, of the time betwen Jurassic and Cretaceous deposits in this area. It is from clues like these that geologists put together the puzzle of the earth's history.

The Dakota Sandstone consists of uniform grains that have been firmly cemented into very hard rock. It is relatively resistant to erosion, and it forms the caprock on Inscription Rock and on other mesas near El Morro.

At places the Dakota Sandstone contains medium- to dark-gray shale and coal that were deposited in swamps ahead of the advancing sea. The Dakota Sandstone is the reservoir rock for much oil and gas in San Juan and Rio Arriba Counties, N. Mex.

The Mancos Shale consists of thin beds of medium- to dark-gray shale and fine-grained sandstone, containing marine fossils. Because the beds of soft shale in the Mancos are easily eroded, it commonly is exposed in areas of low relief in broad valleys.

[10] Leopold, 1943, p. 62.

The Mesaverde consists of light- to dark-gray shale and light-gray to reddish-brown sandstone. It also contains several beds of coal, where great amounts of vegetation accumulated in the swamps.

Coal has been mined from the Mesaverde Group at many places in western New Mexico. Notable were the mines near Gallup, which were operated for many years during the early part of the century. Farther north and northeast, the Mesaverde Group yields great amounts of oil and gas.

Rocks of Cenozoic Age

Our landscape as we see it today was sculptured during the Cenozoic Era, which began about 70 million years ago. During this era, all the seas were drained from the continents, and many mountain ranges of the world rose to their present, or greater, heights. We say "greater" heights because mountains are constantly being worn down by the process of erosion. The geologic history of the last few thousand years can be read in the traces left by man, as well as in those left in rocks by other forms of life.

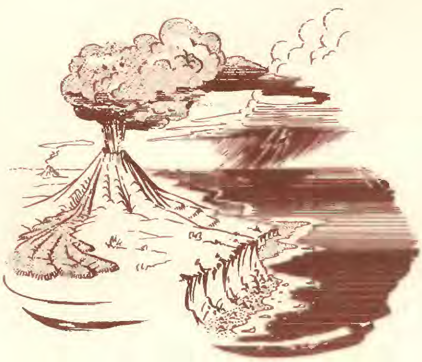
The Cenozoic Era has been divided into two periods: the Tertiary and the Quaternary. Rocks of the Tertiary Period have not been identified in the vicinity of El Morro. Either they have been completely eroded or were not deposited at all. The Quaternary Period began about a million years ago. In many ways it is the most difficult period to interpret near El Morro, although it is the youngest of the geologic periods and extends into present time. This period is difficult to interpret because most of the Quaternary rocks consist of igneous rock and fine to coarse sediments that were deposited in small lakes and stream valleys. Neither of these types of rock is favorable for the preservation of fossils, and the geologist needs fossils to help him make age determinations.

The Quaternary rocks in the vicinity of El Morro have been divided into two units: basalt (an igneous rock) and alluvium (unconsolidated very fine to coarse sand, clay, silt, and gravel). Basalt and alluvium cover all but the western part of El Morro National Monument. The thickness of these units has not been determined except at a few places. At least 200 feet of Cenozoic rocks have been penetrated by wells near El Morro.

Figure 9. Volcanic cinder cone 14 miles east of El Morro.

The igneous rock came from several volcanic cinder cones 12 to 15 miles east of El Morro. Most people assume that volcanoes have only one opening—the crater—but actually they generally also have smaller vents around the sides. Piles of volcanic ash form around these vents; these are called cinder cones (fig. 9).

In the vicinity of El Morro, lava flowed through the vents down the valleys and solidified. The fronts of the flows are commonly marked by large masses of broken black rock. North of El Morro, the lava formed a plain 2 to 3 miles wide and about 10 miles long. Similar lava flows followed other valleys south of El Morro and spread across a few hundred square miles of plains to the south and west.



El Morro's Water Supply

From rocks we obtain many valuable products for our everyday use. Near El Morro some of the rocks contain fluoride minerals, coal, oil, natural gas, and uranium. Many of the barren rocks cannot be excelled for natural splendor—even artists may fail to capture their beauty in the changing light of day. As far as the monument is concerned, however, the most important product of the rocks is ground water.

Ground water is not found in underground lakes or streams, as many people think. The water clings to the rocks and between them. When it rains, part of the water is absorbed by the soil; some runs off the soil into rivers and lakes, and the rest sinks deeper into the ground until it eventually reaches and wets the rocks beneath the soil cover. The rocks at some depth below the earth's surface nearly everywhere are wet, but geologists looking for water have to find a supply that is free to come into a well. Certain rocks lack adequate openings between the rock grains, through which water can move. There may be water in these rocks, but it cannot move fast enough to be of much use. In other rocks the openings are larger and the water will move into wells.

Each of the rock units in the vicinity of El Morro was carefully examined to determine whether or not it was capable of yielding adequate supplies of water to a well. Some rocks, such as shale, can be ruled out immediately because the spaces between the grains of rock are too small to permit movement of much water. Also, shale generally contains a variety of minerals that are easily dissolved. Only small supplies of water containing much dissolved material are generally found in shale.

Sand and sandstone differ widely in their capacity to store and transmit water. Uniformly coarse sand generally yields large supplies of good water to wells. Beds containing mixtures of different sizes of sand grains yield less than those containing sand grains of uniform size. Beds containing mixtures of sand and clay yield even less than those of pure sand. Sandstone is made of grains of sand cemented together by various minerals. Because the spaces between the grains are partly sealed up, sandstone yields less water than sand. The pores in a very fine grained sandstone or one in which grain sizes are mixed may be completely sealed and yield little or no water to wells.

Limestone may be so dense that water does not move easily through it, or it may contain many openings which permit easy movement of water. The openings in limestone are caused by solution of the rock along natural breaks. These openings become larger as water circulates through them, and eventually may become caverns. Wells of large yield may be drilled in beds of cavernous limestone, but the water generally is hard because of a high content of calcium and magnesium carbonate that may have been dissolved from the rock.

Metamorphic rocks and some igneous rocks are generally too dense to store and transmit water. Volcanic-flow rocks (igneous rocks) may be very dense, or they may contain many openings caused by contraction of the rock during cooling. Intensely broken volcanic-flow rocks are generally capable of yielding large supplies of water to wells.

Superimposed on the igneous and metamorphic rocks underlying El Morro is an accumulation of sedimentary rocks. Most of them are not very permeable. However, the San Andres Limestone, of Permian age, and the Chinle Formation (sandstone and limestone), of Triassic age, 4 to 7 miles north of El Morro, yield potable water in ample quantities.

A nearer source of water is the alluvium of Quaternary age. Alluvium is the name given to sand and gravel washed away and deposited elsewhere by streams. The Quaternary alluvium is the only formation within 2 miles of the monument capable of yielding adequate supplies of potable water to wells. The water in the alluvium is of good quality, according to chemical analyses. Alluvium is discontinuous in the area, and test drilling is necessary to locate favorable occurrences of it and to determine its water-bearing properties. The prospects of adequate water supplies are best in the deeper buried valleys; that is, in areas where the alluvium has been covered by lava flows.

Much of El Morro lies in a valley which widens to the northeast between Inscription Rock and a high cliff to the east. This valley, which has been partly filled by alluvium and basalt, is tributary to a larger valley that trends westward of the monument.

Five test wells were drilled in the northeast valley on the monument land. Alluvium was found below the lava flows in only one of the five test wells. The yield of the alluvium in the well was only 3 gallons per minute, which is far from adequate to supply the monument. The test drilling indicates that the buried valley that crosses the monument is very narrow and that an adequate supply of water probably cannot be obtained from wells on monument land. However, the alluvium in a larger buried valley just outside the north boundary of the monument seems to contain a larger supply of potable water.

The Importance of Water

El Morro is a dramatic record of the unique mixture of cultures in the old Southwest, as well as an interesting display of chapters in the geologic history of our earth. Its story is a perfect illustration of the importance of water to any civilization. The Indians settled on top of El Morro because of the pool at the base of the rock. Spanish and American travelers planned their journeys to stop at Inscription Rock because of the pool.

Now we have completed a full circle. People used to come to the rock because of the water; now water must be brought to the rock because of the number of people. So many visitors come to see the inscriptions left by those who stopped to take advantage of the pool that an additional supply of water had to be located. We know from news stories that the distribution of our national water supply may pose serious problems by the year 2000. Yet it is hard to grasp this huge problem and understand it on a national scale. Here at El Morro we can see it demonstrated as though under a microscope. The more numerous the population, the more rich and complicated our civilization becomes, the more we need ample water supplies. Water is an indispensable resource, even for a National Monument.

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