

FIGURE 1—Index map of El Morro area showing the El Morro quadrangle and surrounding quadrangles, major geologic and geographic features, and highways; Qb = Quaternary basalt of North Plains; pC = Precambrian core of Zuni uplift (modified from Dane and Bachman, 1965).

The monument was established by the National Park Service in 1906 for the purpose of preserving the inscriptions of names and dates carved into the bold white sandstone cliffs by early Spanish explorers and other visitors. The oldest of these inscriptions is dated April 16, 1605. The prominent cliffs lie along the south side of a natural east-west route through what was then unexplored, uncharted low mountain, mesa, and canyon country.

The Continental Divide crosses NM-53 10 mi (16 km) east of the quadrangle boundary, and thus the area is drained by the extensive Little Colorado River system, through the Zuni River-Pescado Creek-Ramah Valley tributary network. Parts of the quadrangle are poorly drained and/or have vaguely defined drainage patterns. The northwestern corner is drained by Muerto Canyon, which is tributary to the Ramah Valley via Togeye Canyon. The remainder of the quadrangle is drained by ephemeral tributaries to the Ramah Valley, but in places evidence of overland flow does not exist. Two structural blocks, identified by their associated cuestas and mesas, are the main influence on the local drainage network. The Dakota Sandstone-capped cuesta that extends from Ramah to a point on the west-central boundary of the El Morro quadrangle is herein referred to informally as the Ramah structural block. This block with

gentle southwestward structural dip is on strike with and represents a lateral ramp associated with the Nutria monocline. Directly to the southeast of this lateral ramp is the El Morro block, which has contrasting dips and fold patterns.

The depth of scour and backfill in the major drainages influences the hydrology and water resources of the El Morro and Togeye Lake area. The relatively coarse alluvium that occupies old channels now buried under the North Plains basalt flow is likely to be a good local aquifer. Based on water well drilling information reported by a local rancher, the basalt is 180 ft (55 m) thick in the SE $\frac{1}{4}$  sec. 1 T9N R15W. Drilling through basalt, however, is expensive. General hydrologic information in the area to the west of the El Morro quadrangle is provided by Crouch (1991), Orr (1987), and Roybal et al. (1984).

Annual precipitation from 12 to 14 inches and a lack of arable land allow for very little dry-land farming. Small corn fields are limited to the wider tracts of alluvial valley floors. Annual precipitation increases to 16 inches at the higher elevations in the northern part of the quadrangle (Roybal et al., 1984).

Previous geologic studies in the vicinity include those of Smith (1958), who mapped this area (without benefit of topographic sheets) as part of the Inscription Rock 15-min quadrangle, Maxwell (1986), who mapped and described the El Malpais National Monument area to the east, Goddard (1966), who mapped the central core of the Zuni Mountains and discussed the fluorspar district, and Mapel (1985), who mapped and described the coal resources of the adjacent Togeye Lake quadrangle.

**ACKNOWLEDGMENTS**—This study, primarily to describe the general geology of the area and to look for structural features that may be associated with the Laramide deformation of the Zuni Mountains, was done with the encouragement of Richard M. Chamberlin and Frank E. Kottowski. In addition one of us (CHM) was also interested in the westward projection of the Valle Largo fault, as well as the local character and extent of the Moenkopi Formation and the Sonsela Sandstone Bed of the Chinle Formation. The New Mexico Bureau of Mines and Mineral Resources provided the support for the field work, which was completed in 1989. We want to especially thank Margery Detring for her help in the field, and for the courtesy and cooperation extended to us by Mr. Paul Davis, Mr. Reed Detring, Mr. S. R. Ferguson, and Mr. Sylvester Mirabal we express our gratitude. The text and map were reviewed and improved by Robert O'Sullivan of the U.S. Geological Survey and by R. M. Chamberlin of the New Mexico Bureau of Mines and Mineral Resources; a note of thanks goes to them and to Lynne McNeil, who prepared the manuscript.

## GEOLOGIC HISTORY

The Precambrian core of the Zuni uplift has a long history as a mildly positive area, probably spanning most of Paleozoic time. The evidence based on Precambrian and early Paleozoic structural trends suggests that little or no deposition occurred during pre-Pennsylvanian time. The Pennsylvanian limestones that were deposited were subsequently removed by erosion during the Ouachita (ancestral Rockies)

orogeny, leaving only isolated outcrops. There is thus no sedimentary record on the Zuni uplift of geologic activity during the preceding 270 million yrs of the Paleozoic. Away from the uplift the Pennsylvanian section thickens at a high rate.

As the Pennsylvanian sea retreated continental-fluvialite deposition ensued and imparted a distinctly different aspect to the Permian rocks. The basal Permian unit in the Zuni Mountains area and throughout much of New Mexico is the Abo Sandstone. Commonly, there are several feet of arkosic sandstone at the base of the Abo that grade upward into more mature, finer-grained sandstone and mudstone. The Abo is overlain by the Yeso Formation, which consists of fine-grained, marginal-marine sediments interspersed with evaporite and carbonate beds. Following deposition of the Yeso, a transgression of the Permian seaway resulted in deposition of the Glorieta Sandstone (Pg), a very mature, well-sorted, crossbedded, high-quartz sand deposited in beach, shoreface, and backshore-eolian settings. It is perhaps the most distinctive stratigraphic unit in the Permian, along with its lateral equivalent the Coconino Sandstone in Arizona. The Glorieta is the oldest Paleozoic unit exposed in the El Morro quadrangle. A shallow shelf environment was established relatively soon after deposition of the Glorieta Sandstone, and clastic sediment supply to the seaway was greatly reduced. On this shallow, warm, sediment-starved shelf, limestone began accumulating, ultimately to form the youngest Permian rocks of the Colorado Plateau, the San Andres Limestone (Psa)—the Kaibab Limestone in Arizona. The shallow sea teemed with life, as the San Andres locally is very fossiliferous, especially in the upper part. Productoid brachiopods dominate the faunal assemblage. The writers have noted the occurrence of productoid brachiopods and nautiloid cephalopods in the San Andres Limestone along the southwest flank of the Zuni Mountains from Upper Nutria to El Morro quadrangles. No collection was made, however, from the El Morro quadrangle. The age of the San Andres has been established as late Leonardian (McKee, 1938; Baars, 1962). Baars (1962) has also provided an excellent summary of Permian depositional systems of the Colorado Plateau.

At the close of Permian time, seas retreated, a long period of crustal quiescence ensued, and the karst surface, which had been initiated during Ochoan (latest Permian) time, continued to develop on the San Andres Limestone. Throughout much of Early Triassic time the area was one of low relief and nondeposition. By Middle Triassic time the continental-fluvialite sediments of the Moenkopi Formation had accumulated, although in very moderate thicknesses, across the Zuni Mountains and central New Mexico in general (Stewart et al., 1972). In the El Morro quadrangle we included these strata in the lower member of the Chinle Formation (Fcl), even though the lithologies—sandstone, siltstone, and conglomerate—indicate a Moenkopi presence. These two units were mapped together for the following reasons:

1) mappability; the unit has limited exposure, and the contact between a Moenkopi and a Chinle could not be picked on this quadrangle. The widespread unconformity between the two units elsewhere (Stewart et al., 1972) is not apparent at El Morro.

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## INTRODUCTION

El Morro quadrangle is located 35 mi (56 km) by highway southwest of Grants, New Mexico, along the south flank of the Zuni Mountains. It lies essentially in the transition zone between the Zuni Mountains and the southern Zuni Basin. Ready access is provided by NM-53, which extends east-west across the quadrangle (Fig. 1). Several secondary roads lead north and south of the main highway, allowing easy access to the Zuni Mountains, North Plains basalt flow, and the Ramah-Navajo Agency. No towns or villages presently exist within the quadrangle; however, a store and campground are maintained at El Morro, approximately 1 mi (1.6 km) east of the entrance to El Morro National Monument.

2) lack of biostratigraphic control; no microfossil recovery or identification was attempted on samples from this interval. Kietzke (1988) recovered and identified ostracods and algal remains from a lithologically similar unit in a stratigraphically similar position in the Lucero uplift 60 mi (97 km) to the east. The microfaunal evidence he interpreted as suggesting an Early to Middle Triassic age for these Moenkopi strata. Hayden and Lucas (1989) have correlated provisionally Moenkopi strata in the Zuni Mountains area with the Holbrook Member, which is the uppermost member of the Moenkopi in eastern Arizona. During Late Triassic time this thin blanket of Moenkopi sediments was buried by the thick fluvial and lacustrine sequence that we now know as the Chinle Formation. The Moenkopi and the Chinle were deposited by fluvial systems flowing generally westward across New Mexico and Arizona to deltaic areas in what is modern Nevada (Blakey and Gubitosa, 1983).

During Early and Middle Jurassic time arid climates prevailed, and extensive eolian deposition took place in the Colorado Plateau region. However, in the Zuni Mountains-El Morro area, only the Middle Jurassic is preserved as the Zuni Sandstone (*Jz*), the lateral and homotaxial equivalent of the Entrada and Cow Springs Sandstones (Anderson, 1983). The Zuni Sandstone thins at a moderate to high rate southward from El Morro. From regional relationships we can infer that it pinches out in the subsurface approximately 25 mi (40 km) south of the quadrangle. The Zuni pinchout is due to subtle northward tilting accompanied by pre-Dakota beveling of the landscape.

The area remained stable and featureless for the remainder of the Jurassic Period and through Early Cretaceous time. Some minor reworking of the Zuni Sandstone took place in this time frame, and small, isolated patches of these deposits (*Kl*) are preserved in the El Morro quadrangle. With the advent of Late Cretaceous time, beginning about 96 million yrs ago, the Western Interior seaway was encroaching upon New Mexico, leaving a sedimentary record that indicates lower coastal-plain, marginal-marine, and, finally, marine sedimentation. The Dakota Sandstone (*Kd*) represents, for the most part, coastal-plain and marginal-marine deposition associated with the initial transgression of the seaway. Offshore, open-marine deposition is recorded in the Mancos Shale, which has been removed by erosion in the El Morro area. Regression of the sea, or coastal progradation, produces the depositional facies in reverse order; however, the regression was complicated by numerous major and minor readvances of the sea. The coastal-plain and marginal-marine sequences associated with a regression are commonly coal bearing. These regressive Upper Cretaceous rocks contain the only economic coal beds in New Mexico; however, they also have been removed by Cenozoic erosion in the El Morro area. Only the Dakota Sandstone remains (Fig. 2). Coal-bearing Cretaceous rocks are present a short distance to the west in the southern part of the Zuni Basin.

After more than 30 million yrs of Cretaceous sedimentation the effects of the Laramide orogeny began to be felt in this area. Recurrence of doming and reverse faulting in the Zuni uplift perhaps began early on in the orogeny (about 65 million yrs ago); however, the most intense deformation did not come until later in the Laramide, when the axis of principal horizontal stress had shifted from easterly to northeasterly (Chapin and Cather, 1981). The northeast-directed compressive stress or plate convergence that characterized this late Laramide deformation did not proceed uniformly along broad fronts. One hypothesis put forth by Chamberlin and Anderson (1989) recognizes a buried northeast-trending gravity high in the El Morro area that may have acted as a "rigid crustal beam" transmitting stress from the margins of the Colorado Plateau deep into the interior of the province. This gravity anomaly, called the El Morro gravity high, trends approximately N38°E parallel to the chain of craters vent zone, is no more than 10 mi (16 km) in width, and has its northwest margin immediately east of Inscription Rock in El Morro National Monument. The shift from west-northwest-trending fold axes to north-northwest-trending fold axes in this area (see map) is coincident with the margin of the gravity high. This relationship may reflect a shift in Laramide stresses across a basement fault zone. No significant local shear indicators have been found; however, the extra-local and regional faults, shear indicators, and fold structures support the hypothesis. The hypothesis is based on the concept of indentation-extrusion tectonics as described by Tapponnier and Molnar (1976) and Tapponnier et al. (1982).

Regardless of the exact model and pattern of local compressive deformation during the Laramide, numerous reverse faults, overturned folds, and local monoclines and strike-slip faults were formed or reactivated. Some of these structures were rejuvenated again during the middle to late Tertiary when a different stress field was developing and playing a role in defining the Colorado Plateau and Basin and Range provinces.

During and following the Laramide orogeny several thousand feet of strata were removed from the Zuni uplift, along with some unknown but small amount of Precambrian granitic rock. Crestal elevations at present are near 9,000 ft (2,727 m). Nearest Precambrian basement exposures are 4 mi (6.4 km) to the north; it is 600-800 ft (183-244 m) to the Precambrian basement at the northeastern corner of the quadrangle.

One of the characteristics of the Colorado Plateau with its thicker crust (in relation to the Basin and Range province) is a relative paucity of volcanic rocks. Located as it is in the southeastern part of the Colorado Plateau province, the El Morro area escaped the extensive silicic and intermediate Oligocene volcanism that dominates the landscape beginning 60 mi (97 km) to the south. From 7 to 5 million yrs ago basaltic volcanism occurred in the general area, to the east-northeast near Grants, and 25 mi (40 km) to the east-

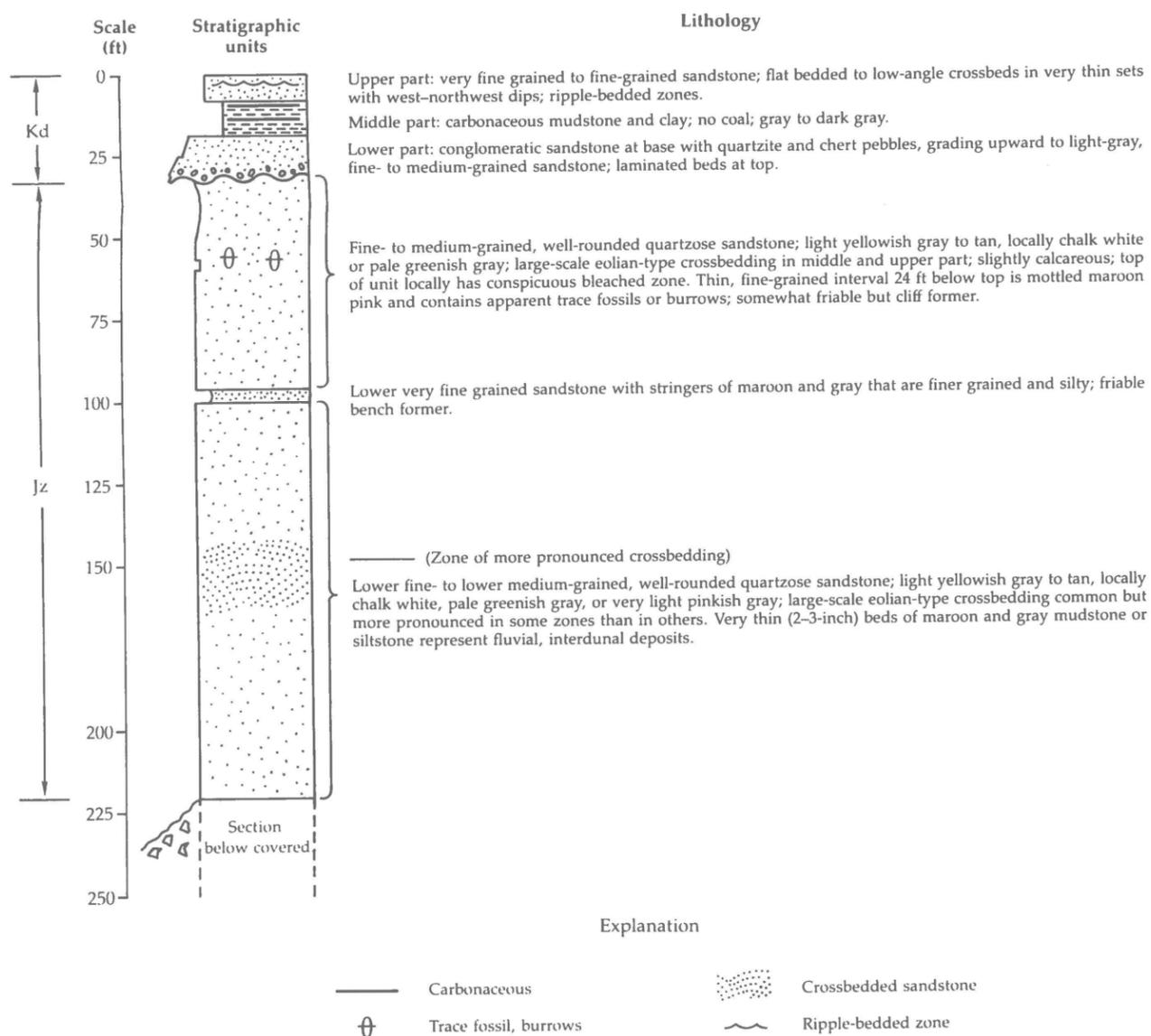


FIGURE 2—Measured stratigraphic section in NE<sup>1</sup>/<sub>4</sub>NE<sup>1</sup>/<sub>4</sub> sec. 8 T9N R14W, Cibola County, New Mexico.

southeast on Cebolleta Mesa. Erosion following those eruptive events led to the evolution of the modern landscape, a process that was controlled by development of the Little Colorado River drainage system. Broad valleys developed on the less resistant strata, such as the Chinle Formation. Gentle dip slopes developed on the more resistant Paleozoic rocks of the southern flank of the Zuni Mountains, and low mesas, capped with the resistant Dakota Sandstone, were left isolated away from the uplift out in the basin. The Chinle valleys were the major drainage lines and the lowest points on the landscape, and thus they were subsequently buried by basaltic lava (*Qb*) from volcanoes to the east of El Morro during the latest Pliocene and Pleistocene (the last 2 million yrs). The vast North Plains basalt flows to the immediate east and southeast of El Morro date from this time period. The cluster of cinder cones and flows that coalesced to form the North Plains appear to have extruded along a series of north-trending en-echelon faults within a zone that trends approximately N38°E. The pattern suggests a right-lateral component of movement in a strike-slip fault zone that impinges on and structurally modifies the southeastern flank of the Zuni uplift.

The Pleistocene basalt flows have subsequently undergone minor weathering with extensive areas covered by Recent alluvium (*Qal*) and windblown sand and silt (*Qe*). Where the soil cover is more than 3–5 ft (1–1.5 m) piñon and juniper have moved in to colonize. Cattle ranching is currently the primary use of land in the El Morro area that lies at the headwaters of the Ramah Valley–Pescado Creek drainage basin, although land subdivisions and tourism are making significant inroads.

Thin, scattered, unmappable lag gravels are present on the mesa tops. They were found on Obe Worthen Mesa and on the larger one, called Bond Mesa, in the south-central part of the quadrangle. The lag is composed of chert and quartzite pebbles of various colors, although mainly black, light brown, white, and red. They appear to be derived from conglomeratic facies of the Dakota Sandstone but commonly overlie this facies. The inference is that they represent erosion and transport of Dakota and perhaps older conglomerate beds during late Tertiary time, resulting in a local piedmont deposit that has since been winnowed out to leave a thin, pebbly lag.

### STRUCTURE

Geologic structure visible in the El Morro quadrangle and vicinity is relatively simple. In the southern part of the quadrangle, Upper Cretaceous rocks over Zuni Sandstone dip gently southward, and in the northeastern part, Permian and Triassic rocks dip more steeply southward to southwestward. This structure reflects the regional pattern of sedimentary rocks dipping in all directions away from the Precambrian core of the Zuni uplift (see Fig. 1). Apparent thinning of the Triassic rocks to the west and the positions and attitudes of several steps in the basalt flows a few miles to the east suggest east–west-trending faults or folds through the center of the quadrangle, now completely hidden by the lava cover (Maxwell, 1986). The Valle Largo fault, which extends into the quadrangle near Caruco Spring, is not visible in outcrop but is indicated by contorted bedding and several minor folds and flexures in SW $\frac{1}{4}$  sec. 13 T10N R14W. Another fault is recognized by a series of anomalous dips and flexures in the upper part of Alamosa Canyon (NE $\frac{1}{4}$  sec. 13 T10N R14W); however, it cannot be traced for any distance and was not mapped. A larger, west–northwest-trending fault is present just north of the northeast corner of the quadrangle (Maxwell, 1986). All these faults appear to be steeply dipping reverse faults, with the south side up 100 ft (30 m) or more, that merge laterally into overturned folds or into numerous splayed faults and monoclines with minor structural relief. Low amplitude monoclinical flexures also are present between the faults. A strike-slip fault may exist 1.5 mi (2.4 km) west of Inscription Rock (or modern name “El Morro National Monument”). Evidence consists of an offset fold axis; the Davis anticline (see cross section) is offset 1.5 mi (2.4 km) to the north across the hypothesized shear in what would be a right-lateral shear, trending approximately N25°–30°E. The hypothesized shear zone would enter the western margin of El Morro quadrangle in sec. 25 T10N R15W, but it appears to be local, not regional, in extent. Nonetheless, the hypothesized shear zone forms the boundary between the Ramah block and the El Morro block, minor structural elements on strike with the Nutria monocline and mentioned in the introduction. The gentle folds in these structural blocks have slightly different axial trends in addition to the offset and the contrasting local dips. The Ramah block, to the north, is a lateral ramp associated with the Nutria monocline. The El Morro block, to the south, exhibits a north-trending fold that terminates the northwest-striking monoclines and cuestas that extend from Gallup to the western margin of the El Morro quadrangle, a distance of more than 40 mi (64.3 km). Indeed, the El Morro block itself contains folds of strongly diverse trends, the west–northwest-trending Davis anticline in sec. 12 T9N R15W (see cross section) and the north-trending fold in secs. 9 and 16 T9N R14W, and thus may be transversed by another northeast-trending fault (shear?). This intrablock shift in axial trends of folds may have more significance for Laramide stress fields than does the (hypothesized) shear zone between the Ramah and El Morro blocks.

Microthrusts preserved in Dakota Sandstone are found in many places in the south-central part of the quadrangle (secs. 3, 4, 9, 10, and 14 T9N R14W) as well as in the small Dakota outcrops along the west-central margin of sec. 25. The microthrusts are commonly present as conjugate sets with slickensides indicating local maximum compression in a N22°–47°E direction, although more easterly trends can be found at the sec. 14 locality.

### HISTORICAL NOTES

The region in and around the El Morro quadrangle had a large Amerind population in prehistoric times. At least eight large pueblo complexes, including the two at El Morro National Monument, and innumerable small ruins (1–10 rooms) are found in the quadrangle. The area had many localities of permanent water and had sufficient moisture and soil suitable for the indigenous style of agriculture. Game animals were probably plentiful, as they are today. The pueblos in the area were built and occupied at least during the 12th and 13th centuries and possibly before and after that period.

The broad flat valley that crosses the center of the quadrangle became a natural passageway for the movement of people and goods during prehistoric time, during the Spanish conquest and settlement, and during the American exploration and settlement. The route was called the “ancient way” by the Spanish, who traveled through the area for 300 yrs, beginning with Coronado in 1540. American explorers began using it in 1849. The U.S. Army surveyed the area as a possible route for a transcontinental railroad in 1853. The route still is traveled because segments of it are paralleled by NM–53.

The abandoned settlement of Tinaja, 3 mi (5 km) north of NM–53, may have been established shortly after 1700, during the period of Spanish settlement following the Pueblo Revolt of 1680. The name appears on early 18th century maps but whether the name pertained to the settlement or to an Indian pueblo approximately 3+ mi (5+ km) west of the townsite is not clear. The Indian pueblo is circular, built around a depression containing a pond of permanent spring water; “tinaja” is Spanish for a large earthen jar used for storing water.

Following American settlement in the 1860s and 1870s, the major income-producing activities in the area were cattle ranching and logging. In 1939 a logging railroad of the George E. Breece Lumber Company was driven up Canyon Largo, east of Tinaja, and into the quadrangle near Caruco Spring, thence northward to the mouth of Water Canyon, and north–northwestward to the center of the quadrangle near its northern boundary (Glover and Hereford, 1986). The railroad was dismantled sometime before 1943, and little evidence of its existence remains today.

El Morro (Spanish, “the headland”) was a major stopping place along the ancient way because of its permanent water hole and probably because of the protection it offered from the elements. The first known historical mention of El Morro is in the journal of the Espejo expedition in 1583, and the oldest proven message carved into the walls of Inscription Rock (El Morro) is by Don Juan de Oñate on the 16th of April, 1605. The last Spanish date at El Morro is 1744. The next authenticated date is by U.S. Army Lieutenant Simpson in 1849 (Lohr, 1959). The El Morro National Monument was established in 1906 to preserve the old inscriptions and to prevent additional name carving. The National Park Service has administered the monument since 1933.

The pool of water at the base of the cliffs in El Morro National Monument is largely responsible for the area’s popularity with early explorers. It is not known if the containment is entirely natural or whether early Indians assisted in creating it. Unfortunately, the only way to tell for certain if it is all natural is to trench through the pile of debris surrounding the pool to determine if the major part is from a rockfall or talus pile or if most of it was carried in by man. The following account assumes a rockfall origin.

Two ephemeral waterfalls empty into the water hole. The north one has a drop of approximately 70 ft (21 m); the south one has a drop of approximately 90 ft (27 m). The catchment basin on top of the mesa that feeds the two falls during times of heavy precipitation is very limited in size, only a few acres. The water that spills over the falls has created a plunge pool below, the severe splashing action creating the initial depression. The depression may be, or perhaps was at one time, partly in bedrock, but indications are that it is now merely in unconsolidated material that has fallen, washed, or blown into this alcove on the lee side of the mesa. The pool is at present approximately 80 ft (24 m) from north to south and 35 ft (10 m) from east to west. The water level is now artificially maintained by a small earthen embankment, and water depth is only several feet. The main source of water is probably rainfall because little evidence of springs exists. However, the permanence of water, even in dry seasons, indicates the likelihood of a small seep.

The initial plunge pool may have become a more effective water trap by a fortuitous rockfall from the cliffs above that built up and strengthened the outside edge of the natural containment. The resulting talus pile stabilized, and blow sand and vegetation covered it. This natural trap became even more effective as the standing water allowed fine-grained suspended sediment to settle out and seal the bottom. The thickness of the fine-grained material at the bottom of the water hole is unknown. The natural water hole thus created was eventually breached, perhaps numerous times, on the north side near the cliff wall. Indians and early travelers probably made minor repairs, modifications, and "improvements" to the basic containment structure.

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