Geology and coal resources of Atarque Lake 1:50,000 quadrangle, New Mexico

(NW quadrant of Fence Lake 1:100,000 sheet)

by Orin J. Anderson, 1987

INTRODUCTION

A compilation of the geology in the northwest quadrant of the Fence Lake 1:100,000 metric-scale map is presented here at a scale of 1:50,000 and is designated the Atarque Lake 1:50,000 quadrangle. Detailed geologic mapping at 1:24,000 of eight 7½-min quadrangles provided the primary data for this compilation (Fig. 1). The four quadrangles that comprise the lower tier are available as open-file reports from the New Mexico Bureau of Mines and Mineral Resources. They are Open-file Report 163 (Venadito Camp quadrangle), Open-file Report 167 (Atarque Lake quadrangle), Open-file Report 171 (Mesita de Yeso quadrangle), and Open-file Report 172 (Shoemaker Canyon SE quadrangle). The upper tier of quadrangles will be released by the U.S. Geological Survey as MF-series maps (Miscellaneous Field Studies).

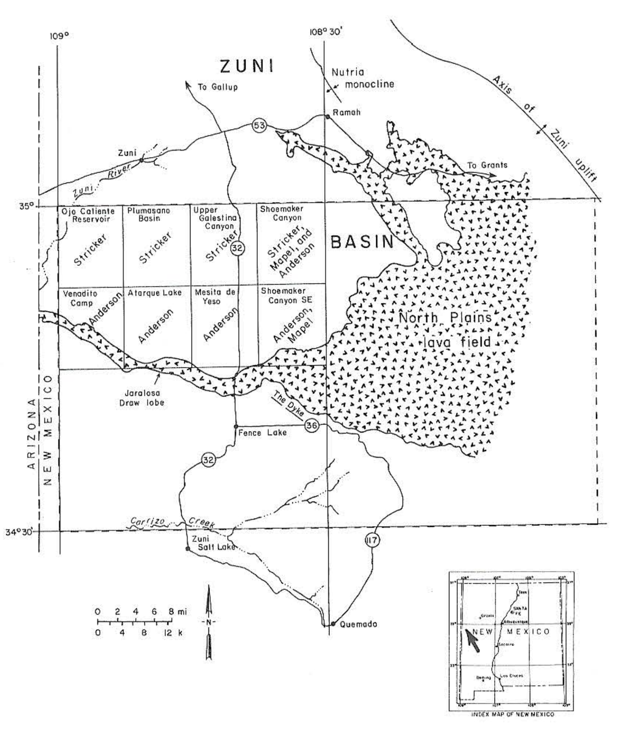

FIGURE 1—Index map of New Mexico and southern Zuni Basin showing location and map authorship of the eight 7½-min quadrangles that comprise the northwest quadrant of the Fence Lake 1:100,000 sheet (dashed outline); also shown is North Plains lava field (pattern) and major roads.

Two of the three authors of the 1:24,000 mapping, Gary D. Stricker and William J. Mapel of the U.S. Geological Survey, carried out the work on behalf of the Zuni Tribal Council and the Ramah Navajo Agency, respectively. Anderson's mapping covered the area from just north of Fence Lake to the southern boundary of the Zuni Reservation and included parts of the Salt Lake coal field on the west and the Gallup–Zuni coal field on the east.

The Atarque Lake 1:50,000 quadrangle is located in western Cibola and southern McKinley Counties 40 mi south of Gallup and 45 mi north of Quemado, via NM–32. The only improved road through the quadrangle is NM–32, but a "fair-weather" county highway traverses the area from northeast to southwest with many ranch roads and dirt tracks branching from it.

Geologically, the Atarque Lake 1:50,000 quadrangle lies near the southeastern margin of the Colorado Plateau physiographic province. As such it has typical Colorado Plateau features, namely broad areas of relatively flat-lying upper Paleozoic and Mesozoic rocks with deeply incised canyons, interrupted locally by abrupt, narrow, monoclinal flexures. The canyons and monoclines offer excellent outcrops of the entire Jurassic and Cretaceous section and of parts of the Permian and Triassic section.

Among the early geological investigations of the area are those of Dutton (1885), who described the rocks of the Zuni Plateau, Darton (1910), who included the Zuni Basin in a regional study, and Sears (1925), whose report on the geology and coal resources of the Zuni Basin extended southward into the northern portions of the present study area. Later investigations by Molenaar (1973) and Hook et al. (1983) have added greatly to our understanding of the intertongued marine–nonmarine Upper Cretaceous sequence in the Zuni Basin.

ACKNOWLEDGMENTS—This work has benefited greatly by discussions with Dr. Richard Chamberlin and Dr. Frank E. Kottlowski of the New Mexico Bureau of Mines and Mineral Resources. Credit goes to Dr. Stephen C. Hook of Texaco Inc. and Dr. William A. Cobban of the U.S. Geological Survey, who did most of the faunal identifications. The drafting assistance of Cindie A. Salisbury and Michael W. Wooldridge of the New Mexico Bureau of Mines and Mineral Resources is gratefully acknowledged.

GEOLOGY

Geologic setting

The eight 7½-min quadrangles treated collectively here as the Atarque Lake 1:50,000 quadrangle lie in the southwestern portion of the Zuni Basin (Fig. 1). The Zuni Basin is a northwest-trending, asymmetric structural sag bounded abruptly on the northeast by the Nutria monocline with steep southwesterly dips (nearly vertical locally, Fig. 2). The Zuni Basin is continuous with the San Juan Basin to the north where the Nutria monocline loses all expression. Structures similar to, and parallel to, the Nutria monocline, but of lesser magnitude, extend nearly the length of the Zuni Basin and account for the northwest-trending outcrop pattern. The Atarque monocline is the most prominent of these subordinate parallel structures. They all have sinuate traces and are typical Colorado Plateau-style monoclines. The southwestern margin of the basin is not as well defined; theoretically, this limit would be the point at which the gentle northeasterly dips of the broad western flank of the basin are no longer discernible, but other criteria, namely structural style, help define the southwestern and southern margins. Southward of the village of Fence Lake (Fig. 1) the northwest-trending asymmetric anticlines and monoclines so characteristic of the Zuni Basin die out; the regional northeastward dips become less discernible; low-displacement, high-angle normal faults become numerous; and Tertiary intrusives, including some northwest-trending Oligocene dikes, begin to appear. This area and these characteristics mark the southward transition from the Colorado Plateau into the Datil–Mogollon volcanic field.

Stratigraphy

In the Atarque Lake 1:50,000 quadrangle the rocks range from the Permian San Andres Limestone to the Coniacian (Late Cretaceous) Crevasse Canyon Formation, but scattered remnants of the late Tertiary Fence Lake and upper Bidahochi Formations also may be found. Along the southern boundary of the Atarque Lake quadrangle, the Jaralosa Draw lobe of the North Plains lava field (1.41 m.y.; Laughlin et al., 1979) follows a paleochannel and extends across the State line into Arizona. The reader is referred to the text section on Tertiary rocks and the map legend for further information on the Tertiary and Quaternary units.

Permian through Jurassic rocks

The San Andres Limestone (Leonardian?), a dense, gray marine limestone, is exposed in one small area near the village of Ojo Caliente in the west-central part of the map. The exposures are on the uplifted eastern side of the Atarque monocline along a segment where the structural relief exceeds 1,000 ft. The limestone has been quarried in several small pits, crushed, and used as road metal on county roads because gravel is a locally scarce commodity. The thickness of the San Andres could not be determined because the base is nowhere exposed; however, a 1963 oil and gas test well a few miles to the northeast (T9N, R18W) penetrated 254 ft of San Andres Limestone (C. H. Maxwell, written comm. 1977).

The Chinle Formation (Upper Triassic) unconformably overlies the San Andres Limestone. The Chinle consists of approximately 1,000 ft of fluvial-channel sandstones, floodplain deposits, and minor lacustrine sediments. These units crop out over an area 6–8 mi wide that extends N35°W from the Atarque Lake area and parallels the Atarque monocline. The thick sequences of mudstone, sandy siltstone, and silty shale that represent floodplain and overbank deposits are generally nonresistant. Thus, more extensive development of northwest-trending strike valleys would be expected behind the monocline were it not for the presence of a very resistant cap of calcrete and silcrete–chalcedony on the upper Bidahochi Formation. This cap preserved the Tertiary fill (Bidahochi) that buried the monocline and diverted the main drainage around the south end of the structure, as is so well demonstrated by the course of the Jaralosa Draw lobe of the North Plains lava field (see map).

South of 34°52'30" the Chinle Formation was mapped as an undifferentiated unit, and in the Mesa Colorado area 5 mi due north of Atarque Lake, the very thin Rock Point Member of the Wingate Sandstone also was included with the Chinle. North of 34°52'30" the Sonsela Sandstone Bed of the Petrified Forest Member was recognized and, therefore, in this area three map units were used for the Chinle Formation: the lower part of the Petrified Forest Member, the Sonsela, and the upper part of the Petrified Forest Member (see map legend).

Several of the sandstones in the Sonsela Bed are either conglomeratic at the base or have chert and quartzite-pebble conglomeratic zones scattered throughout the unit at the base of upward-fining sequences. These conglomeratic beds were likely the source of the chert-pebble conglomerate beds commonly found at the base of the Dakota Sandstone. Other than the locally abundant petrified-wood fragments, for which the Petrified Forest Member is of course well known, no fossils were found.

Very small scale mine workings in the form of a stub adit that leads into an inclined shaft were found in the NE¼NE¼ sec. 13, T7N, R20W. The workings explored a minor fault zone in a Chinle Formation sandstone bed. Some fault breccia is present with much secondary calcite in the form of spar on exposed fracture surfaces. The local people refer to it as the "old gold mine" in Thompson Draw and indicate that it is perhaps 60 yrs old. No gold was ever produced from the workings.

Northward from Mesa Colorado at approximately 34°52'30" latitude, the overlying Rock Point Member of the Wingate Sandstone was mapped as a separate unit. It crops out in a small cliff near the base of Pie Mesa, which extends northwestward along the eastern side of a small topographic depression called Plumasano Basin. The Rock Point Member consists of reddish-brown, flat-bedded, very fine grained silty sandstone and sandy siltstone. It averages approximately 60 ft in thickness in the Plumasano Basin area but thickens northward. Two mi north of Mesa Colorado in W½W½ sec. 30, T8N, R18W, worm trails and small-diameter burrows were noted in the unit, which suggests deposition in some type of shallow-water environment, lacustrine or lagoonal. Harshbarger et al. (1957) hypothesized deposition in a "quiet water system," which they named Rock Point Lagoon. In the extreme south-central part of the map over a very small area near Mesita de Yeso, the Rock Point Member also was mapped as a separate unit. Here it is approximately 30 ft thick (Anderson, 1982); fluted weathering is one of the characteristics of the Rock Point cliffs.

The white to very light pinkish-gray, fine-grained, large-scale crossbedded, massive sandstone that overlies the Rock Point Member is the Zuni Sandstone (Anderson, 1983). The Zuni consists of the undivided equivalents of the upper Entrada and the Cow Springs Sandstones and,

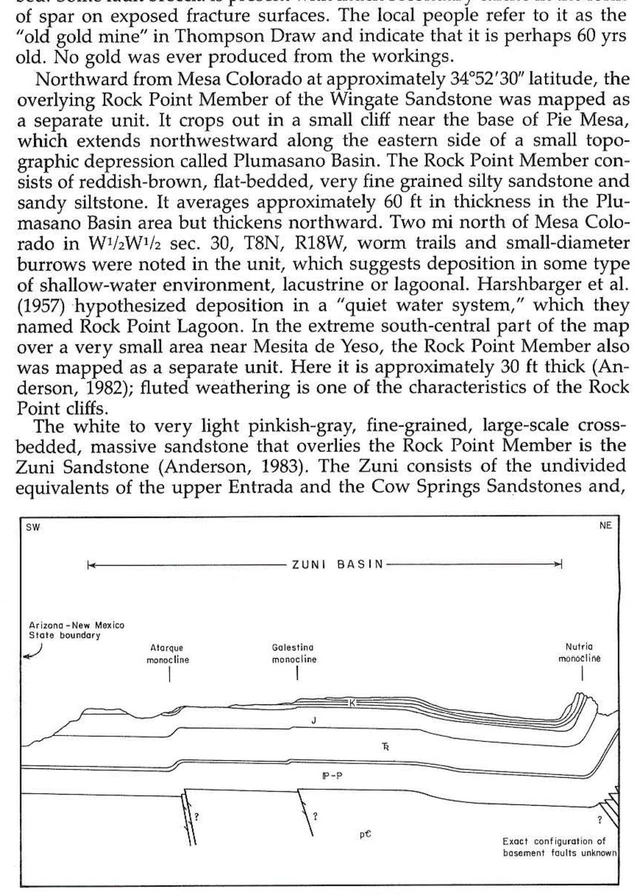

FIGURE 2—Diagrammatic cross section of Zuni Basin.

thus, represents deposition throughout Late Jurassic time, from Callovian through Kimmeridgian. A medial notch in the Zuni Sandstone, sometimes referred to as the "Todilto notch," is generally present throughout the Zuni Basin and probably represents the Todilto–Summerville interval. In the notch are commonly 4 inches of grayish to dusky-red mudstone or silty sandstone. From 8 to 10 inches of relief occur at the notch, the upper and lower surfaces being subparallel. If this oxidized mudstone represents the Todilto–Summerville interval, then the portion below the notch is equivalent to the Entrada Sandstone, and the portion above the notch is equivalent to the Cow Springs Sandstone. Aside from the large white to red chert grains that locally occur widely scattered throughout the lower part (see map legend), the upper and lower portions are lithologically very similar.

The Zuni Sandstone is approximately 500 ft thick in the vicinity of Zuni Pueblo and southward into the north-central part of the map area. Southward from this area the Zuni thins rapidly, the most rapid thinning occurring in the southeast portion of Plumasano Basin in sec. 24, T8N, R19W and secs. 19 and 30 of T8N, R18W. In addition to rapid thinning, the appearance of two atypical facies in the Zuni Sandstone in the same area causes the topographic expression of this part of the section to change drastically from that of the Zuni Pueblo area. The two atypical facies, in ascending order, are: (1) reddish-brown and grayish-red mudstone or sandy siltstone interbedded with the typical light pinkish-gray crossbedded sandstone, and (2) matrix-supported, chert- and quartzite-pebble conglomerate (clasts up to 6 inches in diameter) in two zones approximately 100 ft above the base. The lower conglomerate is 2 ft thick, and the upper one is approximately 7 ft thick; both are well exposed in the NE¼ sec. 24, T8N, R19W. A quartzite- and chert-cobble conglomerate nearer the base of the Zuni Sandstone may be observed in the NE¼SW¼ sec. 19, T8N, R18W, where an aggregate pit has been developed but is not presently active.

Although the medial notch is not recognized in the area of the two atypical facies, these two facies are considered to be near the middle of the Zuni Sandstone. The conglomerates may represent the notch interval locally as a lag deposit. This facies may also be equivalent to the "Beds at Lupton" described by O'Sullivan and Green (1973) as reddish-brown sandstone and chert-pebble conglomerates that unconformably overlie the Chinle Formation or the Rock Point Member of the Wingate Sandstone. Nowhere in the southwestern San Juan or Zuni Basins has a coarse conglomeratic facies been reported in the Entrada Sandstone. By contrast there are numerous localities near the margins of Entrada deposition where reddish-brown silty facies intertongue with sandy eolian facies (Harshbarger et al., 1957, p. 37). The finer-grained facies were water laid and represent deposition in interdunal areas.

Throughout the Jurassic, and especially in the Late Jurassic, the area in which the eolian Zuni Sandstone was deposited lay between an area of subaqueous deposition to the north and the Mogollon Highland to the south. Harshbarger et al. (1957, p. 51) pointed out that northward-flowing streams from the Mogollon Highland traversed the dune area (the present Zuni Sandstone) and contributed coarse-grained sediment to the area of Summerville deposition and later to the area of Morrison deposition. In view of this setting, the presence of fluvial sediments including conglomerates near the medial and in the upper part of the Zuni Sandstone is not surprising. Indeed, more fluvial sediments would be expected throughout the Zuni, and one is forced to conclude that the main fluvial systems lay either west or east of the Zuni–Atarque area.

The uppermost part of the Zuni, that part above the conglomerate beds, generally retains its eolian character with one notable exception: a 20-ft-thick quartzite- and chert-pebble conglomerate bed constitutes the entire Zuni interval in the NE¼ sec. 6, T7N, R18W, where it rests unconformably on the Rock Point Member. The conglomerate closely resembles those found at lower levels in the Zuni in clast size, lithology, matrix, and color. It contains cobble-size material and, thus, is coarser than anything found in the basal Dakota Sandstone, which overlies this sequence. Pebble imbrication in the 20-ft-thick bed indicates a northward transport direction, but this is based on very few observations.

Cretaceous rocks

The Cretaceous rocks exposed in the Atarque Lake 1:50,000 quadrangle range from the Cenomanian Dakota Sandstone to the Coniacian Crevasse Canyon Formation (Fig. 3). The sequence consists of, in ascending order, the Dakota Sandstone (main body), the lower part of the Mancos Shale, the Paguate Tongue of the Dakota Sandstone, the Whitewater Arroyo Tongue of the Mancos Shale, the Twowells Tongue of the Dakota Sandstone, the Rio Salado Tongue of the Mancos Shale, the regressive Atarque Sandstone, and, in the western two-thirds of the map, the coal-bearing Moreno Hill Formation. In the eastern third of the map the stratigraphy above the Atarque Sandstone is more complex owing to the presence of the distal portion of a subsequent marine transgressive–regressive sequence (Fig. 3). The re-advance of the seaway in a southwesterly direction during middle to late Turonian time left a shoreface buildup of variable thickness that has been designated as the upper member of the Tres Hermanos Formation (as redefined by Hook et al., 1983). This upper member, the Fite Ranch Sandstone Member, and the overlying Pescado Tongue of the Mancos Shale are truncated by modern erosion near the Range 16–17 line in the southeastern part of the map. The isolated outcrop in the NE¼ sec. 24, T7N, R17W, which contains the bivalve *Inoceramus dimidius* at the base of the Fite Ranch Member, marks the southwesternmost occurrence of these units (see map). The turnaround point, at which the transgressive Fite Ranch Member grades into the proximal part of the regressive Gallup Sandstone, has been obliterated by modern erosion but was probably no more than 6–8 mi farther to the southwest, which places it near the Atarque monocline. Because no record of this transgression is present south of the Quaternary basalt flow (the Jaralosa Draw lobe), the flow is taken as the point of nomenclature change, from Tres Hermanos Formation and Gallup Sandstone on the north side to the (mostly) equivalent Moreno Hill Formation on the south side. For expediency, NM–32 has been chosen as the east–west boundary of nomenclature change, the Moreno Hill Formation being restricted to the area west of the highway.

The remainder of the Cretaceous section for the eastern third of the map consists of the above-mentioned Gallup Sandstone and the overlying Dilco Coal Member of the Crevasse Canyon Formation. The uppermost member of the Gallup is the distinctive, coarse-grained, feldspathic, fluvial-channel sandstone complex named the Torrivio Member. Because of the gentle northeasterly (1°–2°) dips throughout this area, the Torrivio Member and the overlying Dilco Coal Member are restricted to the northeast corner of the Atarque Lake 1:50,000 quadrangle.

INFLUENCE OF STRUCTURE ON CRETACEOUS STRATIGRAPHY—The major structural elements of the Zuni Basin apparently influenced the Cretaceous stratigraphy. The coincidence of the landward pinchout of the Tres Hermanos–Gallup Sandstone with the Atarque–Galestina monoclines strongly suggests a cause and effect relationship. The monoclines are considered to be the result of northeastward-directed compression during the Laramide orogeny (80–40 Ma.). However, a relatively minor amount of pre-Laramide movement along the same basement structures (Fig. 2) could have influenced the configuration of Late Cretaceous (Turonian) shorelines—the time of deposition of the Tres Hermanos Formation and Gallup Sandstone. Subtle structural controls along the Late Cretaceous seaway and nearshore sedimentation in the San Juan Basin were considered by Cumella (1983). He recognized evidence for compressive deformation during Turonian time in southeastern Arizona. Drewes (1972) placed a date of about 90 m.y. (Turonian) on the deformation that thrust rocks of the Bisbee Group (Lower Cretaceous) into northwest-trending isoclinal folds in the area of the present Empire Mountains (southeastern Arizona). The resulting highlands supplied sediment to the northeastward-flowing streams, which then traversed a broad coastal plain on the way to the Cretaceous seaway. Hayes (1970) suggested this tectonic event may have provided the source for the Gallup Sandstone. The coarse-grained, feldspathic Torrivio Member at the top of the Gallup surely represents a significant tectonic event during this interval.

It is here concluded that northeastward-directed compressional deformation during the Turonian, well documented in southeastern Arizona, produced minor movements in the brittle basement rocks of the Zuni Basin. At first only subtle control was exerted on shoreline configuration, but with time this deformation grew to play a role in determining the landward turnaround point of three transgressive–regressive cycles. Using the terminology of Molenaar (1983), the three cycles with their associated marine-shale tongues shown in parentheses are: T2–R2 (Pescado), T3–R3 (Mulatto), and T4–R4 (Satan). The T2–R2 cycle, during which the Tres Hermanos to Gallup Sandstone transition took place, appears to have been controlled by early movement along the Atarque–Galestina–Defiance monocline zone, whereas the other two cycles are apparently related to early movement along the Nutria monocline. Because significant coal deposits in northwestern New Mexico tend to occur just landward of marine turnarounds (Shomaker et al., 1971; Anderson and Stricker, 1984), recognizing the influence of structure on stratigraphy becomes economically important.

It should be noted that in the model discussed above the upthrown block (Fig. 2) is rotated seaward (northeastward) under compression. The inference is that the uptilted (or overthrust) end of this rotated block provided shoreline control. The downthrown block (on the southwest side) would have then underlain the coastal-plain area, creating the proper conditions for subtle subsidence and peat accumulation.

A significant feature of the Atarque and the Galestina monoclines is that they terminate southeastward along a line that trends N55°E and is coincident with the course of Pinitos Draw. This is 90° to the monoclinal axes, which trend approximately N35°W. Given this geometry plus the fact that no compressional features have been found southeast of the Pinitos Draw trend, there is a real possibility that Pinitos Draw follows the trace of a minor strike-slip fault.

The Atarque monocline apparently terminates abruptly to the northwest as well, in the vicinity of Ojo Caliente, and it is probable that a northeast-trending zone of strike-slip movement exists there also. This results in the segmentation of monoclinal-fold trends in the Zuni Basin. Fold segmentation was recognized by Brown (1984) as a characteristic of Rocky Mountain foreland deformation; he referred to it as compartmental deformation and related it to movement of discrete basement blocks.

Fold structures do not match up across the controlling strike-slip faults, but more importantly one large structure may be balanced by several smaller structures on the opposite side of the fault. This concept applies in all likelihood to the Zuni Basin, inasmuch as the Nutria monocline in one "compartment" may be balanced by the Atarque and Galestina monoclines in another.

Thus, there is some basis for suggesting strike-slip or tear movement along northeast-trending faults and, consequently, this should be taken into account when Late Cretaceous shoreline reconstructions are attempted for this area.

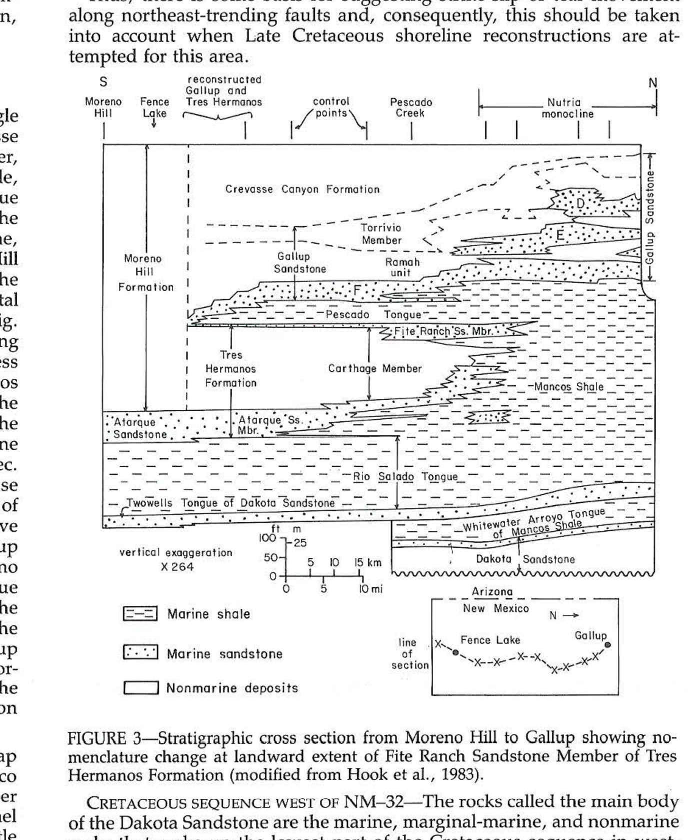

FIGURE 3—Stratigraphic cross section from Moreno Hill to Gallup showing nomenclature change at landward extent of Fite Ranch Sandstone Member of Tres Hermanos Formation (modified from Hook et al., 1983).

CRETACEOUS SEQUENCE WEST OF NM–32—The rocks called the main body of the Dakota Sandstone are the marine, marginal-marine, and nonmarine rocks that make up the lowest part of the Cretaceous sequence in west-central New Mexico (Hook et al., 1980). In the study area, the Dakota Sandstone is approximately 100 ft thick and is composed of a basal, fluvial-channel sandstone of varying thickness but not exceeding 30 ft; a paludal-shale sequence containing carbonaceous shale and thin (<1.0 ft) coal beds; and marginal-marine and marine sandstones, which form the uppermost 20–25 ft of the unit. Fossils collected in the upper marine sands include the bivalves *Pycnodonte kellumi* and *Exogyra levis*, and *Turritella* sp. plus various other gastropods. The Dakota is overlain by the lower part of the Mancos Shale, an 18-ft-thick arenaceous shale that was included in the Dakota Sandstone in many areas. The shale is well exposed only in the east-central portion of the Venadito Camp quadrangle and in the central part of the Upper Galestina Canyon quadrangle, on the south side of Galestina Canyon. Elsewhere it is covered or unrecognizable. This shale tongue is probably equivalent to the Clay Mesa Tongue, which has a type section designated in the Laguna, New Mexico, area (Landis et al., 1973). However, because of the pinchout of an underlying sandstone tongue (the Cubero) a few miles southwest of Laguna, the term Clay Mesa cannot be extended into the study area; hence the informal term, "lower part of the Mancos Shale," is used here (Hook et al., 1980).

Overlying the shale is the Paguate Tongue of the Dakota Sandstone, which consists of a 20–25-ft-thick, massive, cross-bedded, upward-coarsening sandstone unit that commonly has at the top a fossil-hash zone composed almost exclusively of *Exogyra levis* and *Pycnodonte* cf. *P. kellumi*. Large, brown, ferruginous/calcareous concretions also may be present in the upper part; they are particularly well developed in sec. 31, T7N, R20W. The Paguate characteristically weathers to a light-tan or pale grayish-orange color, but near the Atarque monocline it is oxidized to a reddish brown. It is generally a minor cliff former, but outcrops are very limited. The best exposures are those along the drainage paralleling the south edge of the basalt flow in the southwest corner of the map and also around the upper end of Galestina Canyon. Northward, the unit merges with the main body of the Dakota, since the lower part of the Mancos pinches out. Near the village of Twowells, 14 mi due north of Zuni, the Paguate is not present as a lithologic unit distinct from the main body of the Dakota (Hook et al., 1980).

The Whitewater Arroyo Tongue of the Mancos Shale overlies the Paguate Tongue throughout the Zuni Basin. The name was proposed by Owen (1966), who applied it to a "well defined, persistent tongue of marine shale separating the Twowells (Tongue) from the rest of the Dakota Sandstone in the southwestern part of the San Juan Basin." A type section was designated in Whitewater Arroyo in sec. 17, T12N, R19W, near the village of Twowells, where it was stated to be 80 ft thick and described as a gray to olive-gray, silty, oyster-bearing shale. Within the Atarque Lake quadrangle, the Whitewater Arroyo consists of 60 ft of medium- to dark-gray fissile shale containing the relatively large oyster, *Exogyra trigeri* (Coquand), in its middle portion. Also, very near the middle is a distinctive white- to orange-weathering 15-inch-thick bentonite bed. This bentonite bed has been recognized 18 mi to the south in the Twentytwo Spring quadrangle, and 75 mi to the east on D-Cross Mountain an 8-inch-thick bentonite bed in a similar stratigraphic position was noted by Hook et al. (1980). Good exposures of the Whitewater Arroyo Tongue and the bentonite bed occur in the NE¼ sec. 30, T7N, R19W, where it is protected by a cover of Twowells Sandstone, and also along NM–32 in T8N, R18W. Colorless tabular masses of selenite commonly weather out of the bentonite bed.

The Twowells Tongue of the Dakota Sandstone is recognized in this area as a tan to yellow and yellowish-gray-weathering sandstone that "comes and goes." The sporadic nature of the outcrops or surface expression of this unit is due in part to laterally varying degrees of induration, variable grain size, and clay and silt content; however, depositional thickness varies as well. It is up to 30 ft thick in the study area and consists of (1) a basal, flat-bedded, very fine grained sandstone, (2) a middle, very fine to fine-grained, intensely burrowed and bioturbated sandstone, and (3) an upper part that is fine- to medium-grained, planar-crossbedded, and generally 6–8 ft thick. The base is gradational; the top is sharp. Crossbed dip direction is generally north to northeast, but in places the uppermost beds have N30°W dip directions. Herringbone-crossbed sets are present in the upper part; symmetric ripple marks found in the E½NE¼ sec. 20, T7N, R20W and elsewhere are oriented north to just west of north. The oyster *Pycnodonte kellumi* is abundant in many places at the top of the Twowells Tongue in the Mesita de Yeso quadrangle. Commonly found in association with *P. kellumi* are forms transitional to *P. newberryi* along with small specimens of *Exogyra levis*.

Although a wide array of crossbed dip directions was recorded (from N30°W to N25°E), the uppermost sets with the northwesterly dips may reflect longshore-current directions paralleling the late Cenomanian shorelines. The presence of wavy bedding, flaser bedding, and the herringbone crossbedding, however, is evidence of a tidal-flats–tidal-channel origin for portions of the upper Twowells; the presence of clay clasts reinforces this interpretation. The overall origin of the Twowells is somewhat of an enigma in that the lack of coastal-plain or deltaic sediments at the top indicates extensive progradation without significant shoreline regression.

The Rio Salado Tongue of the Mancos Shale represents a rapid return to open-marine, deeper-water conditions or an interruption in sand supply following deposition of the Twowells. It consists of dark- to medium-gray and grayish-brown shale, calcareous shale, and thin calcarenites, with an interbedded shale and very fine grained sandstone sequence at the top where it grades into the overlying Atarque Sandstone.

The name Rio Salado Tongue was proposed by Hook et al. (1983). It is defined as the marine-shale tongue lying between the Twowells Tongue of the Dakota Sandstone and the Atarque Sandstone and is coextensive with these two units. The Rio Salado is approximately 250 ft thick in the Atarque Lake area.

The thin calcarenite and calcareous shale beds that occur 25–40 ft above the base of the Rio Salado are the equivalent of the Bridge Creek Limestone Member of the Greenhorn Formation (Hook et al., 1980). Outcrops of these beds can often be recognized at a distance because the yellow-weathering calcarenites stand out in contrast to the typically gray Mancos Shale. Thin limestone beds are well exposed just west of NM–32 in the SW¼ sec. 6, T6N, R17W, where they contain abundant fragments of *Pycnodonte newberryi* (Stanton) and inoceramid debris. Exposures farther to the west, in sec. 21, T7N, R20W, contain a more diverse fauna. Here, in a sequence of calcareous shale, calcarenite, and thin limestones, a collection of the following mollusks was made with the assistance of William A. Cobban of the U.S. Geological Survey: *Metoicoceras gislinianum*, *Sciponoceras gracile*, *Worthoceras vermiculum*, *Kanibisceras septumseriatum*, *Lucina* sp., and *Psilomya* sp. These beds were deposited during the very late Cenomanian (Greenhorn) transgressive maximum, an event that was marked by the deposition of limestone beds thoughout most of the Western Interior seaway. The beds form important marker horizons, and also the guide fossil *Pycnodonte newberryi* appears in abundance at, or just below, this interval (Hook and Cobban, 1977). *Pycnodonte newberryi* was collected in the NE¼ sec. 1, T6N, R18W. In the subsurface, the Bridge Creek beds may be recognized by the distinctive resistivity kick they produce on the electric log, which is helpful in correlations.

At 100–125 ft above the Bridge Creek Limestone beds, limestone concretions ranging from 2 inches to 2 ft in diameter begin to appear in the section. The concretion-bearing zone is well exposed at several places in the northwest part of the Venadito Camp quadrangle (in T7N, R20W) and particularly well exposed in the E½SE¼ sec. 6, T6N, R19W of the Atarque Lake quadrangle. At the sec. 6 locality the author collected the following ammonites: *Neoptychites cephalotus*, *Morrowites depressus*, *Placenticeras cumminsi*, *Baculites yokoyamai*, and *Mammites nodosoides*. Cobban and Hook (1983) measured a section of the Rio Salado Tongue of the Mancos Shale at this locality and presented a faunal list that includes a new genus and species of ammonite, *Cibolaites molenaari*, in addition to the bivalves *Ostrea* sp., *Mytiloides mytiloides* (Mantell), and *Veniella mortoni* (Meek and Hayden). The ammonites in the concretion-bearing zone, which spans a vertical sequence of nearly 100 ft, indicate an age of late-early to early-middle Turonian.

Hook et al. (1983) proposed the name Atarque Sandstone for the regressive coastal-barrier sandstone unit that overlies the Rio Salado Tongue of the Mancos Shale and records the first major regression of the seaway in this area following the Dakota–Mancos transgression. The Atarque Sandstone prograded northeastward into the Mancos seaway and is therefore a diachronous unit. Hook et al. (1983) determined a middle Turonian age for the Atarque in the Zuni Basin. Throughout the mapped area, the Atarque is a cliff former that consists of a flat-bedded lower sandstone approximately 20 ft thick overlying a transitional zone at the base and a coarser-grained, crossbedded upper sandstone 15–25 ft thick. These two sandstones are similar to the lower and upper shoreface units of Molenaar (1973). The lower shoreface unit is thought to have been deposited offshore beyond the zone where wave action and longshore currents affected sedimentation. Deposition of the upper shoreface unit probably took place in the zone where longshore currents were active. Burrows, including *Ophiomorpha*, are common in the lower flat-bedded unit and are often present near the base and near the top of the upper crossbedded unit.

Above the crossbedded unit is a covered, fine-grained interval that, to the south in the Cantaralo Spring quadrangle (Anderson, 1981), is a shale sequence containing carbonaceous and coaly zones. Overlying the covered interval and locally taken as the top of the Atarque is a thin, very fine grained, burrowed, root-penetrated sandstone. This has been interpreted as a restricted-bay or back-barrier sandstone; it is also discernible to the south in the Cantaralo Spring quadrangle.

In the present usage, the Atarque Sandstone corresponds to the lower Gallup, or the Atarque Member of the Gallup, of Molenaar (1973), who, however, also included the overlying nonmarine carbonaceous shales, fluvial-channel sandstones, and thin coal beds in this member. The faunal evidence presented in Hook et al. (1983) points to a significant age difference between the Atarque and the Gallup. Hook et al. recognize the Atarque as having been deposited earlier than the Gallup Sandstone and as being separated from the Gallup by the Pescado Tongue of the Mancos Shale.

Excellent exposures of the Atarque Sandstone may be found in secs. 8 and 9, T7N, R19W of the Venadito Camp 7½-min quadrangle and in sec. 6, T6N, R19W of the Atarque Lake 7½-min quadrangle. It varies from 50 to 60 ft thick across the two quadrangles.

The Moreno Hill Formation (McLellan et al., 1982) consists of fluvial-channel sandstones, carbonaceous shales, mudstones, and minor thin coals. This nonmarine sequence overlies the Atarque Sandstone and represents the youngest Cretaceous rocks in the western part of the map. The geographic area in which these two new stratigraphic names (the Atarque Sandstone and Moreno Hill Formation) are applied is northwest of Quemado; it is shown as Mesaverde Group on the geologic map of New Mexico (Dane and Bachman, 1965).

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DESCRIPTION OF UNITS

Qae — **Alluvial and eolian deposits**—silt and sand; may exceed 50 ft in thickness locally; restricted to northern and western areas

Qcl — **Colluvium, landslide masses, or toreva blocks**

Qal — **Alluvial deposits, undifferentiated**—clay, silt, sand, and gravel in arroyos, on floodplains, and on gentle slopes

Qb — **Jaralosa Draw lobe of North Plains lava field**—originating from centers to east in the North Plains lava field; olivine tholeiite in composition with K–Ar age of 1.41 m.y. (Laughlin, Brookins, Damon, and Shafiqullah, 1979)

Qt — **Travertine, calcareous sinter deposits**—related to springs in Ojo Caliente area with an additional, isolated occurrence 8 mi east–northeast of Ojo Caliente

Tbv — **Tuffaceous member of upper Bidahochi Formation (Pliocene)**—white rhyolitic tuff occurring as isolated patches just west of center of map

Tbu — **Upper member of Bidahochi Formation (Pliocene)**—highly variable light-gray sandstone and conglomerate and light-brown to light brownish-gray unconsolidated sand; conglomerates are well indurated with calcareous cement and composed of pebble- to boulder-size vesicular basalt and other volcanic rock with minor chert and quartzite; this coarse bouldery facies represents reworked Fence Lake Formation deposits

Tfl — **Fence Lake Formation (Miocene?)**—gray to pinkish-gray, coarse volcaniclastic sandstone and conglomerate; conglomerate consists of vesicular basalt, basaltic andesite, rhyodacite, other volcanic rocks, and minor quartzite; present only in northeast part of map, and assignment to Fence Lake Formation based on its restriction to the highest levels (above 7,500 ft) and lack of the white, rhyolitic tuffaceous units that occur locally in upper part of Bidahochi Formation

Kccd — **Crevasse Canyon Formation, Dilco Member (Upper Cretaceous)**—light-gray and light yellowish-gray, very fine to fine-grained sandstone; crossbedded; ledge forming; occurs in broadly lenticular beds; also light-gray siltstone and brown mudstone and carbonaceous shale with thin coal lenses in basal part; 140 ft thick

Kgt — **Torrivio Member of Gallup Sandstone (Upper Cretaceous)**—ledge-forming, grayish-red, fine- to very coarse grained, crossbedded, feldspathic sandstone; present only in extreme northeast corner of the map; unit ranges up to 40 ft thick locally; east–northeast crossbed dip directions prevalent

Kgc — **Coal-bearing member of Gallup Sandstone (Upper Cretaceous)**—at base is a 30–35-ft-thick fluvial-channel sandstone that rests with sharp erosional contact on the F member; above is a variable sequence of fluvial and paludal rocks including dark-gray, silty-sandy claystone, fissile, brown carbonaceous shale, light-gray siltstone, and light yellowish-gray, crossbedded, ripple-marked sandstone; ferruginous concretions common in shale and claystone beds; contains four coal beds ranging up to 2 ft thick; lowest coal rests on basal fluvial sandstone; next two higher coals contain distinctive grayish-white claystone (tonstein) partings 0.2–0.4 ft thick; coal-bearing member approximately 100 ft thick

Kgf — **F member of Gallup Sandstone (Upper Cretaceous)**—light-gray, very fine to fine-grained sandstone; lower part contains dark-gray silty and shaly partings; upper part somewhat more resistant with more distinct crossbedding and numerous burrows; grades downward into the Pescado Tongue of the Mancos Shale through an interval of 5–10 ft; total thickness of unit approximately 50 ft

Kmp — **Pescado Tongue of Mancos Shale (Upper Cretaceous)**—light- to medium-gray and brownish-gray marine shale; contains large (up to 2 ft in diameter) limestone concretions near the base and very thin, fine-grained sandstone beds in lower half; unit approximately 30 ft thick in southeast; 65 ft thick in northeast

Kthf — **Fite Ranch Member of Tres Hermanos Formation (Upper Cretaceous)**—yellowish-gray to grayish-orange sandstone; coarsens upward from very fine to fine grained; lower part commonly bioturbated and contains *Inoceramus dimidius*; upper part coarser grained, flat to low-angle crossbedded, and burrowed; thickness varies from 2 to 10 ft

Kthc / Kmh — **Carthage Member of Tres Hermanos Formation (Upper Cretaceous)**—paludal shale and mudstone, carbonaceous shale with minor coal, and fluvial-channel sandstone; shales gray to light olive gray; carbonaceous zone 4–6 ft above base locally has up to 1.6 ft of coal in 2 beds separated by 0.2-ft-thick white claystone; Tres Hermanos terminology restricted to areas where the transgressive Fite Ranch Member and Pescado Tongue are present, hence eastern quarter of map, where *Kthc* is 200 ft thick; landward from the limit of the Fite Ranch transgression the equivalent, or partly equivalent, strata are referred to as the Moreno Hill Formation (*Kmh*); thickest section is in sec. 9, T7N, R20W, where basal part contains 4-ft zone with 2.5 ft of coal

Ktha / Ka — **Atarque Sandstone Member of Tres Hermanos Formation (Upper Cretaceous)**—grayish-orange to very pale orange marine sandstone; coarsens upward from very fine to fine grained; well indurated, generally massive cliff former; burrows present in lower and middle parts; commonly fossiliferous—small bivalves—in middle part; upper part strongly crossbedded, predominantly of trough type, and distinguished by its lighter color; maximum thickness approximately 60 ft; member elevated in rank to Atarque Formation (*Ka*) to west (west of NM–32) in those areas landward from the limit of the Fite Ranch transgression

Kmr — **Rio Salado Tongue of Mancos Shale (Upper Cretaceous)**—medium- to dark-gray and brownish-gray marine shale, silty shale, calcareous shale, and calcarenite with thin interbedded sandstone at the very top; weathers to gentle or moderately steep slopes, which are generally covered by colluvium, talus, or landslide debris; base not exposed; calcarenite beds and calcareous shale with an underlying zone containing abundant *Pycnodonte newberryi* (Stanton) occur approximately 35 ft above the base; calcareous zone is Greenhorn Limestone (Bridge Creek Member) equivalent; upper 100 ft of the tongue contains numerous limestone-concretion zones; associated with the concretions locally are the ammonites *Morrowites depressus*, *Mammites nodosoides*, *Placenticeras cumminsi*, and *Neoptychites cephalotus*; also found in this association are *Ostrea* sp., various bivalves, Turritella, and other gastropods; thickness of tongue estimated at 240 ft

Kdt — **Twowells Tongue of Dakota Sandstone (Upper Cretaceous)**—yellowish-gray to pale-olive, shallow-water marine sandstone; coarsens upward from very fine to fine grained; lower part commonly burrowed and bioturbated with these features continuing into the middle, shaly part; upper part is crossbedded in thin sets and/or wavy bedded with thin shale interbeds; locally fossiliferous in all parts but mainly middle and upper; fossils consist of *Pycnodonte kellumi* and small (relative to those in the Paguate Tongue) *Exogyra levis*; also found locally in association with these is *Exogyra trigeri* (Coquand); maximum thickness 30 ft

Kmw — **Whitewater Arroyo Tongue of Mancos Shale (Upper Cretaceous)**—gray to medium dark gray marine shale; slope former; base not exposed; near the middle is a 15-inch-thick white- to orange-weathering bentonite bed not well exposed in this area; selenite crystals common; the relatively large oyster, *Exogyra trigeri*, is locally abundant; estimated thickness of unit is 60 ft

Kdp — **Paguate Tongue of Dakota Sandstone (Upper Cretaceous)**—yellowish-gray to grayish-orange, well indurated shallow-water marine sandstone; coarsens upward from very fine to fine grained; commonly crossbedded in upper, massive part with north–northeast crossbed dip directions, but southeastward dip directions, reflecting influence of long-shore currents, are also present; cuspate and lunate ripple marks well exposed in SE¼ sec. 30, T7N, R19W; *Exogyra levis* and *Pycnodonte kellumi* occur in abundance at top of unit and are well exposed in SW¼NE¼ sec. 31, T7N, R20W; burrows, including *Ophiomorpha*, common in upper part; entire section well exposed in SE¼NW¼ sec. 14, T8N, R18W, where it is 15 ft thick; elsewhere thickness may approach 25 ft

Kml — **Lower part of Mancos Shale (Upper Cretaceous)**—gray to medium dark gray marine arenaceous shale; moderate slope former; outcrops poor; generally included with main body of Dakota Sandstone (*Kd*); thickness may approach 18 ft

Kd — **Main body of Dakota Sandstone (Upper Cretaceous)**—the marine, marginal marine, and nonmarine rocks that make up the lowest part of the Cretaceous sequence in west-central New Mexico (Hook, Cobban, and Landis, 1980); unconformably overlies Zuni Sandstone; basal Dakota is nonmarine sandstone or paludal shale and is well exposed 2 mi west of NM–32 in NW¼ sec. 26, T7N, R18W; basal portion also well exposed along Atarque monocline, and in Galestina Canyon in north-central part of map the entire section may be observed; middle Dakota is paludal shale with very thin, lenticular carbonaceous and coaly beds that are noneconomic; upper 25–30 ft composed of flat, thinly bedded, lower fine-grained sandstone and sandy shale commonly with small-diameter burrows; in many areas a 4–6-inch-thick chert-pebble conglomerate is present in upper 10 ft of unit; total thickness approximately 100 ft

Kdu — **Dakota Sandstone, undifferentiated (Upper Cretaceous)**—includes Paguate Tongue (*Kdp*) and lower part of Mancos Shale (*Kml*); used in southwestern part of map where lithology of Paguate Tongue or where its relationship to main body of Dakota is uncertain; used on cross section

Jz — **Zuni Sandstone (Upper Jurassic)**—white to pale reddish-brown and pale-orange quartzose sandstone; fines upward from medium to very fine grained; in northern part of map a medial notch separates unit into upper and lower parts, particularly well displayed in Galestina Canyon at north boundary of map, in SW¼ sec. 12, T8N, R19W, on south face of Mesa Colorado, and along Atarque monocline in west-central portion of map; lower portion has zones containing chert and feldspar particles up to 1 mm in diameter and may be the equivalent of the Entrada Sandstone; the upper portion is generally somewhat finer grained, crossbedded in thick sets, locally greenish gray, and may be the equivalent of the Cow Springs Sandstone; medial notch cuts upsection to southwest, and upper part is beveled off in southern part of map, south of Mesita de Yeso; atypical facies in lower part consists of reddish-brown, lower very fine grained, silty sandstone interbedded with white to pale-orange, crossbedded, fine-grained sandstone, well displayed in sec. 13, T8N, R19W; very atypical coarse-grained facies in lower part consists of quartzite pebble and cobble conglomerate, well displayed in NE¼ sec. 24, T8N, R19W and in NE¼ sec. 6, T7N, R18W; thickness varies from 90 ft at southern boundary to more than 400 ft at north-central boundary

TRwr — **Rock Point Member of Wingate Sandstone (Upper Triassic)**—pale to moderately reddish brown, flat-bedded sandy siltstone and silty sandstone; not mappable everywhere; thickness ranges from 30 to more than 80 ft; included with Chinle Formation in southwest part of map

TRc — **Chinle Formation, undifferentiated (Upper Triassic)**—grayish-red, purple, reddish-brown, and green/reddish-brown mottled clayey siltstone, mudstone, shale, and sandstone; minor white to very light gray, crossbedded sandstone and pebble conglomerates; locally includes overlying Rock Point Member

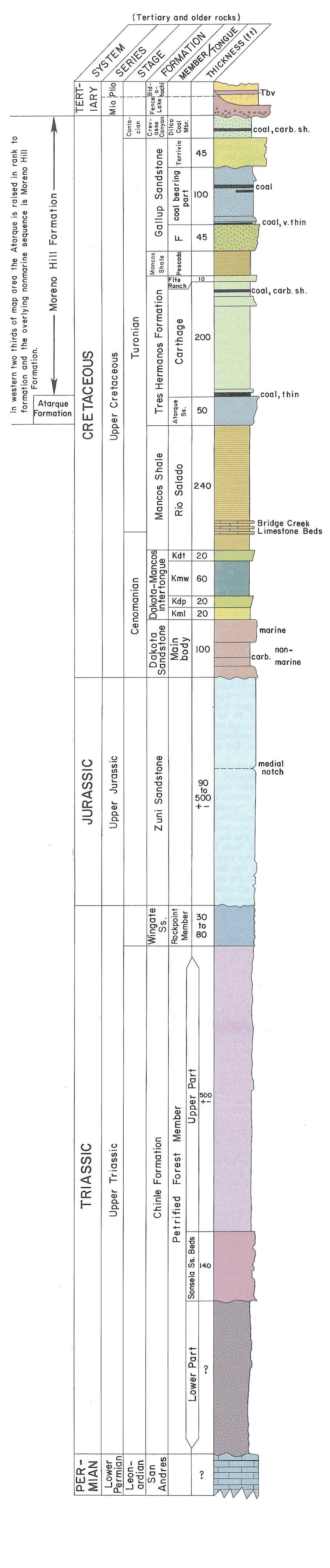
TRcpa — **Upper part of Petrified Forest Member of Chinle Formation (Upper Triassic)**—commonly banded grayish-red to pale reddish-brown and purple, flat-bedded mudstone, siltstone, and sandy siltstone of fluvial origin

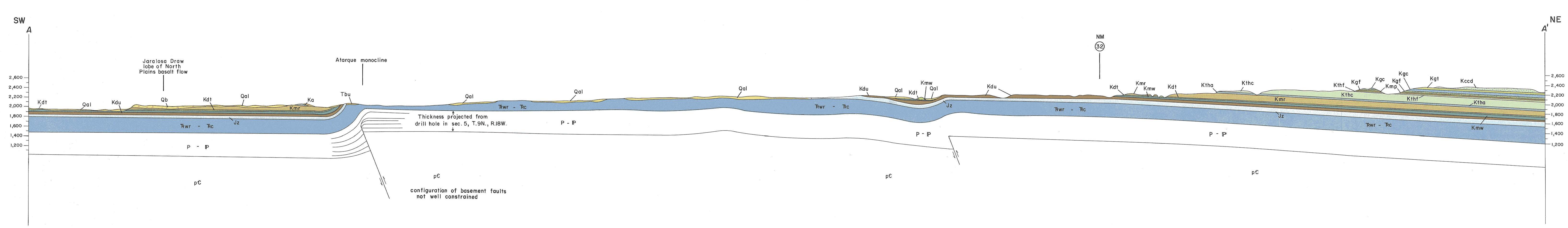
TRcps — **Sonsela Sandstone Bed of Petrified Forest Member of Chinle Formation (Upper Triassic)**—mainly light-gray to yellowish-brown, locally white, fine-grained to conglomeratic fluvial-channel sandstones; the lesser sandstones are separated by beds of bluish-gray to grayish-purple mudstone and siltstone; thickness variable, may exceed 140 ft locally

TRcpb — **Lower part of Petrified Forest Member of Chinle Formation (Upper Triassic)**—dusky-blue, grayish-purple, and light-gray lenticular beds of mudstone, siltstone, and fine-grained sandstone of fluvial origin

Psa — **San Andres Formation (Permian)**—dense, gray, resistant limestone; restricted to one locality along the Atarque monocline in the west-central part of the map

COMPOSITE STRATIGRAPHIC COLUMN





Good exposures of the Moreno Hill in the map area are limited to isolated patches in the northern half of the Venadito Camp quadrangle; the largest of these is in sec. 9, T7N, R20W. Here a carbonaceous shale containing a 3-ft-thick, high-ash coal zone overlain by a thin fluvial-channel sandstone is exposed. The dips are approximately 3° northeastward, and a drill hole penetrated the coal zone at a depth of 150 ft in the northeast corner of the section. Much of the area in adjacent sec. 4 and the E$^{1/2}$ of sec. 5 is underlain by the Moreno Hill, but it is masked by the Tertiary Bidahochi Formation or by alluvial and eolian material. The basal part of the Moreno Hill Formation is exposed in sec. 5, T6N, R19W, where it contains uneconomic coal beds 1–4 inches thick. In this area a remnant of the Moreno Hill Formation is preserved along a gentle synclinal axis west of the Atarque monocline.

CRETACEOUS SEQUENCE EAST OF NM–32—The stratigraphic sequence below the Atarque Sandstone remains the same in the eastern third of the map area. The intertongued Dakota–Mancos sequence undergoes little change, with the Paguate, Whitewater Arroyo, and Twowells Tongues all being well exposed at localities along NM–32 in the eastern part of the Upper Galestina Canyon quadrangle. A very fossiliferous bed occurs at the top of the Twowells along NM–32 in secs. 6 and 7, T6N, R17W. A collection made from this locality consists almost exclusively of *Pycnodonte kellumi*, with some forms transitional to *Pycnodonte newberryi*. Here and eastward through sec. 7 and into adjacent sec. 8 the Twowells displays sedimentary features such as wavy bedding, flaser bedding, and opposed crossbeds, all of which suggest deposition in a tidally influenced environment.

The concretion-bearing, normally fossiliferous, upper part of the Rio Salado Tongue of the Mancos is well exposed in the west-central part of the Shoemaker Canyon SE quadrangle in secs. 14, 22, 23, 27, and 34, T7N, R17W. Unfortunately, no ammonites were found in this area. Good exposures of this part of the section also occur to the north in secs. 28 and 29, T8N, R17W, but access was denied by the present landowner–leaseholder.

In the eastern part of the map area (east of NM–32) the Atarque Sandstone is reduced in rank from formation to member to reflect the fact that the stratigraphy becomes more complex owing to a subsequent marine transgression (Fig. 3). The sandstone associated with this transgression forms the upper part of a regressive–transgressive wedge that has been named the Tres Hermanos Formation by Hook et al. (1983). The Tres Hermanos consists of (in ascending order) the Atarque Sandstone Member, the nonmarine Carthage Member, and the Fite Ranch Sandstone Member.

The Atarque Member is a very pale orange and grayish-orange, upward-coarsening sandstone with distinct lower and upper shoreface units. In addition to these units, an upper unit composed of white to very pale orange, fine-grained, multidirectionally crossbedded sandstone locally forms a conspicuous cliff that rises above a bench developed on the upper shoreface unit. This uppermost sandstone represents another shoreface buildup and, as a result, the Atarque attains thicknesses of more than 60 ft, somewhat thicker than in the western part of the map area.

Fossils are sparse in the Atarque Member. The fossiliferous zone so common at the base of the member farther northward in the Zuni Basin is not present in the Atarque Lake 1:50,000 quadrangle. There are, however, two 4-inch-thick zones higher in the Atarque, in the upper shoreface unit, that contain abundant bivalves. The bivalves, which include *Pleuriocardia* sp. and *Ostrea* sp., are generally small and may be observed in the SW$^{1/4}$ sec. 22 and SW$^{1/4}$ sec. 33, T7N, R17W, where they occur in a brown-weathering, flat-bedded to low-angle crossbedded unit approximately 30 ft above the base of the Atarque Member.

Overlying the Atarque Member of the Tres Hermanos Formation is the coal-bearing Carthage Member. This member was deposited on the emergent coastal plain formed as the sea regressed to the northeast. It consists of paludal shales with thin coals, splay sandstones, and fluvial-channel sandstones. The basal portion is paludal shale. The contact with the underlying burrowed and root-penetrated Atarque Member is sharp. The basal coal zone, where present, lies 3–7 ft above the base and characteristically has a 2-inch-thick white claystone composed of volcanic ash near the middle. Immediately overlying the coal zone is a sequence of thin, flat-bedded, burrowed, and root-penetrated sandstones. These marginal-marine, flat-bedded sandstones have been used locally as an aid in identifying the top of the Atarque, but the top in this area is placed more appropriately at the base of the first significant paludal and/or carbonaceous shale.

The middle part of the Carthage Member is largely shale and mudstone and is poorly exposed. A prominent and widespread fluvial-channel complex is present 30 ft below the top of the member, and this sandstone is in turn overlain by a paludal shale with a carbonaceous zone. This upper carbonaceous zone is best exposed in the NE$^{1/4}$ sec. 24, T7N, R17W and in adjacent sec. 19. At this locality it is 2.5 ft thick and is coaly but does not constitute a coal resource. The carbonaceous zone is capped by a fine-grained splay sandstone, which is in turn overlain by a 20-ft-thick paludal-shale sequence. The total thickness of the Carthage Member is approximately 200 ft.

The Carthage is overlain by the marine Fite Ranch Member of the Tres Hermanos Formation. It is a fine-grained, flat-bedded to low-angle cross-bedded sandstone that locally contains *Inoceramus dimidius* at the base. At the measured section in the NE$^{1/4}$ sec. 24, T7N, R17W, it is 8–10 ft thick. The prominent topographic knob at elevation 7,480 ft is capped by the Fite Ranch Sandstone, and this isolated outcrop represents the southwesternmost occurrence of the member. It originally extended an unknown distance to the southwest. Because the overlying Pescado Tongue of the Mancos Shale is only 30 ft thick and thins quite rapidly southwestward in this area, the turnaround line for the transgression represented by the Fite Ranch Member and Pescado Tongue of the Mancos Shale was probably no more than 5 mi away.

The Fite Ranch varies in thickness locally from 2 to 10 ft and in places cannot be recognized, as in the NE$^{1/4}$ sec. 34, T7N, R16W. Significantly, it does not fine upward as might be expected in a transgressive sequence. To explain this, Hook et al. (1983) stated that the Fite Ranch Sandstone is a transgressive offlap sequence, meaning that long stillstands of the shoreline allowed extensive progradation of sand bodies to take place. These episodes were punctuated by relatively rapid advances of the shoreline, which transgressed its back-barrier and/or lagoonal deposits and then assumed a stillstand in a more landward position.

The southwesternmost occurrence of the Fite Ranch Member is an erosional remnant in the NE$^{1/4}$ sec. 24, T7N, R17W. The overlying Pescado Tongue of the Mancos Shale has been eroded off, and its southwesternmost occurrence is nearly 2 mi to the northeast (see accompanying geologic map). Hook et al. (1983) stated that the presence of the Fite Ranch Member and/or the Pescado Tongue shall determine the area in which the Tres Hermanos nomenclature is to be used. For the map area, however, it was considered appropriate to extend the Tres Hermanos nomenclature southwestward around the end of the topographic feature upon which the Fite Ranch truncation occurs. This carries the nomenclature throughout the Shoemaker Canyon SE quadrangle and into the eastern part of the adjacent Mesita de Yeso quadrangle. The latter quadrangle becomes the one in which the change in stratigraphic nomenclature takes place (Anderson, 1982). To relate this change to a line rather than an area, the following has been adopted by the New Mexico Bureau of Mines and Mineral Resources: the Tres Hermanos nomenclature will be used east of NM–32 and north of the Jaralosa Draw lobe of the North Plains lava field; Atarque Sandstone and Moreno Hill Formation will be used for this interval west of NM–32 and south of the basalt flow. This nomenclature change corresponds to a change in coal-field terminology. The Tres Hermanos outcrop defines the south and southwest edge of the Gallup–Zuni coal field. Coal occurrences in the Moreno Hill Formation to the south and west are part of the Salt Lake coal field.

The Pescado Tongue of the Mancos Shale separates the Fite Ranch Member of the Tres Hermanos Formation from the F member of the Gallup Sandstone. The Pescado is characterized by large limestone concretions at the base and very thin, fine-grained sandstones interbedded with shale in the lower one third to one half. No molluscan fossils were found in the Pescado during this investigation, but Hook et al. (1983) reported *Inoceramus dimidius* present near the middle of the unit farther north in the Zuni Basin. The Pescado thins progressively in a southwesterly direction, and at its southwesternmost outcrop in the E$^{1/2}$ sec. 8, T7N, R16W, it is approximately 30 ft thick. At the Terreo triangulation point in sec. 34 of the same township it is 28 ft thick; the rate of landward thinning in this area is 3–5 ft per mile. Molenaar (1973) has correlated the Pescado with the lower half of the D-Cross Tongue of the Mancos Shale.

The overlying Gallup Sandstone is approximately 200 ft thick and is subdivided into (in ascending order) the F member, an unnamed coal-bearing member, and the distinctive Torrivio Member.

The F member is a 45–50-ft-thick, regressive, coastal-barrier sandstone that marks a transition in the Zuni Basin from an open-marine environment, in which the underlying Pescado Tongue of the Mancos Shale was deposited, to a deltaic and coastal-plain environment, in which the overlying middle and upper parts of the Gallup were deposited. The lower half of the F member is flat-bedded, light-gray, very fine to fine-grained sandstone containing dark-gray silty and shaly partings; it is sparsely burrowed but otherwise unfossiliferous. This part of the member is poorly exposed except for the basal 5–10 ft, which locally forms subdued (rounded) ledges. It grades downward into the Pescado through an interval of 5–10 ft. The upper part of the member is mostly flat-bedded and cross-bedded, light-gray, fine-grained sandstone, which is somewhat more resistant than the lower part. In sec. 4, T7N, R16W, the top of the member consists of a 12-ft-thick bed of light-gray, fine-grained sandstone containing numerous burrows at the top. It is underlain by a 6-ft-thick interval composed of nonresistant shaly and slightly carbonaceous sandstone.

The middle coal-bearing member of the Gallup Sandstone is approximately 100 ft thick. It is the homotaxial equivalent of the informal Ramah unit of Anderson and Stricker (1984). At the base is a fluvial-channel sandstone bed 30–35 ft thick that rests with a sharp erosional contact on the marine sandstone of the F member. The fluvial sandstone is very light gray to very light yellowish gray, mostly fine grained but somewhat coarser at the base, crossbedded, and forms prominent rounded ledges and cliffs.

A variable sequence of fluvial and paludal rocks comprises the rest of the coal-bearing member. Included in the sequence are a dark-gray siltstone and a light-gray and light yellowish-gray, crossbedded and ripple-marked sandstone. Dark reddish-brown ferruginous concretions are common in some of the shale and claystone beds. Generally present along the eastern edge of the Atarque Lake 1:50,000 quadrangle are as many as four coal beds separated by shale, mudstone, and sandstone intervals a few inches to several feet thick. Individual coals commonly are 1–2 ft thick, thickening locally where two or more beds merge. The lowest of the coals rests directly on, or within a few inches of, the basal fluvial sandstone (see stratigraphic column). The next two higher coals contain 0.2–0.4-ft-thick identifiable partings of grayish-white, altered volcanic-ash beds (tonsteins). The ash beds can be useful in correlating the coals in an area of several square miles in this part of the Zuni Basin.

The Torrivio Sandstone Member (Molenaar, 1973) overlies the coal-bearing member and forms the top of the Gallup Sandstone. It consists of 40–50 ft of medium- to very coarse grained, crossbedded, feldspathic sandstone. Crossbed dip directions are almost exclusively east, northeast, and north indicating paleoflow in those directions. The Torrivio is generally reddish brown but is locally bleached. The color and the very coarse grained facies are the two main distinguishing characteristics of the Torrivio, and nearly always one or both are present in any given outcrop. A short distance to the north of the Atarque Lake 1:50,000 quadrangle, however, there are areas where neither of the distinctive characteristics are present, and one may be forced to do some lateral tracing to make certain that the sandstone in question is not a channel sandstone of the underlying coal-bearing member or the overlying Crevasse Canyon Formation.

With one very small exception, the Torrivio Member outcrops are restricted to the Shoemaker Canyon quadrangle in the northeast corner of the map. It is a bold cliff former and caps the mesas between 7,400-ft and 7,600-ft elevations.

The Crevasse Canyon Formation (Allen and Balk, 1954) overlies the Gallup Sandstone and is the youngest Cretaceous unit in the map area. It consists of fluvial-channel sandstones and floodplain and backswamp deposits. The floodplain and backswamp deposits consist of mudstone, shale, carbonaceous shale, and minor, thin coal beds. At few places in the map area does the remaining section of the Crevasse Canyon Formation exceed 100 ft in thickness (see map legend). It is well exposed in the NE$^{1/4}$ sec. 5 and the NE$^{1/4}$ sec. 6, T8N, R16W.

In his report on the Gallup–Zuni Basin, Sears (1925) used the names Dilco Coal Member, Bartlett Barren Member, and Gibson Coal Member for the sequence (in ascending order) above the Gallup Sandstone, all of which, including the Gallup, were at that time members of the Mesaverde Formation. These member names were retained for the new formation name, Crevasse Canyon, first used for this nonmarine sequence overlying the Gallup by Allen and Balk (1954) and later by Beaumont, Dane, and Sears (1956), who revised the entire Mesaverde Group nomenclature.

The Dilco Coal Member is 240–300 ft thick in the northern part of the Zuni Basin (Sears, 1925), where it was named for the abandoned village of Dilco (from Direct Line Coal Company). Thus, the basal 100 ft or so of Crevasse Canyon Formation that occurs as erosional remnants in the northeast corner of the accompanying map may be considered the equivalent of the Dilco Coal Member. Indeed that name is being used by U.S. Geological Survey investigators immediately to the north on the Zuni Reservation (G. D. Stricker, pers. comm. 1983).

Tertiary rocks

Tertiary rocks are present in the western half of the map area and on Mesita de Yeso in the south-central part. In these areas the light-gray and pinkish-gray lithic sandstone and conglomerate that unconformably overlie the Upper Cretaceous, Jurassic, and Triassic rocks are here assigned to the Bidahochi Formation (Miocene–Pliocene). The conglomerates in the unit are composed largely of pebble- to boulder-size volcanic clasts—vesicular basalts, basaltic andesites, and rhyodacites—that indicate an ultimate source to the southeast in the Datil, Mangas, and Gallo Mountains. However, it is likely that much or all of this coarse facies was derived from the coarse-grained, conglomeratic deposit of very similar lithology, although much thicker, that is present over much of the Zuni Plateau and Santa Rita Mesa. The Santa Rita Mesa deposit 7 mi to the south and generally a minimum of 200 ft higher in basal elevation has been designated as the Fence Lake Formation (McLellan et al., 1982). This elevation difference may be the critical factor in distinguishing the two units. The Bidahochi Formation, which is younger than the Fence Lake Formation (Miocene), would be inset below the Fence Lake as it is known to be in the Twentytwo Spring quadrangle to the south (Anderson and Frost, 1982). This topographically lower position plus the local presence of white, rhyolitic ash beds are two of the criteria used to support a Bidahochi assignment. No such ash beds have been reported in the Fence Lake Formation. Perhaps an even more convincing argument for the Bidahochi Formation is the fact that in T7N, R20W these deposits are graded to a late Pliocene–early Pleistocene valley floor now delineated by the 1.41-m.y.-old Jaralosa Draw lobe of the North Plains lava field. In this area the Bidahochi is incised and backfilled across the Atarque monocline, indicating southwest transport directions, which would be consistent with local reworking of Fence Lake Formation deposits. Southwest paleoflow directions are inconsistent with the Fence Lake Formation, which was deposited by a northwest-flowing fluvial system.

Some of the better outcrops of the Bidahochi are in the southwestern part of the map area. Here the unit may exceed 100 ft in thickness, but only the basal part is well exposed. This is also an area where northeast-trending cross folds, more or less orthogonal to the Atarque monocline, were recognized. On the northwest limb of one such anticlinal cross fold in the SW$^{1/4}$ sec. 24, T7N, R20W, the Bidahochi Formation has northwest dips of up to 18°, suggesting that the folding may be as young as late Pliocene. This deformation may be related to an episode of northwest–southeast-directed late Tertiary crustal extension. Field evidence of such extensional deformation this far west of the Jemez lineament (Laughlin et al., 1982) has not thus far been recognized (Richard M. Chamberlin, pers. comm. 1984).

In the northeast corner of the map area, in secs. 35 and 36, T9N, R17W and in sec. 31, T9N, R16W, are two small isolated occurrences of Tertiary rocks. These are composed chiefly of coarse-grained sandstone and bouldery conglomerates. The conglomerates consist of basalt, basaltic andesites, rhyodacites, and other volcanic rocks. This lithology plus the topographically high position, basal elevation 7,600 ft, suggest that they are remnants of the Fence Lake Formation. The unit originally covered much of the southern half of the Zuni Basin, and reworking of these deposits during the Pliocene time provided local source rock for the Bidahochi Formation.

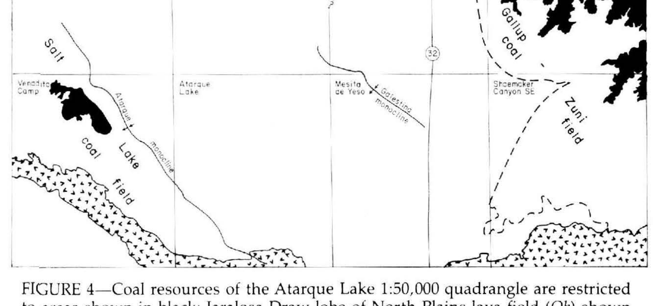


FIGURE 4—Coal resources of the Atarque Lake 1:50,000 quadrangle are restricted to areas shown in black; Jaralosa Draw lobe of North Plains lava field (*Qb*) shown in pattern. Eastern boundary of Salt Lake coal field follows Atarque monocline; western boundary of Gallup–Zuni coal field defined by heavy dashed line.

Coal resources

Coal resources in the roughly 480 mi^2 of the Atarque Lake 1:50,000 quadrangle are restricted to the two areas illustrated in Fig. 4. In the southwestern part, limited to the Venadito Camp quadrangle, is a small area of coal resources within the Salt Lake coal field. In the northeastern part, limited to the Shoemaker Canyon quadrangle and extreme northeastern corner of the Shoemaker Canyon SE quadrangle, is a somewhat larger area of coal resources that lies within the Gallup–Zuni coal field. In this report the southern and western boundaries of the Gallup–Zuni coal field coincide with the southwestern extent of the basal member of the Tres Hermanos Formation, the Atarque Sandstone Member. It should be noted that there are occurrences of high-ash coal in thin, lenticular beds in the underlying Dakota Sandstone that extend several miles farther west, but these beds are generally too thin to be considered a resource.

The portion of the Salt Lake field that extends onto the accompanying map is bounded on the east and northeast by the Atarque monocline (Fig. 4). The demonstrated coal resources within this portion of the field are

TABLE 1—Estimated coal resources in the Moreno Hill Formation, Venadito Camp quadrangle, March 1982, in thousands of short tons; all values rounded; 1,800 short tons/acre ft used in the calculation. Total demonstrated resources (measured + indicated) = 5,800.

Township and range	1.2–2.3 ft Measured	1.2–2.3 ft Indicated	2.3–3.5 ft Measured	2.3–3.5 ft Indicated	Inferred
T7N, R20W	—	—	2300	3500	2500
T8N, R20W	—	—	—	—	1200
Totals	—	—	2300	3500	3700

restricted to approximately a 2-mi^2 area within T7N, R20W. A very small area of inferred resources extends northward into T8N, R20W.

The coal occurs in the lower part of the Moreno Hill Formation, approximately 20 ft above the top of the main part of the Atarque Sandstone. Coal from this part of the Moreno Hill Formation somewhat to the southeast of this area has been classified as high-volatile bituminous B and C (Roybal and Campbell, 1981). Thus, a bituminous rank was assigned to the coal in the present study area, and accordingly the 14-inch minimum thickness was used in the coal-resource calculations (Wood et al., 1983). The main coal bed, as measured in outcrop in sec. 9, T7N, R20W, is 3 ft thick, with two white claystone (tonstein) partings that reduce the aggregate coal thickness to 30 inches. In addition to the outcrop measurements, two drill holes in secs. 9 and 15, T7N, R20W penetrated the main coal bed at depths of 150 ft and 130 ft, respectively. These measurements and drill-hole data provided the basis for the coal-resource figures presented in Table 1.

TABLE 2—Analyses (in %) of coal from a split bed in the Gallup Sandstone exposed in a roadcut in the SE$^{1/4}$NE$^{1/4}$ sec. 33, T8N, R16W, Cibola County, New Mexico. Forms of analysis: A—as received, B—moisture free, and C—moisture and ash free (analyses by the U.S. Department of Energy, 18 February 1980). Descriptions of samples: K98773—0.6-ft-thick upper split above 0.4-ft-thick tonstein, K98772—1.4-ft-thick lower split below the tonstein (from Anderson and Mapel, 1983).

Sample number	Form of analysis	Proximate: Moisture	Proximate: Volatile matter	Proximate: Fixed C	Proximate: Ash	Ultimate: S	Ultimate: H	Ultimate: C	Ultimate: N	Ultimate: O	Heat values BTU/lb
K98773	A	10.6	36.7	42.6	10.1	0.6	4.7	54.7	1.1	28.8	9017
	B	—	41.0	47.7	11.3	0.7	3.9	61.2	1.2	21.7	10085
	C	—	46.3	53.7	—	0.8	4.4	69.0	1.4	24.5	11365
K98772	A	11.3	37.0	45.0	6.7	0.6	4.9	57.7	1.2	29.0	9471
	B	—	41.7	50.7	7.6	0.6	4.1	65.0	1.4	21.4	10673
	C	—	45.1	54.9	—	0.7	4.4	70.3	1.5	23.1	11548

Coal in the Gallup–Zuni coal field is also classified as high-volatile bituminous C, based on the analyses of samples of fresh coal from a bed in the Gallup Sandstone approximately 6 mi north of the map boundary (Sears, 1925, p. 50). Table 2 shows the analyses of two samples of weathered coal from a coal bed in the Gallup Sandstone exposed in a roadcut near the southeastern corner of the Shoemaker Canyon quadrangle. The analyses show ash contents of 6.7% and 10.1%, respectively, and sulfur contents of 0.6% for the weathered coal, which is slightly less than the values reported by Sears (1925, p. 50) for the fresh coal from approximately the same horizon. Heat values of 9017 and 9471 BTU/lb on an as-received basis for the weathered coal (Table 2) compare with an average of approximately 11,000 BTU/lb for the fresh coal as reported by Sears (1925, p. 50). The weathered condition of the coal probably accounts for the low heat values reported in Table 2.

TABLE 3—Estimated coal resources in the Gallup Sandstone, Shoemaker Canyon SE quadrangle, 1 February 1983, in thousands of short tons; all values rounded; 1,800 short tons/acre ft used in the calculation. Total demonstrated resources (measured + indicated) = 1,400; no inferred resources calculated.

Township and range	1.2–2.3 ft Measured	1.2–2.3 ft Indicated	1.2–2.3 ft Total	2.3–3.5 ft Measured	2.3–3.5 ft Indicated	2.3–3.5 ft Total	Total in township
T8N, R16W	120	180	300	95	—	95	400
T7N, R16W	440	140	580	370	20	390	970
Totals rounded	560	320	880	470	20	490	1400

Estimated resources of bituminous coal in the Shoemaker Canyon SE quadrangle total 1.4 million tons. Table 3 lists the demonstrated resources by township according to thickness and reliability categories established by Wood et al. (1983). The estimates are based on coal-bed measurements made at five places in the northeastern part of the quadrangle in sec. 34, T8N, R16W and in secs. 3 and 4, T7N, R16W. All the beds for which resources are estimated are in the coal-bearing member of the Gallup Sandstone. Coal beds and lenses in the Carthage Member of the Tres Hermanos Formation are too thin and discontinuous for resource estimates.

No coal-resource figures are presented herein for the Shoemaker Canyon quadrangle. Most of the coal-bearing areas of this quadrangle are on either Zuni Reservation land or Ramah Navajo Reservation land. Administrative reports from the respective tribal councils have been, or are being, prepared by the Branch of Coal Resources of the U.S. Geological Survey (Box 25046 Federal Center, Denver, Colorado 80225). The coal resources of the Shoemaker Canyon quadrangle are restricted to the coal-bearing member of the Gallup Sandstone and are for the most part limited to T8N, R17W and T8N, R16W. In the latter township the coal occurs in three thickness categories (1.2–2.3 ft, 2.3–3.5 ft, and 3.5–7.0 ft), and generally two white claystone (tonstein) partings 0.2–0.5 ft thick may be observed at every outcrop.

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