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Since September 1978, the U.S. Geological Survey (USGS) and the New Mexico Bureau of Mines and Mineral Resources have been studying the geology and coal resources of the Salt Lake coal field, Catron and Valencia Counties, New Mexico. This work forms a portion of the regional coal resource-assessment program of the Coal Exploratory Program of the USGS. As part of this study the USGS is mapping four 7½-minute quadrangles (Moreno Hill, Rincon Hondo, Fence Lake, and Fence Lake SW), and the New Mexico Bureau of Mines is mapping four 7½-minute quadrangles (Twentytwo Spring, Cantaralo Spring, The Dyke, and Cerro Prieto). Mapping is nearly complete on the Moreno Hill, Twentytwo Spring, Fence Lake SW, and Cerro Prieto quadrangles; now a regional stratigraphic framework that can be applied to map units in these quadrangles must be established. This paper shows how and why the nomenclature applied to the intertongued Dakota Sandstone–Mancos Shale sequence of the southeastern San Juan Basin can be extended into the southern Zuni Basin for use in the Salt Lake coal field.

Correlation

The intertongued Dakota Sandstone–Mancos Shale rock sequence is best developed in well-exposed sections south of Laguna, Valencia County, New Mexico (fig. 1). Here, Landis and others (1973) established the principal reference section for this sequence (fig. 2, section 9; table 1). From bottom to top this sequence consists of the Oak Canyon Member of the Dakota Sandstone, the Cubero Tongue of the Dakota Sandstone, the Clay Mesa Tongue of the Mancos Shale, the Paguate Tongue of the Dakota Sandstone, the Whitewater Arroyo Tongue of the Mancos Shale, and the Twowells Tongue of the Dakota Sandstone. All but the upper two tongues have their type sections in the Laguna principal reference sequence (fig. 2, section 9) and were named by Landis and others (1973). The upper two tongues, the Whitewater Arroyo and the Twowells, with type sections near the village of Two Wells, McKinley County, New Mexico (fig. 2, section 1), were named, respectively, by Owen (1966) and by Pike (1947) and were classified as tongues by Dane and others (1971).

Landis and others (1973, fig. 3) demonstrated that the Paguate Tongue of the Dakota Sandstone merges with the main body of the Dakota Sandstone approximately 12 mi (19 km) west of Grants and that the Clay Mesa Tongue of the Mancos Shale wedges out in the main body of the Dakota Sandstone between the Grants and Mount Powell areas (fig. 1). Consequently, tongues lower than Whitewater Arroyo cannot be recognized in either the Gallup or Two Wells area of the Zuni Basin. However, fossils collected from the top of the main body of the Dakota Sandstone at the Two Wells section (Dane and others, 1971) indicate an age no older than that of the Paguate at its type section (Landis and others, 1973).

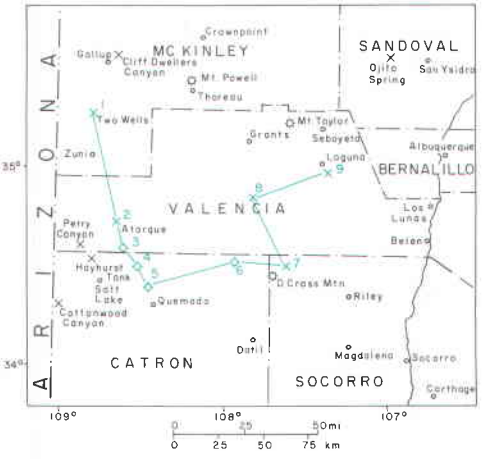

FIGURE 1—INDEX MAP OF PART OF WEST-CENTRAL NEW MEXICO showing the locations of outcrop sections (x) and oil tests (-◇-) and line of section for fig. 2.

The Twowells Sandstone and Whitewater Arroyo Shale can be traced physically from their type sections to the vicinity of Atarque (figs. 1 and 2). South of Atarque the Cretaceous sequence is covered by Tertiary basalts for a distance of 2 mi (3.2 km). South of this basalt cover, the Twowells can be recognized on the basis of the stratigraphic interval separating it from the underlying main body of the Dakota Sandstone (fig. 2, sections 3-6) and the next overlying sandstone unit, the Atarque Member of the Mesaverde Formation of Pike (1947). In addition the Mancos Shale tongue overlying the Twowells contains a distinctive 50-ft (15-m) thick sequence of interbedded limestone and calcareous shale near its base. This limestone sequence is of late Greenhorn age and is equivalent to the Bridge Creek Limestone Member of the Greenhorn Formation (Cobban and Scott, 1972). The base of the Bridge Creek equivalent is a 6-inch (15-cm) thick, white- to orange-weathering, concretionary limestone that generally occurs 20-40 ft (6-12 m) above the top of the Twowells; the uppermost limestone is calcarenite, 2-6 inches (5-15 cm) thick, composed of inoceramid debris. In the subsurface the Bridge Creek equivalent produces a distinctive resistive deflection zone on electric logs.

Throughout the area of west-central New Mexico shown in figs. 1 and 2, we regard the base of the Bridge Creek equivalent as an isochronous surface because this 6-inch (15-cm) thick limestone is lithologically distinctive, widespread, and easily recognizable and because it carries the same vertically restricted molluscan fauna throughout its extent. This fauna includes the late Cenomanian ammonites *Sciponoceras gracile* (Shumard) and *Metoicoceras gibbosum* Hyatt, which are restricted to a vertical range of less than 10 ft (3 m) of section in west-central New Mexico. The datum line for fig. 2 was chosen at the top of the Twowells because this surface is subparallel to the base of the Bridge Creek equivalent and is easily recognizable.

Our interpretation of the thickness of the Twowells in the Huckleberry No. 1 Federal oil test (fig. 2, section 5) differs significantly from those of Gadway (1959) and Foster (1964). Both Gadway and Foster interpreted this unit as two sandstones separated by a medial shale, totaling 85 ft (25.9 m) in thickness (from a depth of 1,725 ft to 1,810 ft). Gadway referred this unit to the Tres Hermanos Sandstone; Foster considered it an unnamed sandstone in the Mancos Shale. We have interpreted the basal 40-ft (12.2-m) sandstone of this interval as the Twowells and the upper 45 ft (13.7 m) as the limestones, calcareous shales, and calcarenites of the overlying Bridge Creek equivalent.

A marine sandstone, 24 ft (7.3 m) thick, separated from the main body of the Dakota Sandstone by a marine shale, 50 ft (15.2 m)

TABLE 1—LOCATION OF SECTIONS SHOWN ON FIG. 2.

1—Two Wells—outcrop section from Dane, Landis, and Cobban (1971, p. 318); measured in NE¼ sec. 17, T. 12 N., R. 19 W., McKinley County, New Mexico
2—Atarque—outcrop section measured by C. H. Dane, E. R. Landis, and W. A. Cobban in sec. 24, T. 6 N., R. 18 W., Valencia County, New Mexico
3—Tiger State No. 1—oil test drilled in sec. 8, T. 4 N., R. 17 W., Valencia County, New Mexico
4—Cleary No. 1 Federal—oil test drilled in sec. 6, T. 3 N., R. 16 W., Catron County, New Mexico
5—Huckleberry No. 1 Federal—oil test drilled in sec. 11, T. 2 N., R. 16 W., Catron County, New Mexico
6—Spanel and Heinze No. 1-9617—oil test drilled in sec. 27, T. 4 N., R. 11 W., Catron County, New Mexico
7—D Cross Mountain—outcrop section measured by B. Robinson in secs. 8, 21, T. 3 N., R. 8 W., Socorro County, New Mexico
8—The Narrows—outcrop section from Landis, Dane, and Cobban (1973, p. J36–J37) measured in secs. 3, 4, T. 7 N., R. 10 W., Valencia County, New Mexico
9—Laguna—outcrop section from Landis, Dane, and Cobban (1973, p. J4–J8) measured in secs. 20, 21, T. 10 N., R. 5 W., Valencia County, New Mexico

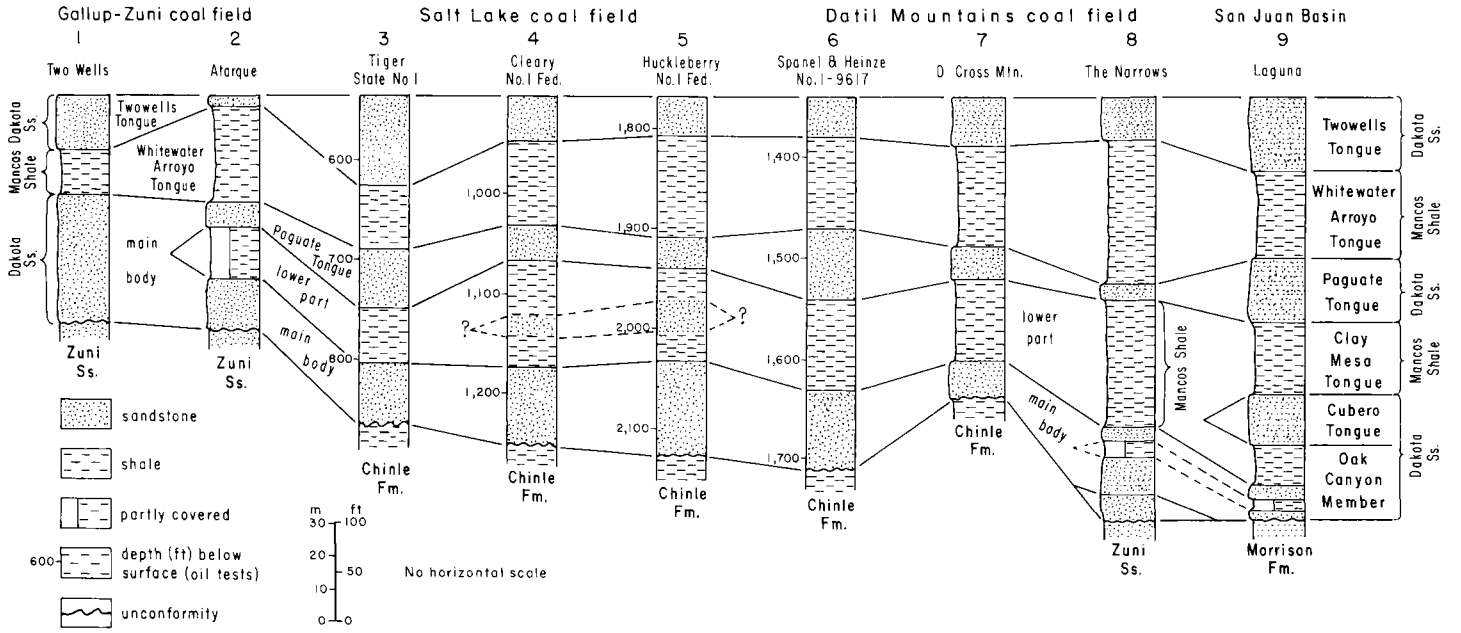

FIGURE 2—GENERALIZED GRAPHIC SECTIONS SHOWING CORRELATION OF THE INTERTONGUED DAKOTA SANDSTONE-MANCOS SHALE SEQUENCE in the southern part of west-central New Mexico. A tongue of Mancos Shale overlies the Twowells Tongue of the Dakota Sandstone. Both the Zuni Sandstone and Morrison Formation are of Jurassic age; the Chinle Formation is of Triassic age. Precise geographic locations of the sections are presented in table 1; the line of section is shown on fig. 1.

thick, is present in the Atarque section but is not present to the north in either the Two Wells section (fig. 2, section 1) or the Cliff Dwellers Canyon section (fig. 1) of Landis and others (1973, p. J32, J33). This sandstone can, however, be correlated to the south with a 60-ft (18.3-m) sandstone in the Tiger State No. 1 wildcat (fig. 2, section 3). From the Tiger State well it can be correlated eastward through the subsurface (fig. 2, sections 3-6) into a surface section at D Cross Mountain (fig. 2, section 7). From D Cross Mountain the marine sandstone can be traced into the type section of the Paguate Tongue of the Dakota Sandstone (fig. 2, section 9).

Fossils collected from the top of this sandstone in the Perry Canyon area of the Twentytwo Spring quadrangle help substantiate this correlation. These fossils include the ammonite *Acanthoceras amphibolum* Morrow, which has been found only in the Paguate Tongue in west-central New Mexico (Cobban, 1977a, b). In addition, an 8-inch (20-cm) thick bentonite bed approximately 35 ft (10.7 m) above the top of the Paguate Sandstone at D Cross Mountain is apparently also present in a similar stratigraphic position in Perry Canyon (fig. 1). We have attached considerable importance to this bentonite bed because 1) bentonites more than 6 inches (15 cm) thick are rare in the Dakota-Mancos sequence in west-central New Mexico and 2) this bentonite is approximately the same age as the marker or "X" bentonite bed, which lies within the *Acanthoceras amphibolum* Zone and has been dated at 92.1 m.y. (Obradovich and Cobban, 1975).

South of Laguna the Clay Mesa Tongue of the Mancos Shale is coextensive with the underlying Cubero Tongue of the Dakota Sandstone. The term "Clay Mesa Tongue," therefore, cannot be extended south of the wedge-out point of the Cubero Tongue into Mancos Shale in secs. 20 and 21, T. 9 N., R. 9 W. (Maxwell, 1977), approximately 11 mi (17.7 km) northeast of the Narrows measured section (fig. 2, section 8). Accordingly, the informal term "lower part of the Mancos Shale" (Landis and others, 1973, figs. 2, 4) is used south of the wedge-out point of the Cubero Tongue. "Lower part" as used on fig. 2 includes rocks of different time-equivalency in different parts of west-central New Mexico. For example, at the Narrows (fig. 2, section 8), the lower part of the Mancos Shale includes rocks laterally and temporally equivalent to the Clay Mesa Tongue of the Mancos Shale, the Cubero Tongue of the Dakota Sandstone, and the upper part of the Oak Canyon Member of the Dakota Sandstone; whereas at Atarque (fig. 2, section 2), it probably only includes rocks laterally equivalent to the Clay Mesa Tongue. South of Atarque, the lower part of the Mancos Shale may include substantial thicknesses of sandstone (fig. 2, sections 4, 5); detailed mapping may indicate that these sandstones belong more properly in the main body of the Dakota Sandstone. Fossils collected from the basal 10 ft (3 m) of the lower part of the Mancos Shale near Hayhurst Tank, Moreno Hill quadrangle, include *Pycnodonte* cf. *P. kellumi* (Jones), *Tarrantoceras rotatile* Stephenson, and *Acanthoceras* aff. *A. alvaradoense* Moreman and indicate an age no older than that of the basal part of the Clay Mesa Tongue at its type section.

The rocks that are called main body of the Dakota Sandstone on fig. 2 are the marine, marginal marine, and nonmarine rocks that make up the lowest part of the Cretaceous sequence in west-central New Mexico and that cannot be included in one of the other named member-rank units in the sequence.

Age of the Dakota-Mancos sequence

Fossils collected from the intertongued Dakota-Mancos sequence within the area encompassed by the sections on fig. 2 indicate an early Late Cretaceous age for the entire sequence. The Twowells and Whitewater Arroyo Tongues are late Cenomanian, whereas the remainder of the member rank units are middle Cenomanian (Cobban, 1977a, b). Palynomorphs from the lower part of the Oak Canyon Member, originally regarded as late Albian, are now considered to be Cenomanian in age (Cobban, 1977a).

The youngest fossils in the Dakota-Mancos sequence occur in the Twowells. We have collected the oyster *Pycnodonte newberryi* (Stanton) from the top of the Twowells in the northeast part of the Twentytwo Spring quadrangle. *Pycnodonte newberryi* ranges from the latest Cenomanian *Sciponoceras gracile* Zone into the overlying earliest Turonian *Pseudaspidoceras* Zone in central and southwest New Mexico (Hook and Cobban, 1977; Cobban and Hook, 1979). In addition, we have collected the ammonite *Pseudaspidoceras* from the top of the Twowells along the New Mexico-Arizona boundary in the Cottonwood Canyon area (fig. 1). These occurrences indicate that the top of the Twowells is becoming younger to the southwest.

The oldest fossils in the Dakota-Mancos sequence occur in the upper part of the Oak Canyon Member at Laguna and near the base of the lower part of the Mancos Shale in the D Cross Mountain area. These fossils generally occur in ferruginous silty to sandy, limy concretionary beds and include 34 species of bivalves, 11 species of gastropods, and five species of ammonites (Cobban, 1977a, b). Many of these species have been recorded

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from the Woodbine Formation of Texas, and most have been recorded from the Thatcher Limestone Member of the Graneros Shale of southeast Colorado (Cobban and Scott, 1972). This fauna will be referred to as the Thatcher fauna and includes the bivalves *Inoceramus eulessanus* Stephenson, *Plicatula arenaria* Meek, *Pycnodonte* cf. *P. kellumi* (Jones), *Exogyra columbella* Meek, and *Ostrea beloiti* Logan; the gastropod *Arrhoges modesta* (Cragin)?; and the ammonites *Turrilites acutus* Passy, *Calycoceras tarrantense* (Adkins), *Borissiakoceras compressum* Cobban, and *Johnsonites sulcatus* Cobban (Cobban, 1977a, b). The Thatcher fauna is middle Cenomanian in age and is the ". . . oldest unquestioned Cenomanian megafossil zone in the Western Interior. . . ." (Cobban, 1961, p. 738).

The oldest Cretaceous fossils that we have collected from the Salt Lake coal field area are from the basal 10 ft (3 m) of the lower part of the Mancos Shale near Hayhurst Tank. These fossils are late middle Cenomanian in age and are younger than those from the Thatcher level, but older than those from the top of the main body of the Dakota Sandstone at the Two Wells section (fig. 2, section 1).

Seboyeta Bay

The results presented in this paper and summarized graphically in fig. 2 show that there is a thicker sequence of marine rocks below the Twowells Tongue in the southern part of the Zuni Basin than in the northern part. Fossils collected from these rocks indicate that the base of this marine sequence is older to the south, thus ruling out depositional thickening as the only causative agent. These results are incompatible with a northwest-southeast-trending Late Cretaceous shoreline that advanced landward in a generally southwesterly direction and retreated seaward in a generally northeasterly direction (Peterson and Kirk, 1977, p. 171). Paleontologic and stratigraphic evidence indicates, however, that this northwest-southeast-trending shoreline was established in New Mexico during latest Cenomanian and earliest Turonian time (Hook and Cobban, 1977, fig. 1) and persisted through middle Turonian time (Cobban and Hook, 1979, fig. 2) and late Turonian time (Hook and Cobban, 1979, fig. 4; 1980, fig. 6).

The marine rocks that include the Thatcher fauna record the earliest transgression of the Late Cretaceous seaway into New Mexico during middle Cenomanian time. These rocks occur over an area of west-central New Mexico with a north-south extent of approximately 75 mi (121 km) and an east-west extent of slightly more than that. This area, centered roughly on Mount Taylor, is herein called Seboyeta Bay, for the community of Seboyeta in northeast Valencia County (fig. 3).

Initial Cretaceous deposits in and around Seboyeta Bay—the lower part of the Oak Canyon Member and time-equivalent rocks in the main body of the Dakota Sandstone—are fluvial conglomerates and sandstones, followed by dark marine shale containing hystrichospherids, dinoflagellates, and spores

FIGURE 3—Map of New Mexico and southern Colorado showing localities where Thatcher fauna has been collected (x) and the approximate position of the Late Cretaceous shoreline (----) during Thatcher time (Middle Cenomanian).

of Cenomanian age. As the bay enlarged, these units were succeeded upward by marine shale and sandstone containing the Thatcher fauna. These marine beds merge northward and westward with the fluviatile sediments typical of the main body of the Dakota Sandstone (Landis and others, 1973).

Fossils definitely of Thatcher age are present as far west as sec. 31, T. 15 N., R. 12 W., McKinley County, just west of the Thoreau to Crownpoint road, where they are in sandstone 57 ft (17.4 m) below the top of the main body of the Dakota Sandstone. The northernmost occurrence is near Ojito Spring, Sandoval County, where the Thatcher fauna occurs 5 ft (1.5 m) above the main body of the Dakota. To the south, a collection 10 ft (3 m) above the top of the main body of the Dakota Sandstone near D Cross Mountain, Socorro County, is the last unquestionable fauna of Thatcher age. Southeast of D Cross Mountain at Carthage, fossils collected from the base of the Mancos Shale reveal an age no older than that of the Clay Mesa at its type section.

Thus, only to the east is there a possible inlet from the main body of the Western Interior seaway. Unfortunately, we have not collected the Thatcher fauna at the sections that crop out in the area where it might be present. We have not yet found a Thatcher level in a section south of San Antonito, Bernalillo County; nor in a section at Lamy, Santa Fe County; nor in an intermediate section between these two, at Rosario, west of Cerrillos, Santa Fe County. The regional stratigraphical and paleontological results summarized above absolutely compel that an avenue to the sea must have been open to the east; it may, however, have been considerably narrower, with a stronger northeasterly trend than indicated on fig. 3.

Seboyeta Bay expanded in three directions (north, west, and south) until early late Greenhorn time (latest Cenomanian to earliest Turonian) when it merged with the main body of the Western Interior seaway. Limestone beds were then deposited throughout most of the Western Interior seaway. In west-central New Mexico the base of these limestones is generally within the lower 20-40 ft (6-12 m) of the Mancos Shale tongue overlying the Twowells.

By logical inference, Seboyeta Bay expanded (transgressed) into the southern Zuni Basin sooner than it did into the northern part because of a faster southwesterly transgression rate. This explanation would account for the thicker and older sequence of Cretaceous rocks in the Salt Lake coal field area without having to invoke inter- and intra-formational unconformities for which we have no evidence.

Pike (1947) had come to a similar conclusion more than 30 years ago. In the discussion of his measured section near Atarque, Pike (1947, p. 36) noted that this section ". . . differs from those to the north in that it shows a considerable thickening of that part of the Mancos Shale below the zone of [*Pycnodonte*] *newberryi* . . . and in the presence of a thick massive sandstone within this enlarged shale section. . . . The significance of these relationships is rather important in that they seem to indicate an advance of the sea in this locality, perhaps in a local embayment, earlier than anywhere else in the Mesa Verde–Atarque area."

Summary

The stratigraphic nomenclature applied to the intertongued Dakota Sandstone–Mancos Shale sequence of the San Juan Basin can be extended in part into the southern Zuni Basin for use in the Salt Lake coal field. The upper two tongues of this sequence, the Twowells and Whitewater Arroyo, can be traced in surface sections from their type sections in the northern Zuni Basin to Atarque, just north of the Salt Lake coal field, where the Cretaceous sequence is covered by Tertiary basalt. From Atarque these members can be correlated into surface and subsurface sections in the coal field to the south.

An additional marine sandstone tongue, separated from the main body of the Dakota Sandstone by a marine shale tongue, is present at Atarque and in the Salt Lake coal field, but is not present in the northern part of the basin. Paleontologic evidence from the Salt Lake coal field indicates that the sandstone tongue is of the same age as the Paguate Tongue at its type section and that the shale tongue is no older than the Clay Mesa Tongue at its type section. The sandstone tongue can be correlated through subsurface and surface sections with the Paguate at its type section south of Laguna. The shale tongue is probably equiva-

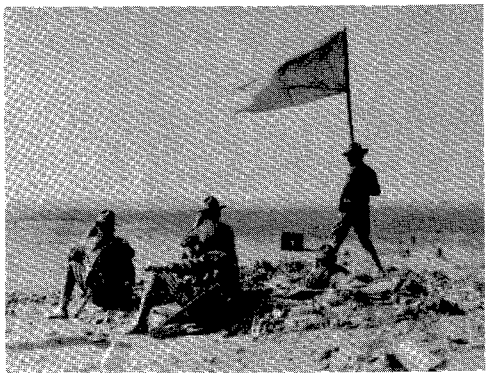
(continued on p. 46)

of gas-filled cavities when the rock cooled. East of Villa Hill, rocks exposed along the paths are a typical cross section of volcanic flows, showing flow basalt that is locally brecciated and contains small angular fragments of the gravels onto which it was extruded.

To the north-northeast is Columbus, and in the distance are the rugged Florida Mountains. On the eastern skyline, across the irrigated sandy Columbus Valley, the low volcanic hills of the West Potrillo Mountains stretch southward into northern Chihuahua. Other volcanic hills and ranges lie to the south amid sandy plains south of Palomas in northern Mexico. Underground water from ancient rains, stored in sand and gravel underlying the plains around Columbus, is now pumped to irrigate the green fields that circle the town.

During past centuries the Mimbres River (which rises in the Mogollon and Black Range areas north of Santa Rita) has, during flood stage, swept past Deming, rushed around the north and east sides of the Florida Mountains, and passed east of Columbus into Mexico to fill playas below Palomas.

To the southwest are the rugged peaks of Sierra de Palomas in northern Chihuahua, and on the western horizon is the sharp peak of Big Hatchet Mountain in southwest New Mexico. Sierra de Palomas' extension across the Mexican-American border (15 mi to the west) is the Carrizalillo Hills; the Cedar Mountains form the low skyline ridges to the west-northwest. Five miles to the northwest, bold, jagged triple peaks of the three sisters (Tres Hermanas Mountains) block distant views in that direction.



SOLDIERS ON LOOKOUT ATOP VILLA HILL, March 10, 1916 (courtesy New Mexico Historical Society).

Pancho Villa State Park is on the low edges of the large alluvial fan that extends southeast from the Tres Hermanas Mountains. Pebbles, cobbles, and boulders in the park were derived from rock outcrops in those mountains; they include fragments of quartz, feldspar, monzonite, rhyolite, latite, basalt, limestone, chert, and andesite. Mines in the northwest Tres Hermanas Mountains operated until the 1920's and produced about one-half million dollars worth of zinc, lead, silver, gold, and copper. Present-day outcrops of interest to rock hounds contain Mexican onyx, calcite, spurrite, and dumortierite. □

F. E. Kottlowski (revised 1980)

Dakota-Mancos terminology *(continued from p. 44)*

lent to the Clay Mesa Tongue, but that term cannot be extended into the Salt Lake area because of the pinchout of the underlying Cubero Sandstone Tongue of the Dakota Sandstone into Mancos Shale 30 mi (48 km) southwest of the Laguna section. Consequently, the informal term "lower part of the Mancos Shale" is applied to this unit. Similarly, the rocks that make up the lowest part of the Cretaceous sequence in the southern Zuni Basin cannot be included in one of the other named member-rank units and are simply referred to as the main body of the Dakota Sandstone.

The Dakota-Mancos sequence in the Salt Lake coal field consists of—from bottom to top—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, and the Twowells Tongue of the Dakota Sandstone.

Seboyeta Bay, an east-west lobe of the Western Interior seaway about 75 mi (121 km) long and wide, and roughly centered on Mount Taylor, provides an explanation for the thicker and older Dakota-Mancos sequence found in the southern Zuni Basin. Seboyeta Bay formed in middle Cenomanian time and expanded in a northerly, westerly, and southerly direction until latest Cenomanian to earliest Turonian time, when it became indistinguishable from the main body of the Western Interior seaway. Deposition of marine rocks occurred earlier in the Salt Lake coal field than in the northern Zuni Basin apparently because of a faster southwesterly transgression rate.

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