Stratigraphy of the Dakota Sandstone and intertongued Mancos Shale along the southern flank of the San Juan Basin, west-central New Mexico

Donald E. Owen and Owen, Donald E., Jr.

2003, pp. 325-330. https://doi.org/10.56577/FFC-54.325

in:

Geology of the Zuni Plateau, Lucas, Spencer G.; Semken, Steven C.; Berglof, William; Ulmer-Scholle, Dana; [eds.], New Mexico Geological Society 54 th Annual Fall Field Conference Guidebook, 425 p. https://doi.org/10.56577/FFC-54

This page is intentionally left blank to maintain order of facing pages.

New Mexico Geological Society Guidebook, 54th Field Conference, Geology of the Zuni Plateau, 2003, p. 325-330.

STRATIGRAPHY OF THE DAKOTA SANDSTONE AND INTERTONGUED MANCOS SHALE ALONG THE SOUTHERN FLANK OF THE SAN JUAN BASIN, WEST-CENTRAL NEW MEXICO

DONALD E. OWEN[1] AND DONALD E. OWEN, JR.[2]
[1] Department of Geology, Lamar University, Beaumont, TX 77710; [2] 2610 Evalon, Beaumont, TX 77702

Abstract.—The bold cliff exposures of the Dakota Sandstone and intertongued offshore marine Mancos Shale between the Church Rock area on the west and the Laguna area on the east are a key area for understanding the complex depositional history of these strata. Two sequence boundaries at the K-2 and K-3 unconformities, four prominent marine-flooding surfaces at the top of the lower Oak Canyon Member and the tops of the Cubero, Paguate, and Twowells Sandstone Tongues of the Dakota, and two widespread bentonites in the upper Oak Canyon (A bentonite) and the lower Whitewater Arroyo Shale Tongue of the Mancos (X bentonite) are the key correlation surfaces on these outcrops. Progressively lower Morrison Formation strata, the Jackpile, Brushy Basin, and Westwater Canyon Members, are erosionally truncated westward along the basal Dakota unconformities. The basal Dakota Encinal Canyon Sandstone Member is only present in the Laguna area. The marginal marine and offshore Oak Canyon onlaps the K-2 unconformity, and the Dakota main body, an informal fluvial unit derived from the west, onlaps the K-3 unconformity, which truncates the K-2 westward. The K-3 surface becomes a correlative conformity as the Dakota main body grades into shoreface Cubero Sandstone eastward. The Clay Mesa Shale Tongue of the Mancos wedges out westward between the Cubero and Paguate shoreface sandstones. The Whitewater Arroyo Shale and Twowells Sandstone at the top of the Dakota thin westward, but extend completely across the study area.

INTRODUCTION

Bold cliffs formed by the various north-dipping Dakota Sandstone members mark the southern flank of the San Juan Basin from Mesa Gigante east of Laguna to White Rock Mesa (Stop 5, Day 2, NMGS Field Conference, 2003) near Church Rock on the west. Prominent shale members of the Mancos form dipslopes between the sandstone cliffs from Mesa Gigante on the east to the Ambrosia Lake area in the central part of the study area. The lower shale tongues wedge-out westward, so that a thick, lower Dakota sandstone cliff is prominent west of the Ambrosia Lake area to White Rock Mesa, with a strike valley developed in the uppermost Mancos Shale tongue (Whitewater Arroyo Shale) and a cuesta formed by the uppermost Dakota Sandstone tongue (Twowells Sandstone) to the north. The purpose of this paper is to describe these east-west stratigraphic changes and relate them to several key correlation surfaces (marine-flooding surfaces and the X bentonite) and two sequence-bounding unconformities (K-2 and K-3).

The junior author of this paper has been most diligent in recognizing and tracing key bentonite beds on outcrops. Bentonites, long used for correlation in the Upper Cretaceous strata of the Western Interior Basin, have gone mostly unrecognized in the Dakota Sandstone of the San Juan Basin. However, many of the frequently used log markers within the San Juan Basin Dakota have been shown to be bentonites on the surface (Owen and Head, 2001, p. 3-4, 11). The truncation of the A bentonite in the upper Oak Canyon shale of the Dakota has led to recognition of a new sequence boundary in the Dakota at the K-3 unconformity (Owen and Head, 2001, p. 4, 12). Another bentonite (X) confirms that the upper part of the Dakota main body fluvial complex is the lateral equivalent of the marine Paguate Sandstone Tongue of the Dakota.

STRATIGRAPHY

Nomenclature

All of the formally named members of the Dakota and intertongued Mancos are present in the eastern part of the study area near Laguna (Table 1). The stratotypes of nearly all these members and the underlying Jackpile Sandstone Member of the Morrison Formation also are in the Laguna area. The exceptions are the Whitewater Arroyo and Twowells members, whose stratotypes are south of Gallup, southwest of the study area. Table 1 summarizes the pertinent stratigraphy of the Laguna area.

An informal fluvial unit, the Dakota main body (Landis et al., 1973), occurs in the lower-to-middle part of the section in the area west of the Ambrosia Lake area. This wedge-shaped, valley-fill complex (Fig. 1) rests on a newly recognized unconformity, referred to as K-3, continuing the K-1, K-2 unconformity nomenclature established by Molenaar (1977).

Sequence Stratigraphy

In addition to the formal lithostratigraphic units with their boundaries at lithologic changes, three other types of surfaces may be used to subdivide the Dakota and adjacent units. First are sequence boundaries, which comprise three major subaerial erosional unconformities of regional extent, in ascending order: SBK-1 at the base of the Burro Canyon Formation, not present in the southern San Juan Basin study area; SBK-2 at the base of the Encinal Canyon Member (Aubrey, 1988) in the Laguna area and at the base of the Oak Canyon Member to the west; and SBK-3 at the base of the Dakota main body where the newly recognized K-3 unconformity is present. This sequence boundary extends eastward into the marine environment as a locally scoured, but generally gradational, correlative conformity at the base of the

TABLE 1. Idealized "layer cake" lithostratigraphy of the Dakota Sandstone and adjacent units in the Laguna area, New Mexico. The lower four units are nonmarine; the upper six units are marine.

Formal Lithostratigraphic Members and Tongues	(Original Reference)
Twowells Sandstone Tongue of Dakota Sandstone	(Pike, 1947)
Whitewater Arroyo Shale Tongue of Mancos Shale	(Owen, 1966)
Paguate Sandstone Tongue of Dakota Sandstone	(Landis et al., 1973)
Clay Mesa Shale Tongue of Mancos Shale	(Landis et al, 1973)
Cubero Sandstone Tongue of Dakota Sandstone	(Landis et al., 1973)
Oak Canyon Member of Dakota Sandstone	(Landis et al., 1973)
Encinal Canyon Member of Dakota Sandstone	(Aubrey, 1988)
Jackpile Sandstone Member of Morrison Formation	(Owen et al., 1984)
Brushy Basin Shale Member of Morrison Formation	(Gregory, 1938)
Westwater Canyon Sandstone Member of Morrison Formation	(Gregory, 1938)

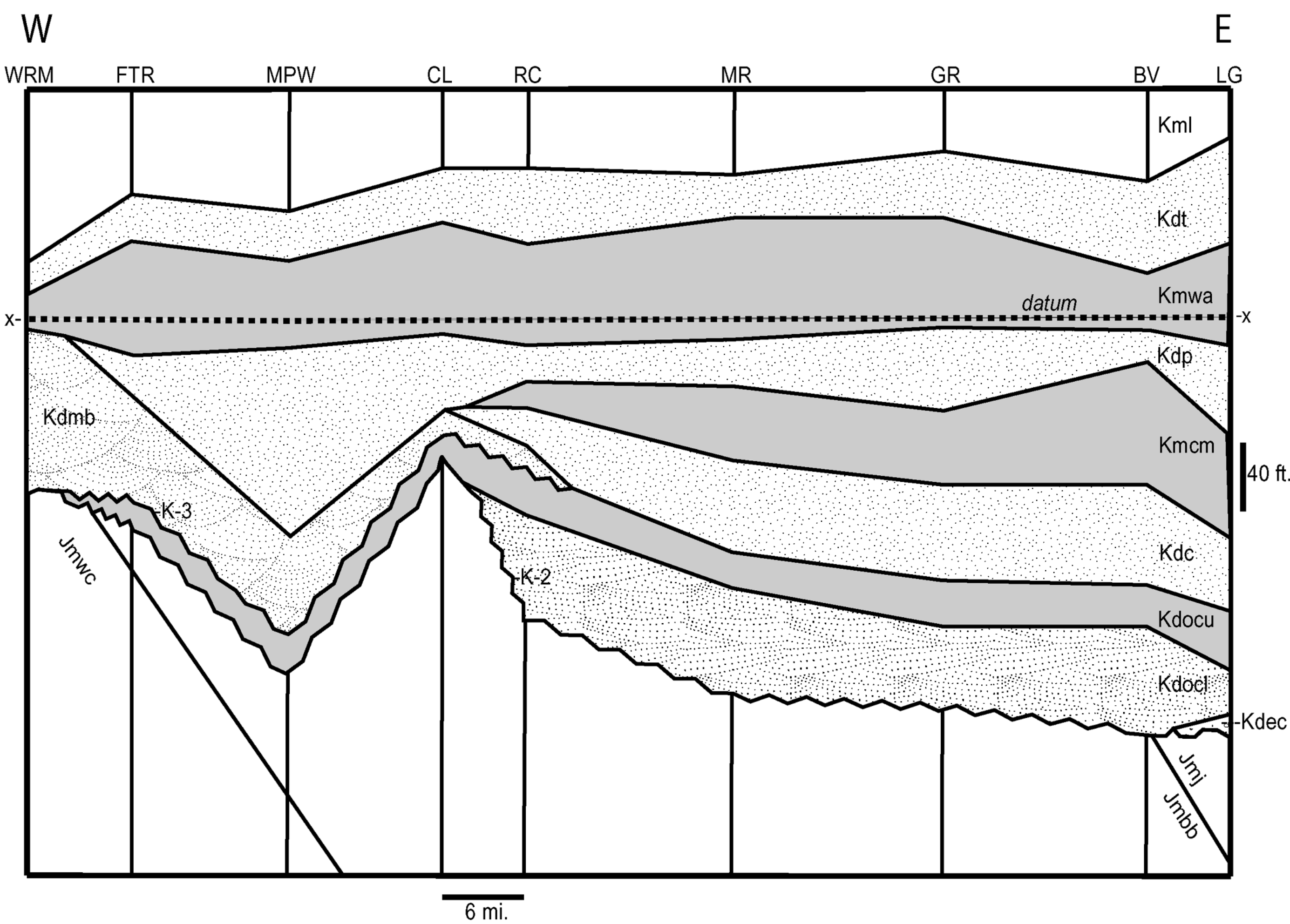

FIGURE 1. West-east stratigraphic cross-section of Dakota Sandstone and adjacent units across southern San Juan Basin outcrop belt from White Rock Mesa on west to Laguna on east. Kml = lower Mancos Shale; Kdt = Twowells Sandstone; Kmwa = Whitewater Arroyo Shale; x = X bentonite; Kdp = Paguate Sandstone; Kmcm = Clay Mesa Shale; Kdc = Cubero Sandstone; Kdmb = Dakota main body; Kdocu = upper Oak Canyon shale; Kdocl = lower Oak Canyon sandstone; Kdec = Encinal Canyon Sandstone; Jmj = Jackpile Sandstone; Jmbb = Brushy Basin Shale; Jmwc = Westwater Canyon Sandstone. Sample locations: LG = Laguna (Sec. 20 & 21, T.10N, R.5W), WRM = White Rock Mesa (NW Sec. 36, T.16N, R. 17W); FTR = Fallen Timber Ridge (NE Sec. 34, T.16N, R.15W); MPW = Mount Powell West (NW Sec. 6, T.14N, R.13W); CL = Casamero Lake (NE Sec. 31, T.15N, R.11W); RC = Rincon Canyon (Sec. 34 & 35, T.14N, R.11W); MR= Marquez Ranch (Sec. 9, 16, & 21, T. 13N, R.9W); GR = Grants (Sec. 3 & 10, T.10N, R.9W); BV = Budville (Sec. 24, T.10N, R.7W).

Cubero Sandstone Member. Second are marine-flooding surfaces that cap parasequences, the most prominent in the study area are at the top of the lower Oak Canyon sandstones, Cubero Sandstone, Paguate Sandstone, and Twowells Sandstone. Third are bentonites, the most prominent of which are within the upper Oak Canyon shales in the study area (A bentonite of Owen and Head, 2001) and the lower Whitewater Arroyo shales (B bentonite of Owen and Head, 2001), shown on Figure 1. The B bentonite is correlative with the widespread X bentonite of the Western Interior according to Roberts and Kirschbaum (1995, p. 8-9). They dated the X bentonite at 95 Ma, within the late Cenomanian.

Detailed Stratigraphy of Study Area

Jackpile Sandstone

In the study area, the Jackpile is present only in the Laguna area near its stratotype. It can be seen to be gradually truncated by the K-2 unconformity in exposures between Laguna and Budville north of highway I-40 (Fig. 1). It is continuous, although of variable thickness east of Laguna. Distribution of the Jackpile and overlying marine units of the Dakota Sandstone east of Laguna were reported in Owen (1982).

Encinal Canyon Sandstone

In the study area, the Encinal Canyon, like the Jackpile, is only present in the Laguna area near its stratotype. Also, it can be seen to be gradually truncated by the initial transgressive surface at the base of the lower Oak Canyon sandstone in exposures east of Budville and north of highway I-40 (Fig. 1). Although Aubrey (1988, p. 61-62) interpreted an isolated outcrop on top of the Zuni Sandstone at El Morro National Monument, south of the study area, as Encinal Canyon, our recent examination of these strata indicates that they are basal Dakota main body similar to that in the Zuni embayment to the west (Owen and Sparks, 1989). The Encinal Canyon (Aubrey, 1988), which was named later than the Jackpile, was included in the stratotype of the uppermost Jackpile as bed 16 at the top (Owen et al., 1984, p. 46-47).

Oak Canyon Member

The lower part of the Oak Canyon Member, which is dominantly sandstone, is continuous from east of Laguna to the area north of Prewitt between the Rincon Canyon and Casamero Lake measured sections where it onlaps the Brushy Basin Member of the Morrison Formation at the K-2 unconformity and wedges out (Fig. 1). Sandstone facies in the lower Oak Canyon are variable. From Laguna to Grants, it consists of thick-bedded, fine-grained sandstones with abundant trace fossils, especially large *Skolithos* in the eastern part and *Ophiomorpha* in the western part. Crossbedding, though variable, indicates a northerly to westerly transport direction and indicates possible influence of tidal currents. North and west of Grants, the lower Oak Canyon becomes more variable, containing medium-grained, locally pebbly, crossbedded, channel-fill sandstones that appear to be fluvial or distributary channel-fills. An especially thick, prominent one with some coal beds is at the Marquez Ranch section at the eastern end of the Ambrosia Lake valley. Locally, small *Skolithos* burrow-fills occur at the top of sandstone beds. Crossbedding orientations are quite variable, indicating transport to the east, southeast, south, and southwest.

The upper part of the Oak Canyon Member, which is dominantly shale, is continuous from east of Laguna to almost the western extent of the study area. Its westernmost extent is in Second Canyon, 4 miles east of the White Rock Mesa section (Stop 5, Day 2). It rests directly on the K-2 unconformity from the Casamero Lake section west. The A bentonite is present near the base of the shale in the eastern part of the area, but was not observed in the western. In the eastern area, the upper Oak Canyon is clearly a tongue of the marine lower Mancos Shale with marine fossils, but from the Casamero Lake section westward it loses much of its marine character, becoming carbonaceous and unfossiliferous (except for a few *Skolithos* in sandy beds), although without coal beds. It is truncated by the K-3 unconformity at the base of the Dakota main body, and is completely absent west of Second Canyon. The upper Oak Canyon of this paper was included in the Dakota main body by Landis et al. (1973, p. 12), but it is below the recently recognized K-3 unconformity and appears continuous with the marine upper Oak Canyon east of Grants as shown by Landis et al. (1973). It may record the maximum marine transgression in the San Juan Basin Dakota, but this is difficult to demonstrate because of erosion of its former western part by the K-3 erosion surface. The westward onlap of this and higher units took place on the western shore of Seboyeta bay (Cobban and Hook, 1984), a Cenomanian-Turonian embayment of the shoreline that was centered near Laguna.

Dakota main body

The correct stratigraphic position of the Dakota main body has been in question since this informal name was first used extensively by Landis et al. (1973) after Owen (1966, p. 1025) casually mentioned ".... the main body of Dakota Sandstone..." They included the basal Dakota fluvial to littoral section of sandstone and carbonaceous shale (with coal, locally) of the western part of the San Juan Basin in the Dakota main body, which rested directly on a basal unconformity later called K-2 by Molenaar (1977). They stated that the Dakota main body strata "... cannot be included, or have not yet been included, in one of the other named rock units in the sequence" (Landis et al., 1973, p. 22). With the recognition of the K-3 unconformity at the base of the Dakota main body (Owen and Head, 2001), we can now place the main body strata in its correct stratigraphic position with respect to the other named rock units. Fluvial crossbedding and channel-fill sandstone trends are variable, but show an average easterly paleocurrent flow. A spectacular valley-fill deposit is well displayed at Stop 5, Day 2 (Figs. 2-3). The K-3 unconformity cuts down through the Oak Canyon Member and progressively lower stratigraphic units across the San Juan Basin, eventually reaching down to the Chinle Group (Triassic) in the Zuni embayment to the southwest (Owen and Sparks, 1989). Eastward, the Dakota main body grades laterally into the Cubero Sandstone Member, a shoreface sandstone, in the Ambrosia Lake area and in the subsurface of the San Juan Basin (Owen and Head, 2001, p. 12). The upper Cubero also onlaps the Dakota main body to the west of the Ambrosia Lake area (Fig. 1). A similar gradation and onlap

FIGURE 2. Photograph of Westwater Canyon Sandstone Member of Morrison Formation (Jmwc) and Dakota Sandstone main body (Kdmb) at west end of White Rock Mesa (Stop 5, Day 2, NMGS Field Conference, 2003), McKinley County, NM. Note cross-sectional view of filled incised valley above K-3 unconformity.

relationship between the upper part of the Dakota main body and the Paguate Sandstone Member exists to the east of the White Rock Mesa area. Figure 1 illustrates these and other stratigraphic relationships from Laguna on the east to White Rock Mesa to the west. Figure 1 is an improvement on the cross-section of Walters et al. (1987, p. 273), now based on more data and a better understanding of the stratigraphic correlations.

Cubero Sandstone

The Cubero is present only east of the Casamero Lake area. East of its onlap of the Dakota main body it thickens, especially in the Budville area near its stratotype. The lower contact is the correlative conformity of the K-3 unconformity. This contact is locally sharp and scoured, but gradational in most of the area east of Rincon Canyon. The Cubero normally consists of two coarsening-upward, shoreface sandstone parasequences with a thin, silty parasequence at the top. The upper sandy parasequence onlaps the Dakota main body. Crossbedding, where preserved from the usual bioturbation, indicates a southerly longshore current flow. *Ophiomorpha* and other trace fossils are locally present. The prominent marine-flooding surface at the top of the Cubero extends westward on top of the Dakota main body to the point that it is truncated by the basal Paguate Sandstone at the wedge-out of the Clay Mesa Shale (Fig. 1).

Clay Mesa Shale

The Clay Mesa Shale is a wedge-shaped body of Mancos Shale that separates the underlying Cubero Sandstone from the overlying Paguate Sandstone. Its lower contact is at a sharp marine-flooding surface; its upper contact is gradational. Landis et al. (1973, p. 12) showed it wedging-out between Grants and Mount Powell, and Green (1976) mapped a wedge-out of lower Mancos Shale in what he mapped as Dakota main body just west of Mt. Powell. Our Mt. Powell measured section is 0.3 mi. east of his wedge-out. This shale wedge appears to be in the upper part of the Paguate and is not Clay Mesa Shale, which is not present this far west. We show the Clay Mesa wedging-out between the Rincon Canyon and Casamero Lake measured sections (Fig. 1). The Clay Mesa is mostly silty clay shale with marine fossils.

Paguate Sandstone

The Paguate Sandstone extends across the entire study area except for the White Rock Mesa measured section on the western end of Figure 1. Even there, thin, rippled sandstone at the top of the Dakota main body just below the X bentonite can be recognized as the nearshore fluvial or distributary equivalent of the Paguate. Eastward, in Second Canyon and extending to the Fallen Timber Ridge measured section, the Paguate is a complex of shoreface marine sandstones with trace fossils such as *Ophiomorpha* cut by small distributary channel-fills. Fossil reed molds also are present in sandstones deposited in coastal marshes. East of the Fallen Timber Ridge section, where no channel-fills were observed, as far as the Casamero Lake measured section, the basal contact of the Paguate with the Dakota main body is marked by a thin sandstone bed with rounded quartz and chert pebbles, a rarity in Dakota shoreface sandstones. These pebbles appear to be a lag deposit transported to the upper shoreface through the distributary channels to the west. The scoured surface at the base of the pebble bed may be a ravinement surface.

In the Mount Powell area and extending approximately 8 miles west to Fallen Timber Ridge, the Paguate is extremely thick, more than 100 feet of bioturbated, rippled, and crossbedded sandstone in most of the area, and forms a bold cliff, combined with the underlying Dakota main body on most exposures. The contact may be recognized from afar by the color change from gray main body to light brown Paguate, and at close range by the pebble lag at the Paguate base. *Ophiomorpha* and *Thalassinoides* are locally present, and north-dipping crossbedding is prominent. This thick area of Paguate extends northward into the subsurface of the San Juan Basin, where the Paguate forms a prominent paleodelta (Owen and Head, 2001, p. 6, 18).

Whitewater Arroyo Shale

The Whitewater Arroyo Shale extends completely across the study area as a tongue of Mancos Shale typically around 80 ft thick and forming a strike valley between the Paguate and Twowells ridges. It is poorly exposed in most areas, which makes accurate thickness measurement and location of the key X bentonite bed in its lower part difficult. Where thickness and position of the X bentonite were difficult to measure on the surface, they were measured on logs of nearby uranium exploration drill holes. Marvin (1967), in an important early study, was the first to correlate unequivocally the Whitewater Arroyo and Twowells across the study area based on uranium exploration drill-hole logs. He confirmed the suggestion of Owen (1966, p. 1026-1027) that these two members extended across the southern San Juan Basin. The lower contact of the Whitewater Arroyo is at a marine-flooding surface, and its upper contact is gradational over many feet with the overlying Twowells Sandstone. The Whitewater Arroyo,

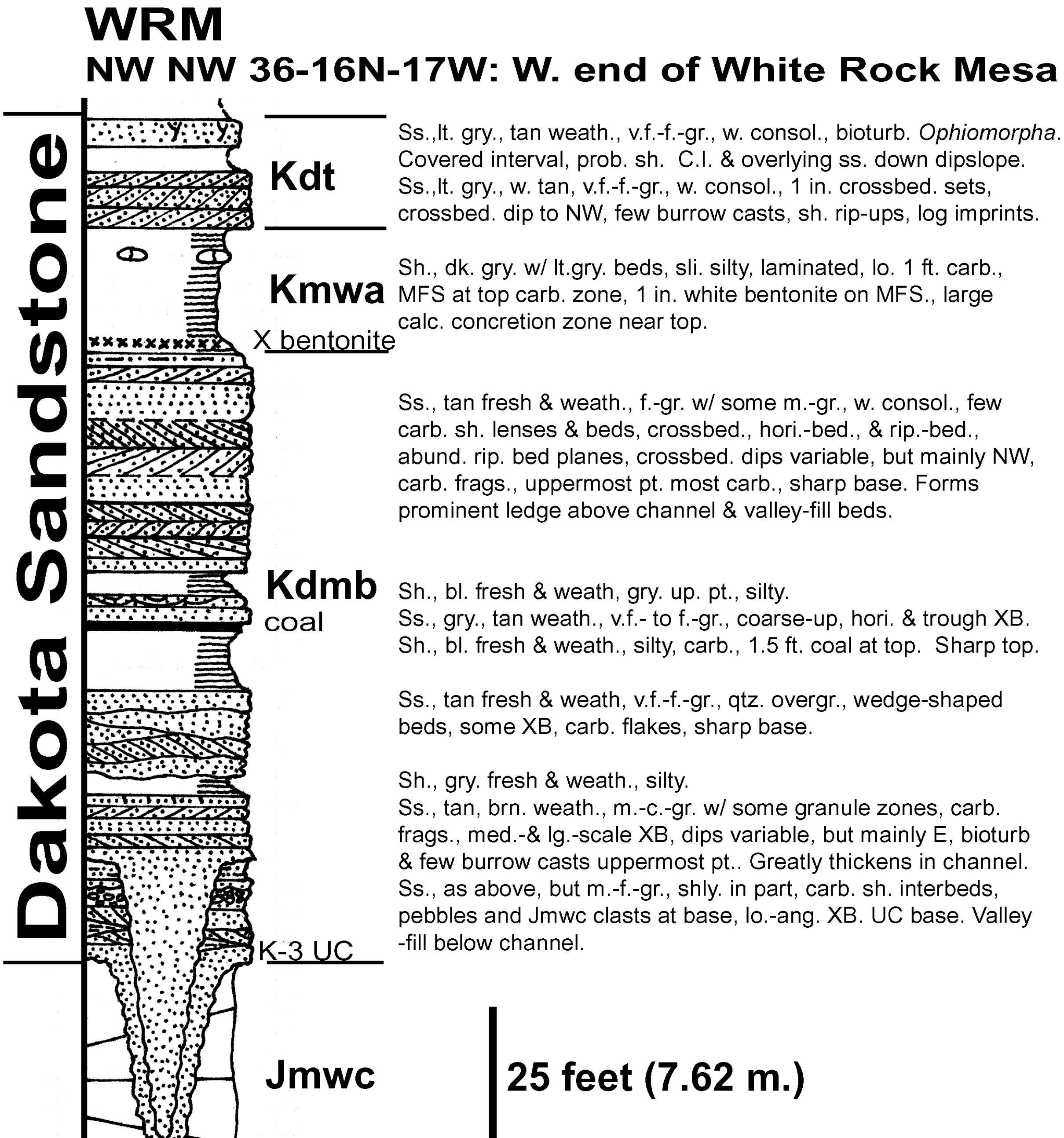

FIGURE 3. Measured section and description of Dakota Sandstone and intertongued Whitewater Arroyo Shale Tongue of Mancos Shale at west end of White Rock Mesa (Stop 5, Day 2, NMGS Field Conference, 2003), McKinley County, NM.

like the Clay Mesa, is mostly silty clay shale with marine fossils. It extends well beyond the study area southward throughout the Zuni embayment (Owen and Sparks, 1989) and southwestward into Arizona, but only as far northwestward as Window Rock.

Twowells Sandstone

The Twowells Sandstone extends across the whole study area without much variation in thickness except from Mount Powell westward, where it thins. It extends well beyond the study area southward throughout the Zuni embayment (Hook et al., 1980; Owen and Sparks, 1989) and southwestward into Arizona, but only as far northwestward as Window Rock. It thickens southward into the Zuni embayment and thins toward Window Rock where it onlaps the Dakota main body at the wedge-out point of the underlying Whitewater Arroyo Shale. In its thicker eastern area, it consists of two sandy parasequences at most localities, but in the thinner western area, only one sandy parasequence. South of the plane of the cross-section (Fig. 1), local marine erosion at the base of the upper parasequence has cut out the lower parasequence in an area near McCartys, New Mexico, as reported by Wolter (1987). The Twowells is mostly bioturbated with many *Ophiomorpha* burrow casts locally, but it has some crossbedded strata indicating a southeastward longshore paleoflow. Some fining-upward strata occur near the top below a sharp marine-flooding surface. The lower Mancos Shale overlies it. No Greenhorn limestone beds occur in this southern part of the San Juan Basin (Dane, 1960, p. 48), but calcareous shale marks the Greenhorn maximum-flooding interval, more obvious on nearby well logs than in outcrops.

CONCLUSIONS

The bold cliff exposures of the Dakota Sandstone with Mancos Shale tongues on the southern flank of the San Juan Basin best display the east-west stratigraphic changes produced by transgressions and regressions of the shoreline from a fluvial source area to the west to the marine basin to the east. Shoreface sandstones of the Cubero, Paguate, and Twowells tongues prograded eastward as relative sea-level decreased, and the Oak Canyon, Clay Mesa, and Whitewater Arroyo marine shales transgressed westward as relative sea-level increased. This lower package of strata onlapped the K-2 unconformity, which erosionally truncates progressively lower strata to the west. The Dakota main body fluvial-deltaic complex prograded eastward onto the K-3 unconformity, which truncates the K-2 unconformity and grades into a correlative conformity at the base of the Cubero Sandstone in the marine basin to the east.

ACKNOWLEDGMENTS

We acknowledge the subsurface expertise of Charles F. Head, Burlington Resources, Inc., who helped correlate surface exposures to well logs of nearby uranium exploration drill holes and petroleum exploration wells; he also helped measure sections on the high cliffs near Mt. Powell on the continental divide and provided much insight into the subsurface Dakota. James B. Stevens, Lamar University, provided advice on computer drafting of figures for this paper.

We are very grateful to the Navajo Nation for permitting access to their lands to gather much of the field data for this paper, including the White Rock Mesa section (Stop 5, Day 2, NMGS Field Conference, 2003).

REFERENCES

Aubrey, W. M., 1988, The Encinal Canyon Member, a new member of the Upper Cretaceous Dakota Sandstone in the southern and eastern San Juan basin, New Mexico: U. S. Geological Survey, Bulletin 1633-C, p. 57-69.

Cobban, W. A., and Hook, S. C., 1984, Mid-Cretaceous molluscan biostratigraphy and paleogeography of southwestern part of Western Interior, United States; *in* Westerman, G. E., ed., Jurassic-Cretaceous biochronology and paleogeography of North America: Geological Association of Canada, Special Paper 27, p. 257-271.

Dane, C. H., 1960, The boundary between rocks of Carlile and Niobrara age in San Juan Basin, New Mexico and Colorado: American Journal of Science, Bradley Volume, v. 258A, p. 46-56.

Green, M. W., 1976, Geologic map of the Continental Divide quadrangle, McKinley County, New Mexico: U. S. Geological Survey Geologic Quadrangle Map GQ-1338, scale 1:24,000.

Gregory, H. E., 1938, The San Juan country: U. S. Geological Survey, Professional Paper 188, 123 p.

Hook, S. C., Cobban, W. A. and Landis, E. R., 1980, Extension of the intertongued Dakota Sandstone-Mancos Shale terminology into the southern Zuni basin: New Mexico Geology, v. 2, p. 42-46.

Landis, E. R., Dane, C. H. and Cobban, W. R., 1973, Stratigraphic terminology of the Dakota Sandstone and Mancos Shale, west-central New Mexico: U. S. Geological Survey, Bulletin 1372-J, 44 p.

Marvin, R. G., 1967, Dakota Sandstone-Tres Hermanos relationship, southern San Juan Basin area: New Mexico Geological Society, Guidebook 18, p. 170-172.

Molenaar, C. M., 1977, Stratigraphy and depositional history of Upper Cretaceous rocks of the San Juan Basin area, New Mexico and Colorado, with a note on economic resources: New Mexico Geological Society, Guidebook 28, p. 159-166.

Owen, D. E., 1966, Nomenclature of Dakota Sandstone (Cretaceous) in San Juan Basin, New Mexico and Colorado: American Association of Petroleum Geologists Bulletin, v. 50, p. 1023-1028.

Owen, D. E., 1982, Correlation and paleoenvironments of the Jackpile sandstone (Upper Jurassic) and intertongued Dakota Sandstone-lower Mancos Shale (Upper Cretaceous) in west-central New Mexico: New Mexico Geological Society, Guidebook 33, p. 267-270.

Owen, D. E., and Head, C. F., 2001, Summary of the sequence stratigraphy of the Dakota Sandstone and adjacent units, San Juan Basin, northwestern New Mexico and southwestern Colorado: *in* Broadhead, R., Cather, M., and Brister, B. S., eds., Proceedings for low permeability and underdeveloped natural gas reservoirs of New Mexico: New Mexico Bureau of Mines and Mineral Resources, p. 2-19.

Owen, D. E., and Sparks, D. K., 1989, Surface to subsurface correlation of the intertongued Dakota Sandstone-Mancos Shale (Upper Cretaceous) in the Zuni embayment, New Mexico: New Mexico Geological Society, Guidebook 40, p. 265-267.

Owen, D. E., Walters, L. J., Jr., and Beck, R. G.,1984, The Jackpile Sandstone Member of the Morrison Formation in west-central New Mexico--a formal definition: New Mexico Geology, v. 6, p. 46-52.

Pike, W. S., 1947, Intertonguing marine and nonmarine Upper Cretaceous deposits of New Mexico, Arizona, and southwestern Colorado: Geological Society of America, Memoir 24, 103 p.

Roberts, L. N. R., and Kirschbaum, M. A., 1995, Paleogeography of the Late Cretaceous of the Western Interior of middle North America--coal distribution and sediment accumulation: U. S. Geological Survey, Professional Paper 1561, 115 p.

Walters, L. J., Jr., Owen, D. E., Henley, A. L., Winsten, M. S., and Valek, K. W.,1987, Depositional environments of Dakota Sandstone and adjacent units in the San Juan Basin utilizing discriminant analysis of trace elements in shales: Journal of Sedimentary Petrology, v. 57, p. 265-277.

Wolter, N. R., 1987, The depositional history of the Cenomanian Twowells Tongue of the Dakota Sandstone, New Mexico [M. S. thesis]: Baton Rouge, Louisiana State University, 273 p.