Dakota Sandstone and lower Mancos Shale stratigraphy at the Red Wash measured section and nearby wells in the Four Corners platform, Navajo Reservation, San Juan County, New Mexico

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2010, pp. 107-112. https://doi.org/10.56577/FFC-61.107

in:

Geology of the Four Corners Country, Fassett, James E.; Zeigler, Kate E.; Lueth, Virgil W., [eds.], New Mexico Geological Society 61 st Annual Fall Field Conference Guidebook, 246 p. https://doi.org/10.56577/FFC-61

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DAKOTA SANDSTONE AND LOWER MANCOS SHALE STRATIGRAPHY AT THE RED WASH MEASURED SECTION AND NEARBY WELLS IN THE FOUR CORNERS PLATFORM, NAVAJO RESERVATION, SAN JUAN COUNTY, NEW MEXICO.

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ABSTRACT—The Dakota Sandstone of the Four Corners Platform consists of a thick White Rock Mesa Member with thin westward edges of the Whitewater Arroyo Shale and Twowells Sandstone Members, overlain by the complete Graneros Shale and Greenhorn Limestone Members of the Mancos Shale. A key outcrop is at Red Wash on US highway 64 west of Shiprock, NM. Paleocurrent interpretations of fluvial crossbedding indicate an ENE transport direction. Logs of 100 wells in the nearby subsurface provide details that show thinning of the lower fluvial section and thickening of the upper marine section to the east.

INTRODUCTION

The excellent outcrop of the upper part of the White Rock Mesa Member (Owen and Owen, 2005) of the Dakota Sandstone in Red Wash (W 1/2, SE 1/4, Sec. 10, T. 30 N., R. 19 W.) and overlying lower Mancos Shale through the Greenhorn Limestone Member above the Dakota to the west of Red Wash typifies these stratigraphic units in the Four Corners Platform area (Figure 1 and 2). Detailed measured sections complete with an outcrop gamma-ray log, paleocurrent data, organic geochemistry, and palynology are available. Logs of approximately 80 wells penetrating the Dakota within the New Mexico portion of the Four Corners Platform and approximately 20 wells southeast of The Hogback monocline were used in this study. Most of these logs may be downloaded from the NMOCD website (http://ocdimage.emnred.state.nm.us/imaging/LogFileCriterea.aspx).

During the early years of petroleum exploration (1920s) in the San Juan Basin, several shallow-depth oil fields close to the outcrop belt near the west edge of the Four Corners Platform were discovered in the Dakota Sandstone of the Four Corners Platform, west of The Hogback monocline; all are surface anticlinal structures. These include Hogback (1922; Dakota production 5,211,391 barrels to date), Rattlesnake (1924; Dakota production

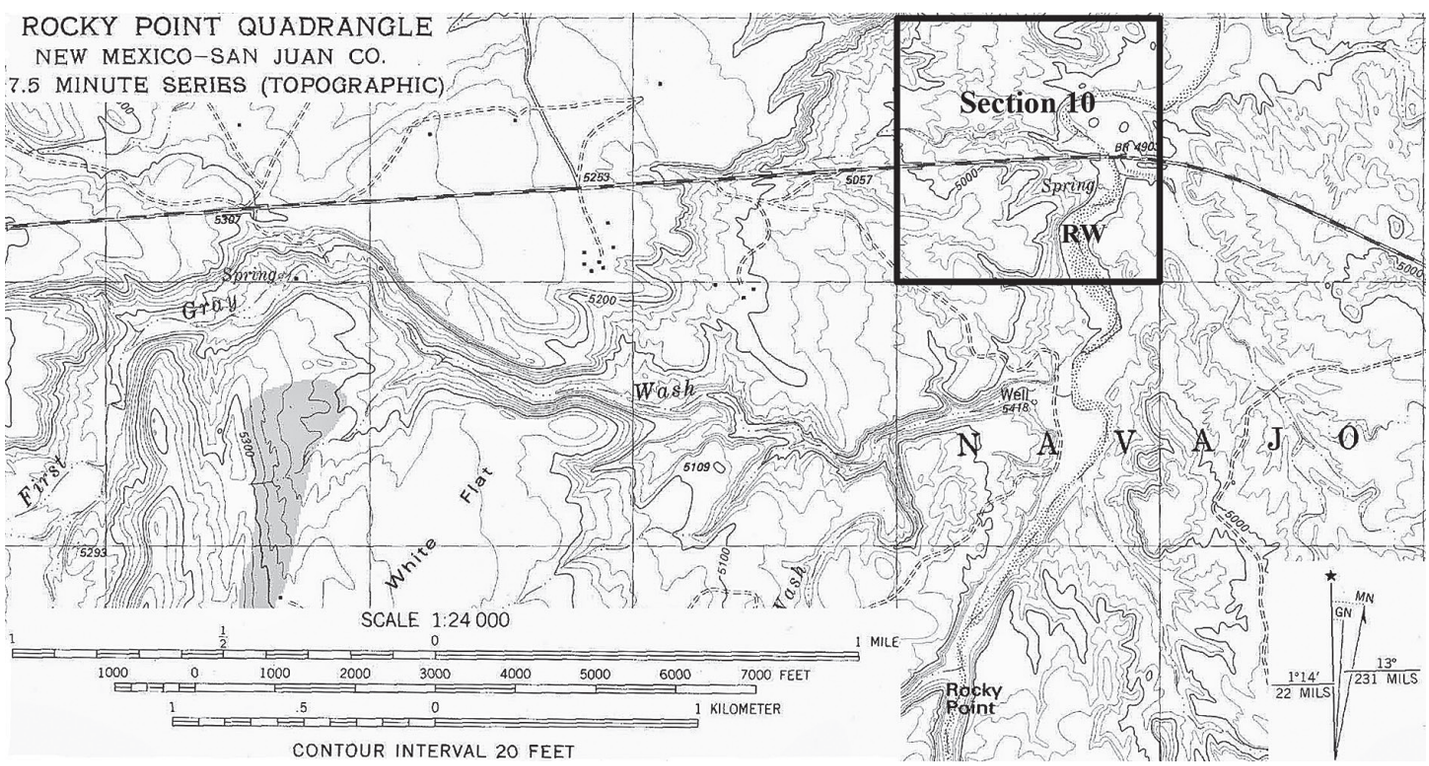

FIGURE 1. Index map of Red Wash Dakota Sandstone outcrop (RW) on west bank of Red Wash just south of US highway 64 in W 1/2, SE 1/4, Sec. 10, T. 30 N., R. 19 W., Navajo Reservation, San Juan County, NM.

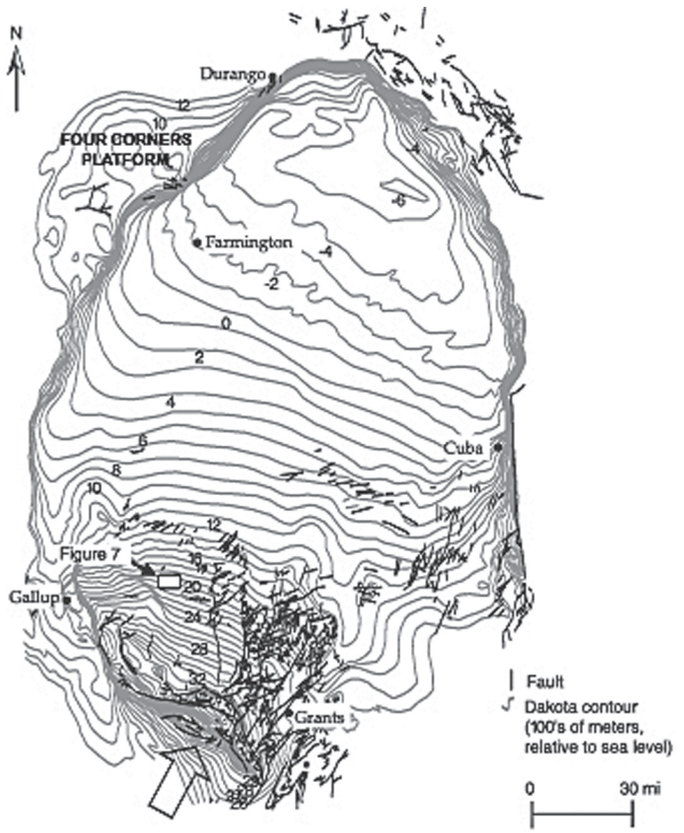

FIGURE 2. Index map of Four Corners Platform and San Juan Basin. Datum is top of Dakota Sandstone. From Lorenz and Cooper (2003).

4,321,753 barrels to date), and Table Mesa (1925; Dakota production 1,353,516 barrels to date). All of these fields are within an 18-mile radius to the southeast of the Red Wash outcrop, with Rattlesnake field only 5 miles south-southeast. Dakota production from all three fields comes from less than 1000 feet depth.

Previous work on the Dakota stratigraphy of the Four Corners Platform area includes a preliminary regional paper by Owen (1973) that illustrated the Red Wash outcrop, a thesis by Kostura (1975) that included a measured section and paleocurrent data at the Red Wash and other nearby outcrops, and the regional subsurface Dakota study of Head and Owen (2005). Studies of the lower Mancos Shale at Red Wash, including the upper part of the Dakota, include the Curiale et al. (1992) organic geochemistry analysis and outcrop gamma-ray log of the Dakota through Greenhorn section, and the brief Witmer et al. (1992) palynofacies analysis of the same section. A paper by Owen & Owen (2003, p. 327-328) describes the stratigraphic position of the "Dakota main body" which became the White Rock Mesa Member of the Dakota in the Owen and Owen (2005) paper, which names and describes the stratotype of the White Rock Mesa Member of the Dakota south of Red Wash near Church Rock, NM.

RED WASH STRATIGRAPHY

At the Red Wash locality on the west bank of Red Wash just south of the U.S. Highway 64 bridge, the ledge-forming upper part of the White Rock Mesa Member, the thin edge of the Whitewater Arroyo Shale Member of the Mancos Shale (Owen, 1966), and the western edge of the Twowells Sandstone Member of the Dakota, capped by a very thin oyster (*Pycnodonte*) coquina, are exposed. The upper part of the White Rock Mesa contains a variety of trace fossils, including root casts, burrow casts, and reed molds (Figure 3). Curiale et al (1992, p. 63) reported vitrinite, indicating paludal, distributary, and fluvial paleoenvironments for the White Rock Mesa, and Dinoflagellate cysts, indicating the first marine incursion in the Whitewater Arroyo. These are overlain by the shoreface sand and coquina of the Twowells, which contains a few burrow casts.

The gray Graneros Shale Member and the white Greenhorn Limestone Member of the Mancos Shale form the slope to the top of the close escarpments on both sides of Red Wash. The measured sections in this paper were taken on the west side of Red Wash (Figure 4). The lower part of the White Rock Mesa Member, not completely exposed at this locality, and the uppermost part of the Brushy Basin Member of the Morrison Formation were measured along 2.5 miles of First Gray Wash (Figure 1), the first western tributary to Red Wash upstream to the south. Total thickness of the White Rock Mesa Member is approximately 190 feet in the complete measured section, but only the upper 90 feet or so is exposed in Red Wash (Figure 5).

Paleocurrent directions measured from 122 crossbedding measurements in the White Rock Mesa sandstones in the total Red Wash section yield a mean transport direction of 60° (ENE) (Figure 6), close to the regional mean on the Four Corners Platform of 50° (Kostura, 1975, Figure 15). A correction of +27° was added to the Kostura (1975) thesis data because of a sign error in one of his computer programs. Thus, the streams that deposited the White Rock Mesa sandstones had an average flow direction to the ENE toward the shoreline in the eastern San Juan Basin (Owen and Owen, 2005, Figure 5). Trends of Individual stream channel sandstones on the Four Corners Platform vary in their

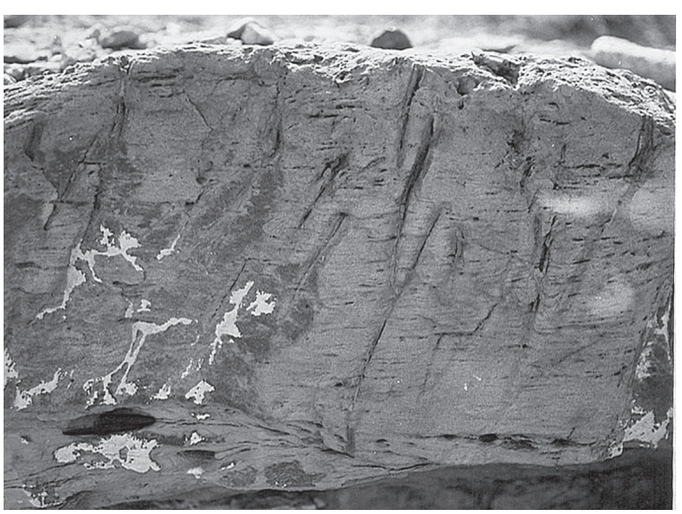

FIGURE 3. Near-vertical reed molds near top of White Rock Mesa Member sandstone at Red Wash, NM. Note 2.25-inch long black pen cap at lower left.

FIGURE 4. Panorama of upper part of Dakota Sandstone overlain by lowermost part of Mancos Shale on west bank of Red Wash just south of US highway 64 in W 1/2, SE 1/4, Sec. 10, T 30 N., R. 19 W., Navajo Reservation, San Juan County, NM. Panorama courtesy of Richard Allen Ashmore.

orientation from northerly to southeasterly—the prominent, isolated, small channel sandstone enclosed in shale (unit 6 in Figure 5) at the Red Wash outcrop may be traced along the outcrop on the south side of highway 64 at Red Wash for approximately 1000 feet with an azimuth of approximately 100°.

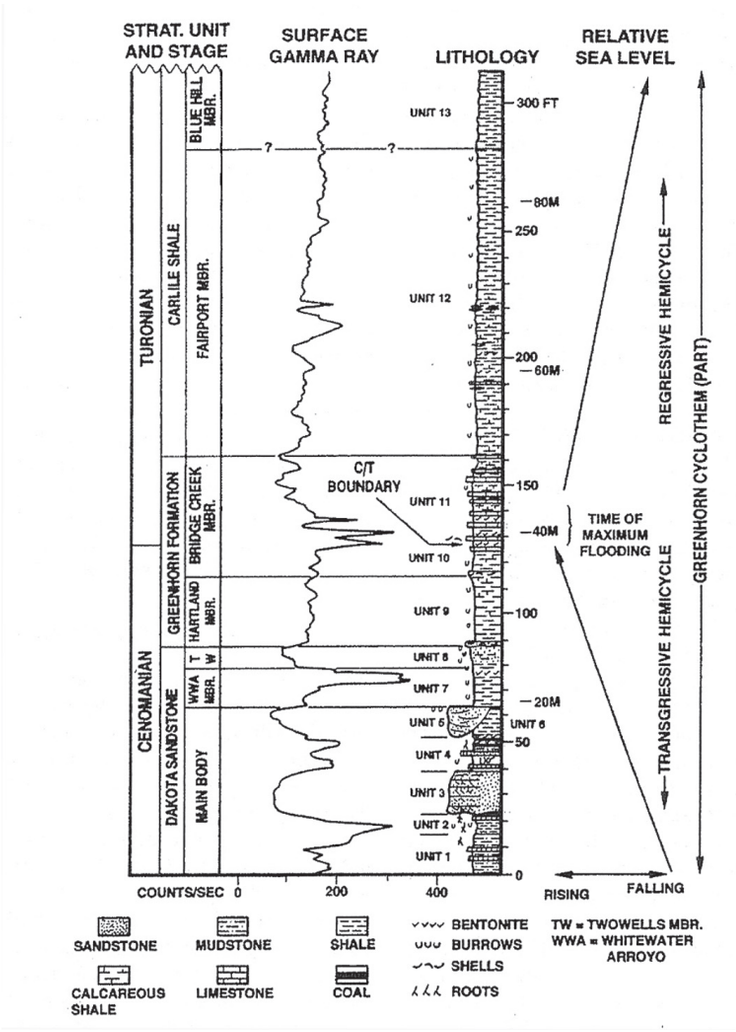

FIGURE 5. Measured stratigraphic section and surface gamma-ray log of upper Dakota Sandstone and lower Mancos Shale at Red Wash, NM. From Curiale et al., 1992.

The stratigraphic section of lower Mancos Shale above the Dakota and through all of the Greenhorn Limestone Member is well exposed on hillsides above the Dakota on both sides of Red Wash. On the west side of Red Wash, a measured section with a surface gamma-ray log of the upper Dakota, Graneros, Greenhorn, and 12 feet of overlying shale was published by Curiale et al (1992, p. 60). It is reproduced here as Figure 5. The log shows the high gamma-ray peaks of volcanic ash-rich clay at approximately 50 feet (unit 4) in the White Rock Mesa Member (the main body of Curiale et al, 1992, p. 60), at approximately 75 feet (unit 7) in the Whitewater Arroyo Member, and three peaks between 125 and 145 feet in the Greenhorn Limestone Member (Bridge Creek Member of Curiale et al, 1992, p. 60). All of these bentonites may be observed on outcrops in this area. The lowest one (at ~50 feet in Figure 7) might better be called a tonstein rather than a bentonite, as the ash seems to have fallen into a small area of swampy organic-rich muds associated with coal.

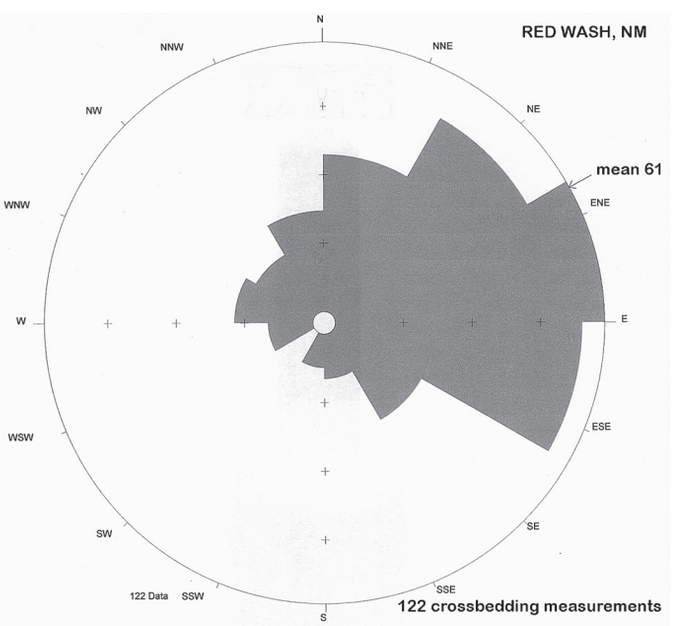

FIGURE 6. Rose diagram of fluvial paleocurrent flow directions in complete White Rock Mesa Member sandstones at Red Wash measured section. Average flow to ENE (~61°). Modified from Kostura (1975).

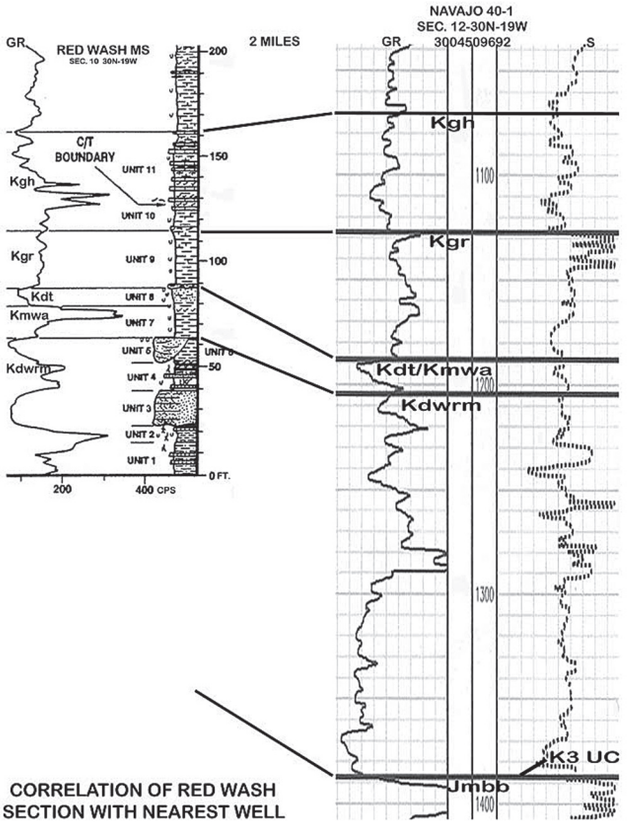

FIGURE 7. Correlation of lower part of measured stratigraphic section (Figure 5) of Curiale et al. (1992) with Navajo 40-1 well two miles to the East. Abbreviations of stratigraphic nomenclature used in this paper: Jmbb = Morrison Formation, Brushy Basin Member; Kdwrm = Dakota, White Rock Mesa Member; Kmwa = Mancos, Whitewater Arroyo Member; Kdt = Dakota, Twowells Member; Kgr = Mancos, Graneros Member; Kgh = Mancos, Greenhorn Member. GR = gamma-ray curve. S = sonic curve. UC = unconformity.

The second one (at ~75 feet in Figure 5 & 7) is the widespread X bentonite described by Head and Owen (2005, p. 437 & 441). The other three are typically developed in the upper part of the Graneros Shale and lower part of the Greenhorn Limestone.

Note that the stratigraphic terminology (Hartland; Bridge Creek; Fairport; Blue Hill; etc.) used by Curiale et al. (1992) differs from the traditional Graneros, Greenhorn, etc. lithostratigraphic terminology used here. The names used by Curiale et al (1992) were chronostratigraphically correlated from the Pueblo area section (Curiale, et al, 1992, p. 57) on the western edge of the Great Plains approximately 150 miles across the Southern Rocky Mountains to the San Juan Basin by some previous workers based on interpreted age of index fossils, not lithology. This Great Plains terminology is not used in this paper, because extension of lithostratigraphic units based on their interpreted age violates the North American Code of Stratigraphic Nomenclature (NACSN, 2005, Article 23e). If one uses the age of the Greenhorn Limestone at Red Wash to call it the Bridge Creek Limestone, then one might as well call the White Rock Mesa Member of the Dakota at Red Wash the Lincoln Limestone Member, as it is the approximate age equivalent to this Great Plains unit. To quote the Code, " concepts of time or age play no part in defining lithostratigraphic units nor in determining their boundaries…". Chronostratigraphic units such as the Cenomanian and Turonian Stage and subdivisions should by used for age relationships for the sake of clarity. However, it is useful to know the ages of the units at Red Wash to approximate the amount of time transgression along the western side of the Western Interior Seaway, but one should not make the mistake of confusing rock layers with their age.

SUBSURFACE STRATIGRAPHY

Subsurface stratigraphy of the Dakota in the Four Corners Platform is fairly well displayed in well logs, although many of the SP curves in these fresh-water charged, shallow sandstones are reversed. Many of these old (~1960s) logs do not have a gamma-ray curve. Most of the logs record a thick White Rock Mesa Member, mostly sandstone, but with variable proportions of shale and thin coal, onlapped by the thin Whitewater Arroyo Shale and Twowells Sandstone Members—the thickness of the onlapping strata increases eastward toward The Hogback Monocline. Also, on the outcrop northward a few miles from Red Wash, the onlapping Whitewater Arroyo and Twowells may be seen to lap out gradually to their zero edge and are absent from there northeastward into Colorado near Cortez.

Figure 8 is an E-W stratigraphic cross-section of these and closely underlying and overlying units across the Four Corners Platform. Note the onlap of the Paguate Sandstone Member and underlying Clay Mesa Shale (shown as a combined unit, the informal Paguate interval (Head and Owen, 2005, p. 435) near the eastern edge of Figure 8. Also note that the Burro Canyon Formation is present under the White Rock Mesa Member of the Dakota in the subsurface in the eastern part of the study area, but not on or near the outcrop in the study area, where the White Rock Mesa Member unconformably overlies the Brushy Basin Member of the Morrison Formation. The Burro Canyon is present on the outcrop in Colorado north of the study area.

Figure 9 is an isopach map of the White Rock Mesa Member in the Four Corners Platform based on the well data. The White Rock Mesa varies significantly in thickness due to the facts that (1) its lower boundary is the K3 unconformity with considerable channel incision locally, and (2) the sandstone-shale ratio varies considerably in short distances laterally, resulting in thickness variations due to differential compaction of shale and coal versus sandstone, as can be observed at many outcrops in the area.

The isopach map of the White Rock Mesa Member in the Four Corners Platform area (Figure 9) shows that it is thick (averaging ~160 feet, comparable to ~190 at the Red Wash outcrop), with a minimum thickness of 80 feet east of The Hogback monocline and a maximum of 213 feet to the west. It thins irregularly eastward. The thickness variations should be expected in a fluvial, coastal plain unit, especially one that rests on an unconformity, the K3 unconformity (Owen and Owen, 2005), which is a chan-

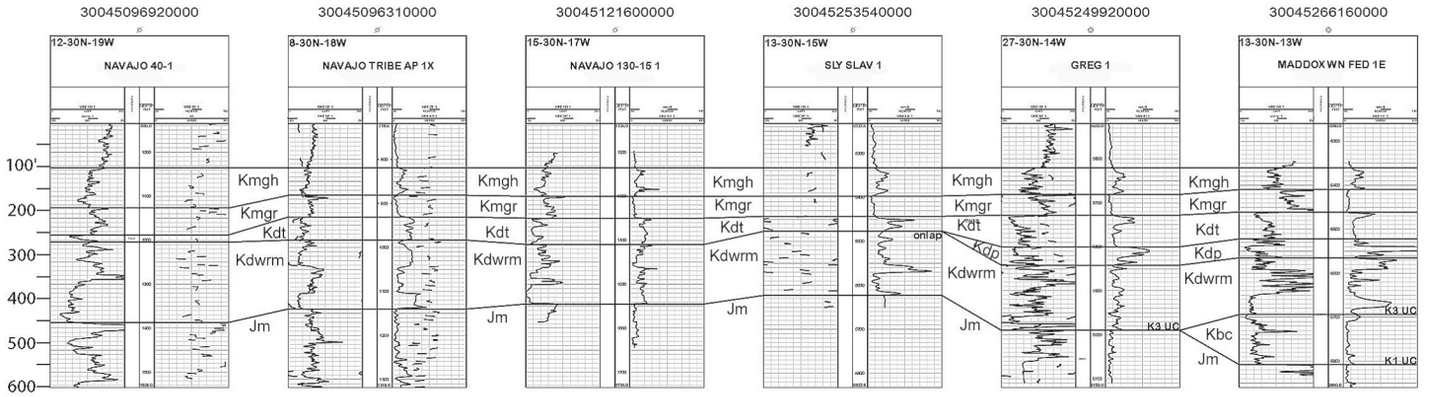

FIGURE 8. Stratigraphic cross-section of Morrison-Dakota-lowermost Mancos from just east of Red Wash outcrop to just east of The Hogback Monocline. Jm = Morrison; Kbc = Burro Canyon; Kdwrm = White Rock Mesa; Kdp = Paguate/Clay Mesa; Kdt = Twowells/Whitewater Arroyo; Kmgr = Graneros; Kmgh = Greenhorn. Note truncation of K1 unconformity by K3 unconformity and onlap of Kdp on Kdwrm.

neled surface with 10s of feet of relief. See Owen and Owen (2005, p. 229), for a San Juan Basin-wide isopach map of the White Rock Mesa Member. It attains its greatest regional thickness in the Four Corners Platform area and wedges out into marine rocks short of the outcrop on the east side of the San Juan Basin, where the whole Dakota stratigraphic section is almost all

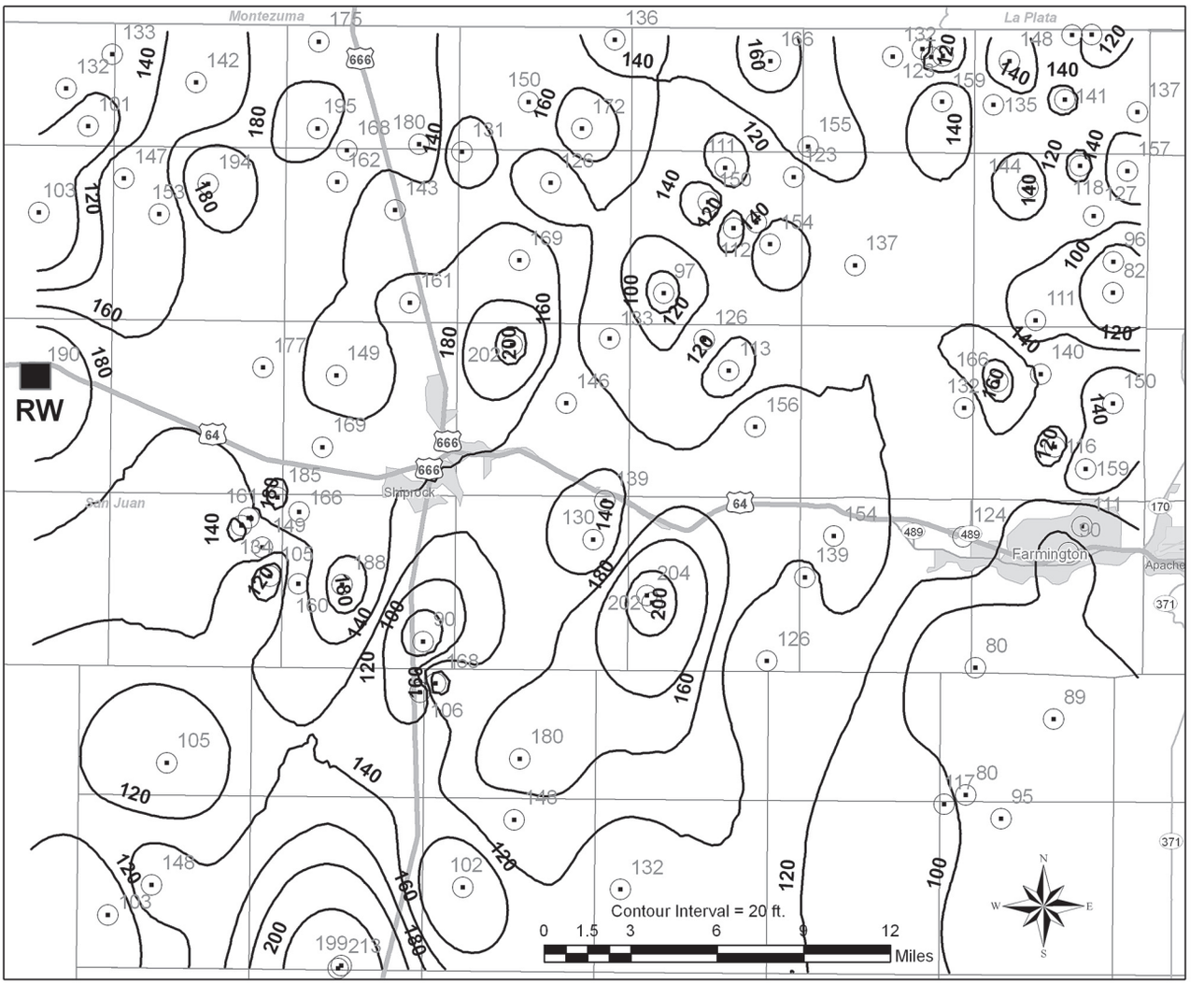

FIGURE 9. Isopach map of White Rock Mesa Member on Four Corners Platform and northwest part of the Central San Juan Basin in the southeast area of the map. RW is Red Wash measured section location with thickness.

marine (Owen et al, 2005).

CONCLUSIONS

1. The Dakota Sandstone of the Four Corners Platform consists of a thick White Rock Mesa Member with thin westward edges of the Whitewater Arroyo Shale and Twowells Sandstone Members, overlain by the complete Graneros Shale and Greenhorn Limestone Members of the Mancos Shale.
2. Paleocurrent interpretations of fluvial crossbedding in the White Rock Mesa Member at Red Wash, east of Beclabito, NM, indicate a ENE transport direction, which is typical for the Four Corners Platform.
3. An isopach map of the Dakota Sandstone in the Four Corners Platform shows thinning of the fluvial section to the east.

ACKNOWLEDGMENTS

We are very grateful to Kate Zeigler, Joe Kruger, and Richard Ashmore for preparation of several figures in this paper. The Navajo Nation Minerals Department has granted many permits for us to work in this area for many years—we greatly appreciate their cooperation in allowing access to the best-exposed Dakota outcrops in the San Juan Basin.

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