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The Dakota Sandstone (Cretaceous) of the southern part of the Chama Basin, New Mexico--A preliminary report on its stratigraphy, paleontology, and sedimentology

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THE DAKOTA SANDSTONE (CRETACEOUS) OF THE SOUTHERN PART OF THE CHAMA BASIN, NEW MEXICO-A PRELIMINARY REPORT ON ITS STRATIGRAPHY, PALEONTOLOGY, AND SEDIMENTOLOGY

by

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INTRODUCTION

The purpose of this report is to summarize present information on the Dakota Sandstone of the southern part of the Chama basin in southern Rio Arriba County, northern New Mexico. The Dakota forms an arcuate, generally south-facing rim rock which caps the various mesas east of the Chama Canyon extending from Mesa de los Viejos on the west to Mesa del Yeso on the east and continuing northeastward as part of Magote Ridge (Fig. 1). Detailed thickness measurements, lithological data, trace-fossil descriptions, and primary sedimentary structure measurements were emphasized at eight measured-section locations (Fig. 1) during field work in August, 1973. The orientation, type, size, shape, and boundaries of crossbedding, by far the most abundant inorganic sedimentary structure, were measured in detail. Later laboratory measurements were made of grain-size distribution by sieving, shale mineralogy by X-ray diffraction, and sandstone petrography from samples collected. A computer analysis of the crossbedding data is in progress in May, 1974. This data is being integrated with earlier observations reported by Owen (1963, 1966, 1969, and 1973) to form a M.S. thesis by Grant (1974, in preparation). The authors' names are listed alphabetically in this paper to indicate an equal share of the work.

The authors appreciate research grants from the Society of Sigma Xi and Bowling Green State University which made the latest study possible. We also thank John R. Kostura of Bowling Green for designing the computer analysis used and Kathleen Grant for assistance with field work.

STRATIGRAPHY

General

The Dakota Sandstone of the San Juan-Chama basin region is a complex nonmarine and marine elastic rock stratigraphic unit deposited probably during Albian and Cenomanian (latest Early Cretaceous and earliest Late Cretaceous) time in response to a regional transgression of the epeiric Cretaceous sea (Landes and others, 1973, p. 1-2, and Owen, 1973, p. 38-39). Fluvial rocks in the northwestern part of the San Juan Basin and marine rocks in the southeastern part form most of the Dakota while the Chama basin Dakota contains intermediate amounts of marine and nonmarine sediments, as is also the case in the southwestern part of the San Juan Basin.

In the southern part of the Chama basin the Dakota forms the basal strata of the Cretaceous System unconformably overlying the probable Upper Jurassic Morrison Formation—a succession of approximately 600 feet of varicolored mudstones with a few lenticular sandstones (Smith and others, 1961, p. 13 & 15). The Dakota-Morrison contact is a regional disconformity with local channeling and local angularity as, for example, at the Highway 84 section (Fig. 2). The contact is commonly unexposed due to slumping of resistant lower beds of Dakota sandstone downslope over weak Morrison mudstones.

In the study area the Dakota Sandstone can be subdivided into lower sandstone, middle carbonaceous shale, and upper sandstone units that stand out prominently on the steep cliffs of the area (Fig. 3). These general subunits have been recognized by others in our study area (Smith and others, 1961), traced throughout the Chama basin (Bingler, 1968, p. 24-25), and extend north into most of adjacent Archuleta County, Colorado.

Although the three subunits of the Dakota are lithologically distinct, subunit contacts are difficult to trace precisely. Sandstone beds and lenses, similar to those of the upper sandstone unit, occur within the middle carbonaceous shale unit, and carbonaceous shale beds commonly subdivide the upper sandstone unit (Fig. 4). The subdivision used in Figure 4 is based mainly on physiographic expression. The lower sandstone unit, which contains a few thin lenses of light green to locally reddish noncarbonaceous mudstone, is most easily traced laterally because many of the mudstone lenses can usually be seen to wedge-out within a single exposure. Good exposures of the lower sandstone are laterally discontinuous due to downslope movement of higher Dakota material over them.

Lower Sandstone Unit

Much, if not all, of the lower sandstone unit has been discussed by several authors (Smith and others, 1961, p. 15; McPeek, 1965, p. 25-26; Landis and Danke, 1967, p. 2-3) as the possible thin, southeasternmost equivalent of the Burro Canyon Formation, a probable Lower Cretaceous conglomeratic sandstone and green-red mudstone unit mainly present in southeastern Utah and adjacent parts of Colorado. Young (1960, p. 164 and 1973, p. 13) preferred to call these beds the Cedar Mountain Formation of the Dakota Group. However in this paper the possible Burro Canyon or Cedar Mountain beds are included in the lower sandstone unit and are not recognized separately because these beds have not been definitely traced back to the Burro Canyon type locality in southwestern Colorado or Cedar Mountain type locality in southeastern Utah and it would be impossible to map the formation in question as a separate unit at a scale of 1:25,000 as is required by the American Commission on Stratigraphic Nomenclature (1970, p. 6). This practice of not separating possible Burro

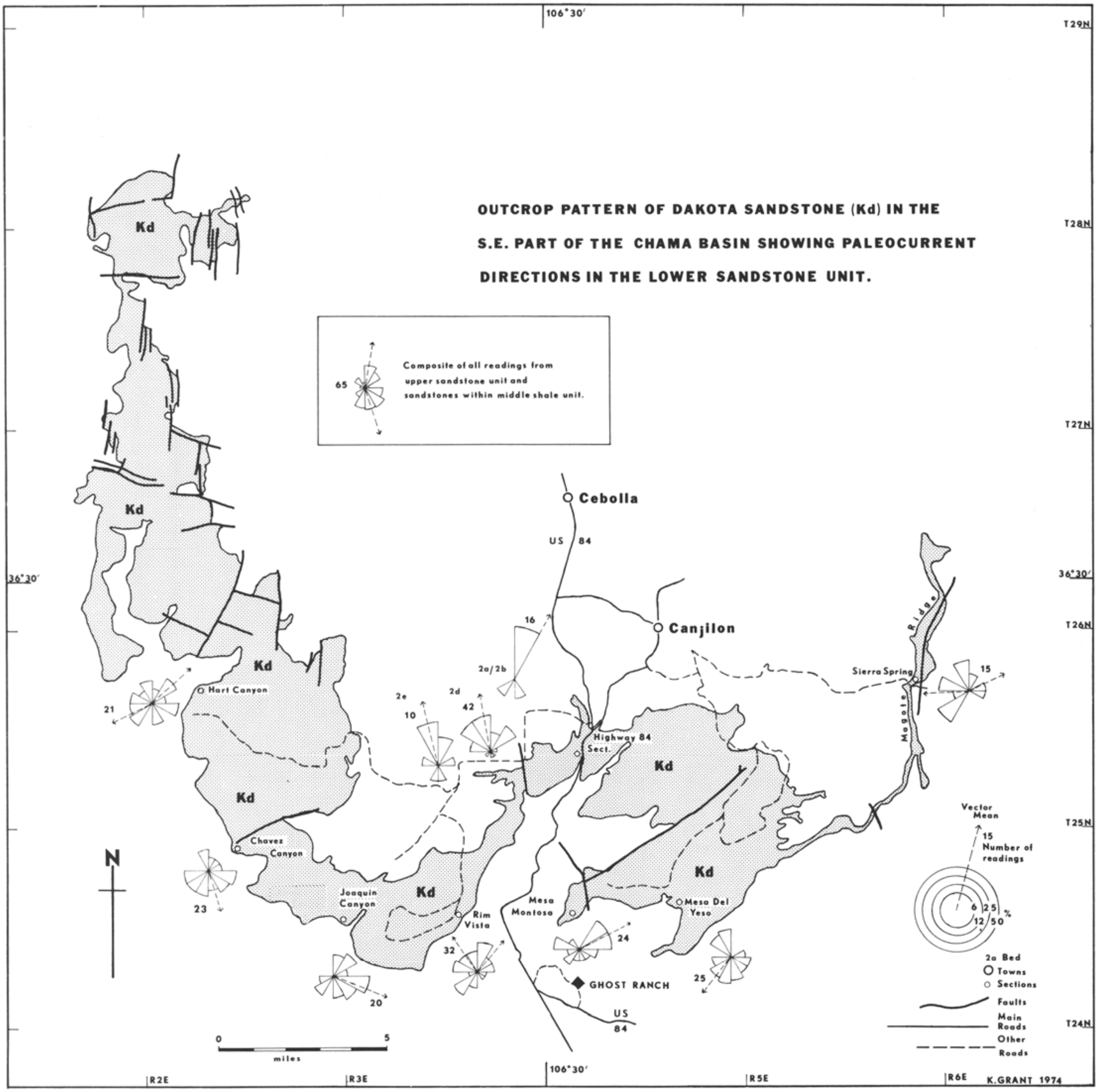

Figure 1. Outcrop pattern of Dakota Sandstone (Kd) in southern Chama basin with measured-section locations and rose diagrams of crossbedding azimuths. Lower sandstone unit crossbedding azimuths indicated by individual rose diagrams. Composite of all other crossbedding azimuths indicated in enclosed rose diagram.

Canyon strata follows that of Smith and others (1961) who mapped most of the study area at 1:24,000 and Landis and Dane (1967), who mapped the Tierra Amarilla Quadrangle to the north.

As so defined, the lower sandstone unit has an average thickness of 135 feet and consists of light colored, highly cross-bedded, coarse-grained quartz sandstone, some of which is pebbly, and locally conglomerate. Lenses and pebble to boulder-size clasts (Fig. 5) of green, locally reddish, mudstone occur within the sandstone. This sandstone is a fluvial deposit apparently laid down by a widespread series of braided streams in the Chama basin area (Owen, 1973, p. 39-42).

At most exposures, the uppermost part of the lower sandstone unit is finer grained and more carbonaceous than sandstones below, and consists of channel-type sandstone beds interbedded with overbank carbonaceous shale. A Dakota-Burro Canyon contact could be placed at the base of these carbonaceous strata, although with great difficulty, especially in mapping anything less than excellent exposures. This contact probably records a gradient and climatic change from braided-

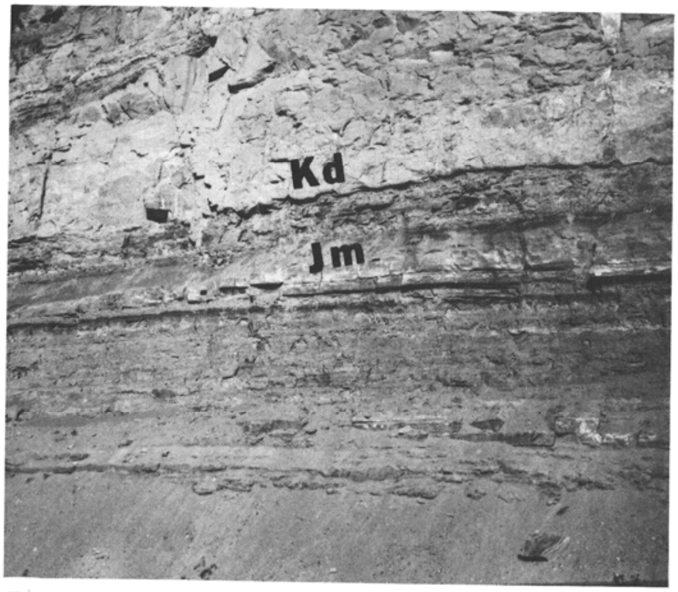

Figure 2. Dakota Sandstone (Kd) disconformably overlying Morrison Formation (Jm) at Highway 84 section. Contact is locally angular (Owen, 1973, Fig. 4) and channeled as followed laterally along this roadcut.

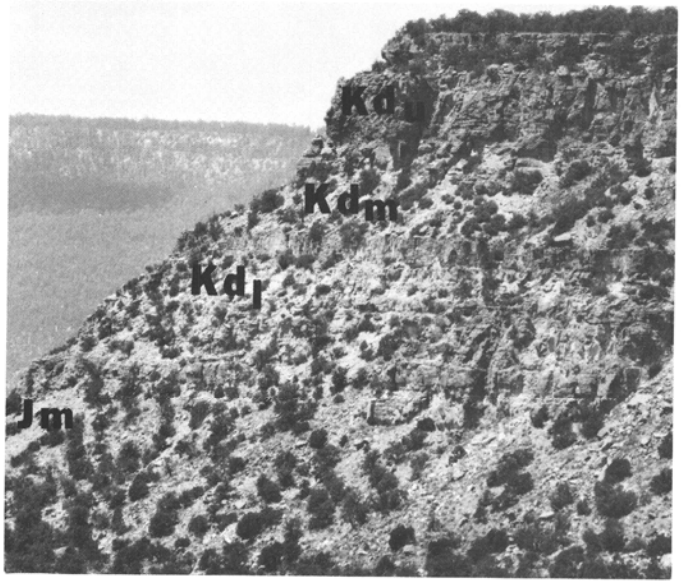

Figure 3. Typical physiographic expression of Dakota Sandstone in southern part of Chama basin. Located 1.1 mile west of Joaquin Canyon section. Jm = Morrison Formation; Kd_l = lower sandstone unit; Kd_m = middle shale unit; Kd_u = upper sandstone unit. Total thickness of Dakota is approximately 400 feet.

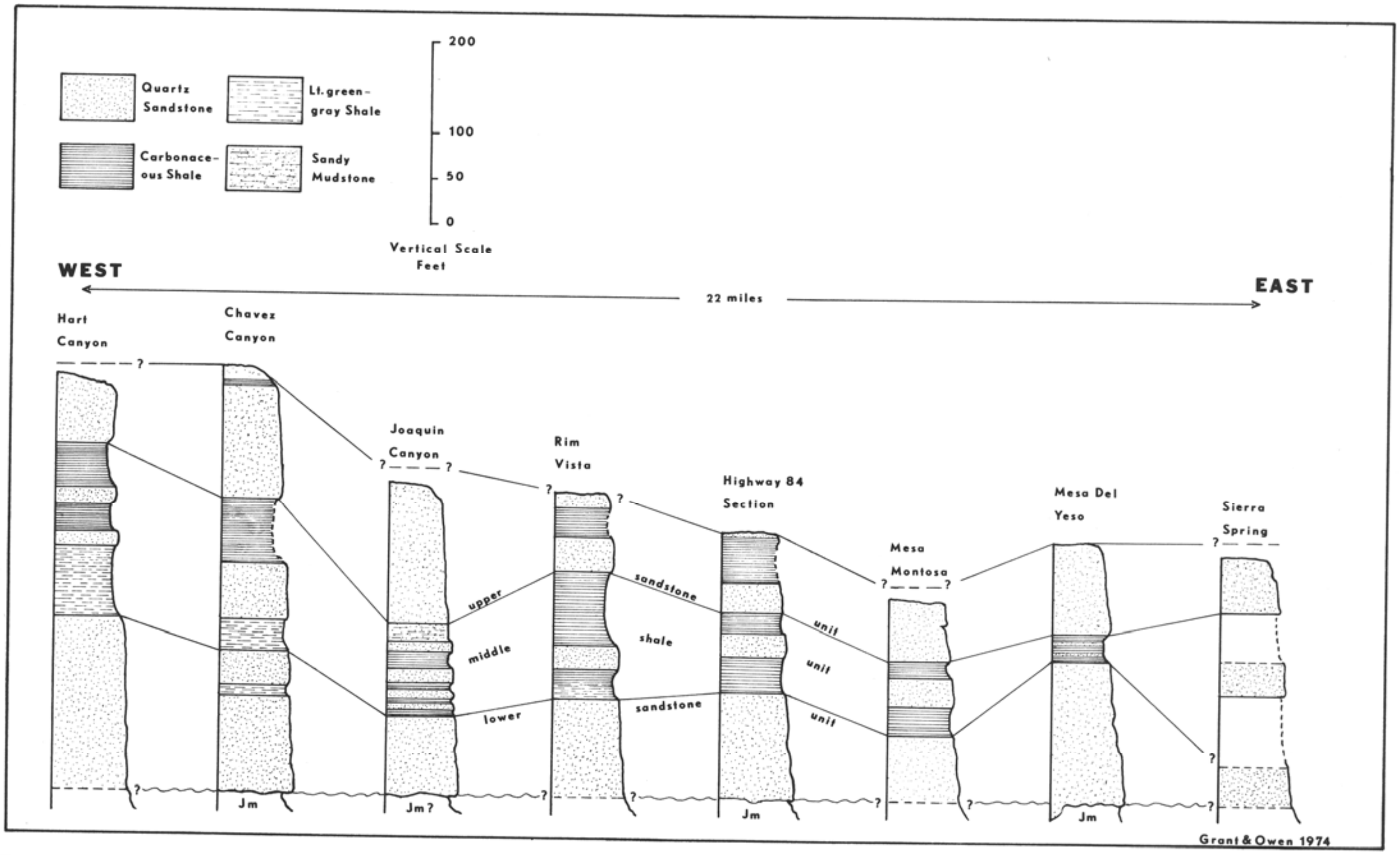

Figure 4. Generalized measured sections of Dakota Sandstone in southern part of Chama basin with major rock-stratigraphic units identified. No horizontal scale. See Figure 1 for location of sections.

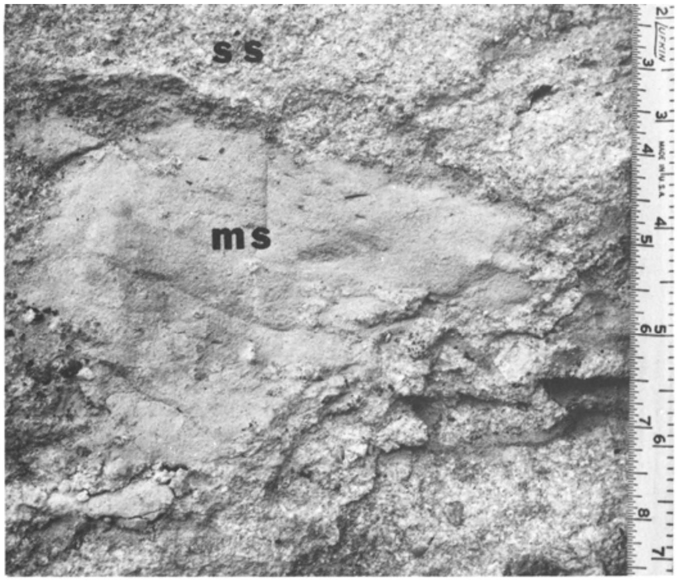

Figure 5. Clast of green mudstone (ms) enclosed in sandstone (ss) of lower sandstone unit. Mesa Montosa section. Scale numbered in tenths of a foot on right and inches on left.

stream conditions to meandering streams with vegetated floodplains (see Owen, 1973, p. 42).

Middle Shale Unit

All exposures of the Dakota in the area contain some prominent carbonaceous shaly strata in the central part of the formation. However, the exact contacts of this unit are quite difficult to recognize consistently and to trace laterally. The lower boundary is in a zone of channel sandstones and overbank shale. Where sandstone predominates in the middle shale it can be included easily in the lower sandstone unit, especially where exposures are poor and the shale forms largely covered slopes. Interstratified with the beds of carbonaceous shale are thin to locally thick sandstone beds quite similar to those of the upper sandstone unit. Where these sandstones are thick and prominent, the tendency is to include the interbedded shales in the upper sandstone unit, especially where the sandstones are abundant in the upper part of the middle unit. Also, the thin, green to greenish-gray mudstones which are generally included in the lower sandstone unit, are locally thick and form the lower part of the slope exposure of the middle unit. Should these beds be included in the middle shale unit because of their position and slope-forming expression or should they be included with the lower sandstone unit because of their color and apparently different depositional environment? In the latter case, the contact between the lower sandstone and middle shale would be placed at a green mudstone—dark grey shale contact where outcrops are good enough to expose this contact. Fortunately no repeated interbedding of green and dark grey lutites were observed.

An average thickness for the middle shale unit is, as explained above, difficult to cite. However, as defined, it is commonly about 120 feet thick but varies from as little as 30 feet at Mesa del Yeso to 190 feet at Hart Canyon. A general eastward thinning may be seen in Figure 4, except possibly at the Sierra Spring section where exposures are very poor due to the dense vegetation at the high elevations on Magote Ridge.

The middle shale unit records the various transitional environments between fluvial and shallow-marine conditions. Owen (1973, p. 45) interpreted it largely as a coastal shale, probably deposited in a variety of floodplain, paludal, and low-salinity paralic locations along a low coastal area. What may be delta-foreset beds are prominent in this unit in the Mesa del Yeso area.

Upper Sandstone Unit

The upper sandstone unit is quite distinct from the lower sandstone unit, being a tan to brown, generally fine-grained sandstone, containing only a few crossbedded strata and displaying abundant burrow-cast trace fossils which are especially evident on exposed bedding planes. The upper contact with the Mancos Shale is rarely well exposed. A prominent, thick bed of sandstone, with a locally ripple-marked upper surface, caps the rim of mesas of the area and forms a good physiographic break, but the top of a thinner sandstone bed with a distinctive yellowish weathering color lies about 30 to 60 feet above the rimrock (Fig. 6). This sandstone, which is separated from the rimrock in most areas by a covered shale interval, probably forms a better stratigraphic and genetic Dakota-Mancos contact. The top of this yellowish weathering sandstone is the contact used by Smith and others (1961). As so defined, the upper sandstone has an average thickness of 115 feet in the study area.

The upper sandstone unit was interpreted by Owen (1973, p. 45-47) as a coastal sandstone deposited in a variety of shallow-marine to beach and barrier-island environments. The sedimentary structures and trace fossils are similar to those of the marine Cubero, Paquate, and Twowells Sandstone Members of the Dakota in the southeastern part of the San Juan Basin. However, marine bivalves, gastropods, and ammonites are rare or absent in the Chama basin, unlike the southeastern San Juan Basin. The upper sandstone units of the Chama basin

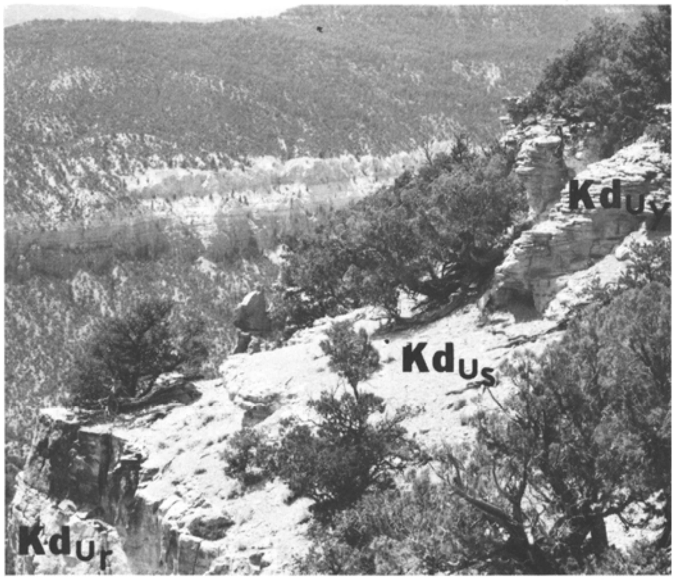

Figure 6. Yellowish sandstone (Kd_{uy}) of uppermost Dakota on upper right overlying slope-forming shaly strata (Kd_{us}) above cliff-forming sandstone (Kd_{ur}) of rimrock on lower left at Chavez Canyon section. Stratigraphic interval from top of rimrock to top of yellowish sandstone equals 28 feet. Prominent cliff in distance formed by Entrada Sandstone west of Chama River.

may have been deposited in a more restricted, less saline environment, as compared with the upper part of the Dakota farther south.

PALEONTOLOGY

One specimen of the marine bivalve *Inoceramus* was collected from non-carbonaceous grey shale in the middle shale unit at the Mesa del Yeso section and another *Inoceramus* specimen was found in surface float near the top of the upper sandstone unit at the Highway 84 section. These are the only body fossils observed in the Dakota of the study area. Adams (1957, p. 80) and Muehlberger (1967, p. 21) reported bivalves from the upper sandstone unit of the Dakota in the Chama area. A few samples of green mudstone were washed and examined for microfossils, but none were found. The dark shale samples await examination. Poorly preserved coaly fossils of plant stems and leaves may be seen locally in well exposed parts of the carbonaceous sandstones in the upper part of the lower sandstone unit and in carbonaceous shales in the lower part of the middle shale unit, for example, at the Highway 84 section.

By far the most abundant fossils in the Dakota of the area are trace fossils, especially burrow casts. These are most obvious in the upper sandstone unit where many bedding planes, especially bottoms of beds, are covered by burrow casts (Fig. 7). Burrowed zones may also be seen on cliff faces as approximately one-inch thick laminae where the sand matrix has been weathered out from between the burrow casts leavingcavities (Fig. 8). Many of the shaly beds also contain trace fossils; some strata are completely bioturbated (Fig. 9).

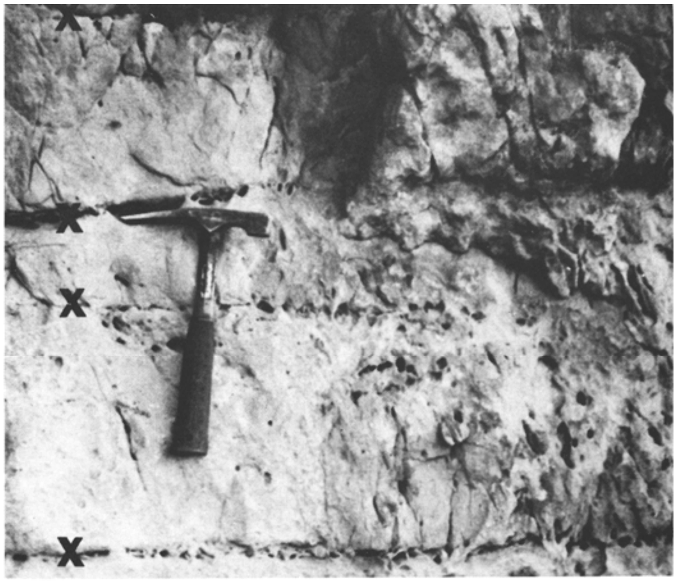

Figure 8. Horizontally burrowed zones of Thalassinoides *in upper sandstone unit at Mesa Montosa section. Burrowed laminae marked by X. Vertical dimension of hammer is 0.93 foot.*

As Owen (1973, p. 45) observed, a crude vertical zonation of trace fossils exists in the Dakota. From bottom to top, the lower beds contain no trace fossils, higher beds contain isolated vertical burrow casts, and the upper beds contain variously oriented, but especially horizontal, branching burrow casts. No definite trace fossils were observed in the noncarbonaceous part of the lower sandstone unit, although a few suspicious markings were seen. The trace fossils first appear in the carbonaceous, uppermost part of the lower sandstone unit at some exposures (the Joaquin Canyon section, for example) but in the lower to middle part of the middle shale unit at most exposures (the Highway 84 section, for example). The abundance, average size, and variety of trace fossils generally increases upward to a maximum within the upper sandstone unit.

The lowest occurring definite trace fossils are commonly discrete, vertical, unbranched, unornamented tube-fillings with

Figure 7. Burrow casts of Thalassinoides *on base of bed in upper sandstone unit at Mesa Montosa section. Scale is numbered in inches at top and centimeters at bottom. Note inverted Y-shape of large form of* Thalassinoides *at left and small form elsewhere.*

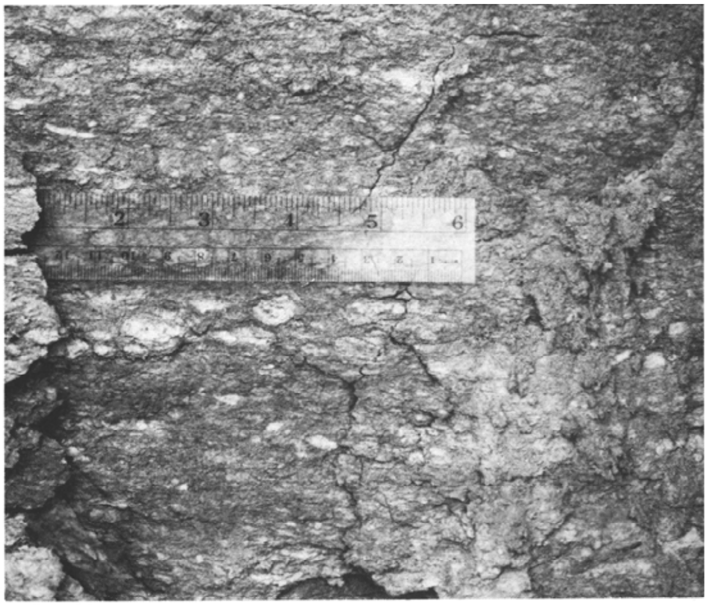

Figure 9. Bioturbated uppermost part of middle shale unit at Hart Canyon section. Lighter colored filling of Planolites *burrows is more sandy than enclosing matrix. Scale numbered in Inches above and centimeters below.*

a circular cross-section in plain view. The most common of these forms appear to indicate burrowing downward from a single bedding plane to depths averaging approximately four inches; the average diameter is about 0.5 inch. Some of these tubes appear to taper downward, but this may be an illusion due to a slanting exposure. Some have a funnel-shaped upper surface. At the Rim Vista section (Fig. 4), the burrows have been filled with small pebbles and coarse sand from above (Fig. 10). This more common form is known as *Tigillites* (Hantzschel, 1962, p. 218). The less common form is longer and less wide, does not taper, and was observed filled only with fine-to-medium-grained sand. This form is identified as *Skolithos,* although the tubes are less crowded together than in the typical development. Neither of these vertical-tube type trace fossils are as common as other forms, having been observed in only half of the measured sections.

The next most abundant trace fossils are small, irregular burrow fillings generally parallel to bedding planes (Figs. 9 & 11), but some are variously oriented. A few appear to branch and others cross over one another. These are given the general name *Planolites.* As exposed, they have an average length of approximately one inch, but a few are as long as 2.5 inches. Their diameter averages 0.17 inch, but ranges from 0.1 to 0.5 inch. Many have an elliptical cross-sectional shape but this may be due to post-depositional compaction. *Planolites* occurs locally in the middle shale unit and the upper sandstone unit at most exposures as well as in the uppermost part of carbonaceous sandstone of the lower sandstone unit at the Joaquin Canyon section. The muddy beds are commonly bioturbated by the larger of the *Planolites* burrows (Fig. 9).

By far the most abundant trace fossil is *Thalassinoides,* a large smooth-surfaced filled burrow and tunnel system with common Y-shaped forks (Fig. 6), which were probably produced by decapod crustaceans (Hantzschel, 1962, p. 218). A distinct widening at the junction of branches may be observe in some specimens. Like *Planolites,* many *Thalassinoides* have an elliptical cross-sectional shape, probably due to compaction. A large majority of the *Thalassinoides* observed are oriented parallel to bedding planes; they completely cover the bottom of many beds. However, some are perpendicular or diagonal to bedding. They most commonly occur in distinct thin (— 1 inch) concentrations parallel to bedding and spaced a few inches to a few feet apart (Fig. 8). Smaller numbers of variously oriented *Thalassinoides* may occur between the concentrated zones.

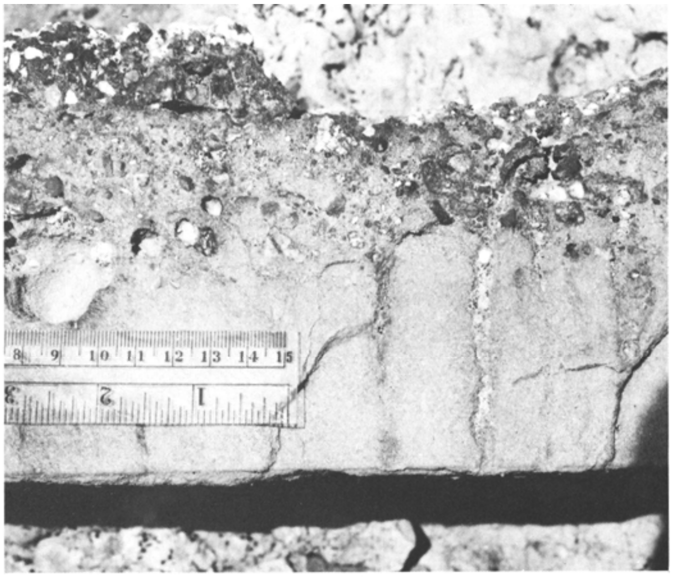

Figure 10. Pebble- and sand-filled burrows of Tigillites *in thin sand and conglomerate bed in lower part of middle shale unit at Rim Vista section. Scale numbered in centimeters above and inches below.*

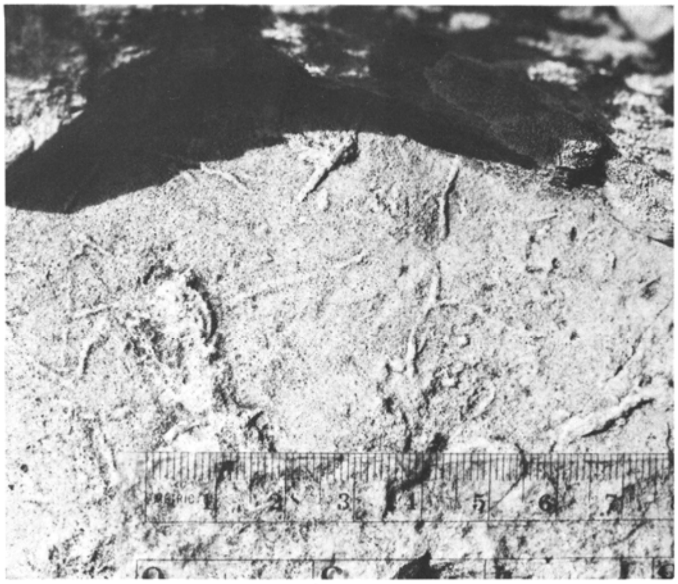

Figure 11. Small Planolites *on top of bed in uppermost part of lower sandstone unit at Joaquin Canyon section. Scale numbered in centimeters.*

Two distinct sizes of *Thalassinoides* are present in the Dakota of the study area. The small form, which is the most common, averages about 3.5 inches in length, as exposed, but some were observed as long as 5.5 inches. The width of the burrow filling averages 0.4 inch but ranges from 0.1 to 0.6 inch. The large form averages about 7.0 inches long, as exposed, but some were observed as long as 2.5 feet. The width of the large burrow filling averages 0.5 inch, but some as large as 1.0 inch across were measured. Both the small and large forms of *Thalassinoides* may occur together (Fig. 6) or separately.

Thalassinoides is present mainly in the upper sandstone unit although a few of the small forms occur in sandy beds in the upper part of the middle shale unit. *Thalassinoides* apparently indicates marine conditions of deposition.

SEDIMENTOLOGY

Sandstones

Petrology

The Highway 84 section, which is the best exposed, least weathered, and most easily accessible exposure, was chosen for representative sample collection and analysis. Sixteen sandstone samples were disaggregated and sieved to 0.25 phi-intervals according to the methods of Folk (1968, p. 34-35). Grain-size distribution was measured in thin-sections of four well cemented sandstones according to the method of Friedman (1958). Grain-size parameters were calculated by the method of moments using a computer and the formulae of McBride (1971, p. 117). Mineralogical determinations were made by point-counting grains in 16 thin-sections. A general description of the sandstones at the Highway 84 section follows (see Fig. 12).

Upper Sandstone Unit: fine-grained, subangular to subrounded, moderately well- to well-sorted, fine-skewed, leptokurtic, locally cherty quartz arenite.

Middle Shale Unit, sandstones: fine- to very fine-grained, angular to subangular, well-sorted, near-symmetrically-skewed, leptokurtic quartz arenite.

Lower Sandstone Unit: fine- to medium-grained, subangular to rounded, moderately well- to well-sorted, fine-skewed, leptokurtic, locally cherty quartz arenite.

Crossbedding.

A total of 290 azimuths of crossbedding were measured at the eight section localities, 77 percent being from the lower sandstone unit. The data were analyzed with the aid of a computer to obtain a vector mean (or two vector means for bimodal distributions) for the lower sandstone unit at each locality (Fig. 1). Also, a similar summation of all azimuths from sandstones in the middle shale unit and the upper sandstone unit was calculated (Fig. 1).

Crossbedding in the lower sandstone unit is polymodal; vector resultants vary considerably from section to section (Fig. 1). However, a general northerly to northeasterly paleocurrent flow direction is suggested. A secondary southeasterly to southwesterly flow direction is suggested also. Evidence of centripetal flow toward the center of the Chama basin appears to exist.

Crossbedding directions in the largely marine sandstones of the middle shale unit and upper sandstone unit show a primary vector mean toward the south-southeast and a secondary mean toward the north-northeast, somewhat a reversal of the lower sandstone unit directions.

Regional paleogeographic reconstructions from data in such

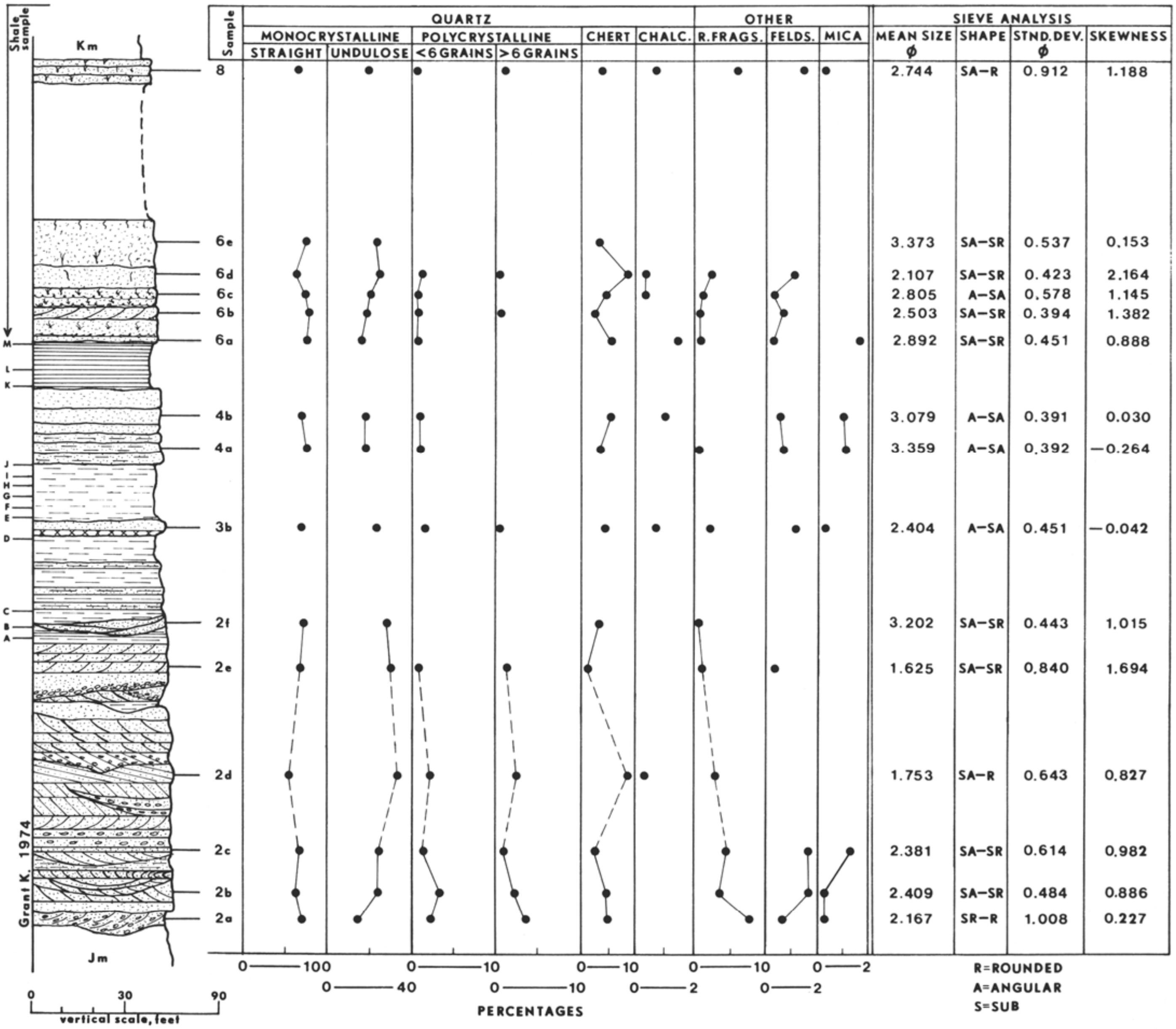

Figure 12. Stratigraphic column of Highway 84 section with petrographic data, grain-size distribution, and shale sample positions.

a small area are difficult. The view of streams flowing to the north across a coastal plain to a sea to the north is consistent with the view of Haun and Kent (1965, p. 1791) that Cretaceous seas entered New Mexico from the north. However, the change in character of the Dakota to entirely marine rocks as close as 55 miles south of the study area, as discussed by Landes and others (1973), is difficult to reconcile with a southward-transgressing sea. Perhaps the uplift east and north of the Chama basin, where the Dakota rests on Precambrian rocks (see Haun, 1959, Fig. 4 and Muehlberger, 1967, p. 23-24), locally complicated the regional paleogeographic setting in the Chama basin area. The exposures of Dakota Sandstone between the Chama basin and the marine rocks west of San Ysidro, New Mexico may be the key to deciphering the paleogeographic picture; they are currently being studied by one of the authors (Owen).

Other crossbedding parameters in addition to the azimuths were recorded for use in environmental interpretations. These include set and coset thickness, length, width, and angle of foresets, external shape (wedge, tabular, or trough) and internal shape (convex, concave, planar, sigmoidal, etc.) of sets, and nature of the lower boundary of sets. Multivariate analysis of these parameters is being carried out at the time of writing of this paper, but some observations are apparent now. Wedge-shaped sets (71%) dominate over tabular sets (26%); trough-shaped sets are uncommon (3%), see Figures 13, 14, and 15. Of the wedge-shaped sets, 59 percent have planar foresets (Fig. 16) and 39 percent have convex-up foresets (Fig. 12). Of the tabular sets, 66 percent have planar foresets and 30 percent have convex-up foresets. Other shapes, including oversteepened and contorted foresets (Fig. 18), account for the remaining small percentages. Size of the sets does not seem to show any consistent relationship with the type of crossbedding. Nearly all of the crossbedding measurements were made on cliff-type exposures, so that some misinterpretation of the shape is possible due to the lack of a good three-dimensional exposure.

Figure 14. Tabular crossbedding in middle part of lower sandstone unit at Mesa Montosa section. Note medium-scale crossbedding in lower part and small-scale crossbedding in upper part. Vertical dimension of hammer is 0.93 foot.

The types of crossbedding in the lower sandstone unit, excluding the uppermost carbonaceous part, compare closely with a hypothetical model for braided-stream deposits and the Sharon Conglomerate (Pennsylvanian) of northeastern Ohio, which also has been interpretated as a braided-stream sandstone (Coogan and others, 1974). The Sharon contains more tabular and less wedge-type crossbedding and more gravel than the lower sandstone unit of the Dakota; otherwise they are quite similar.

Shales

Shales were analyzed to determine whether the shales in the three Dakota units (Fig. 4) contain a diagnostic suite of min-

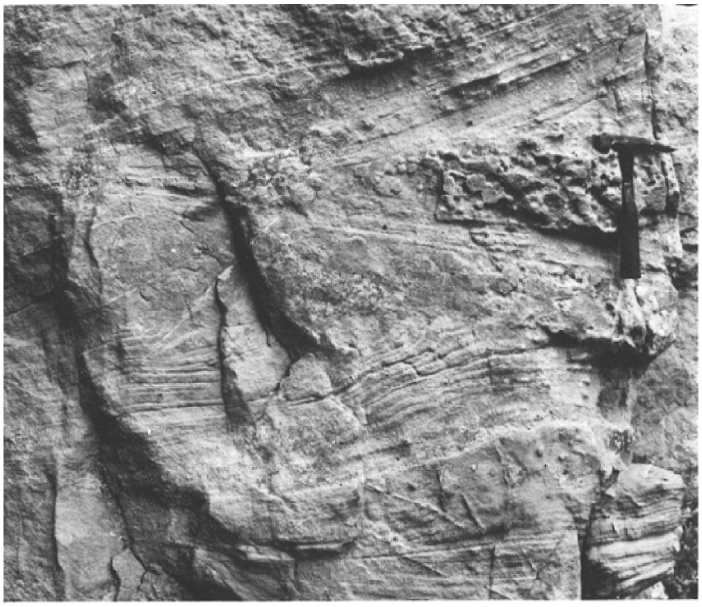

Figure 13. Wedge-shaped crossbedding in lower part of lowe sandstone unit at Mesa Montosa section. Vertical dimension o hammer is 0.93 foot.

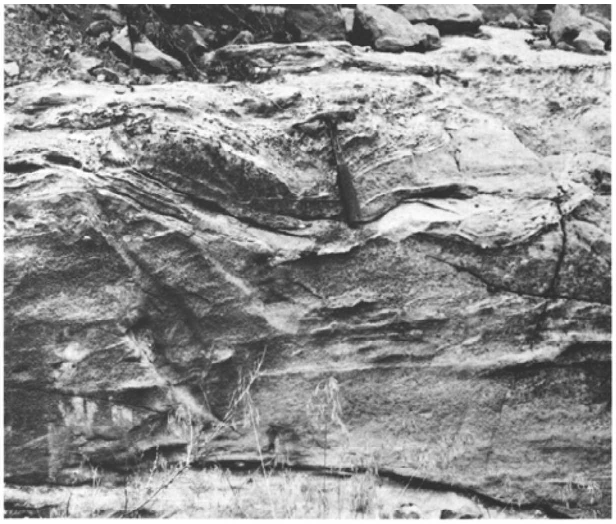

Figure 15. Trough-shaped crossbedding near hammer in uppermost part of lower sandstone unit at Highway 84 section. Vertical dimension of hammer is 0.93 foot.

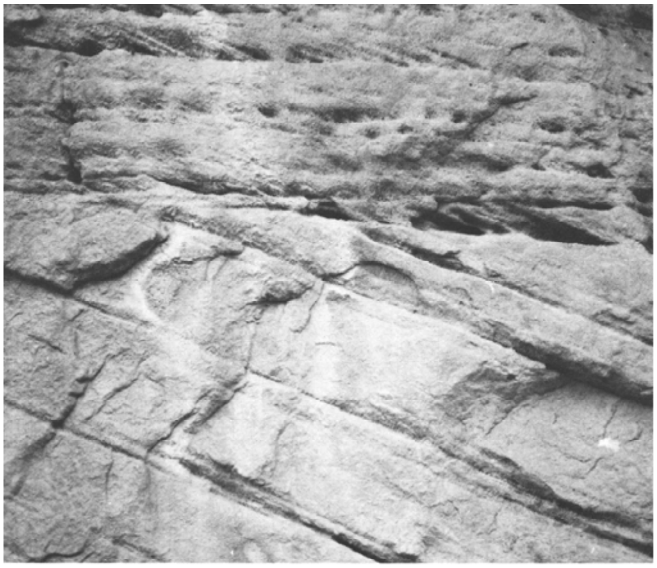

Figure 16. Planar-type foresets at Mesa Montosa section. Thickness of sandstone shown is 1.5 feet. Enlargement of Figure 14.

Figure 18. Oversteepened crossbedding to left of hammer in lower part of lower sandstone unit at Mesa Montosa section. Vertical dimension of hammer is 0.93 foot.

erals. Samples were prepared according to the method of Devine and others (1972) in which disaggregated and suspended sediment is centrifuged onto glass slides. Mineral percentages were calculated from the X-ray diffraction peak intensities utilizing the equation of Devine and others (1972, p. 469) which is a modification of an equation derived by Moore (1968).

The data presented is a compilation of the ratios of the percentages of the most common minerals identified from the diffractograms for 14 shale samples from the Highway 84 section. Figure 12 indicates the location of each of the samples within the section. Reference to Table 1 shows that three groupings of mineral ratios are present. Cross-reference to the lithologic column of Figure 12 indicates that these three groupings of minerals coincide with three essentially different shale units as defined by field observations. The lowermost group (group 1, samples A-D) is typified by greenish-grey silty shale interbedded with thin (1-2 feet) sandstone beds. The middle group (group 2, samples E-K) is diagnostic of the fairly

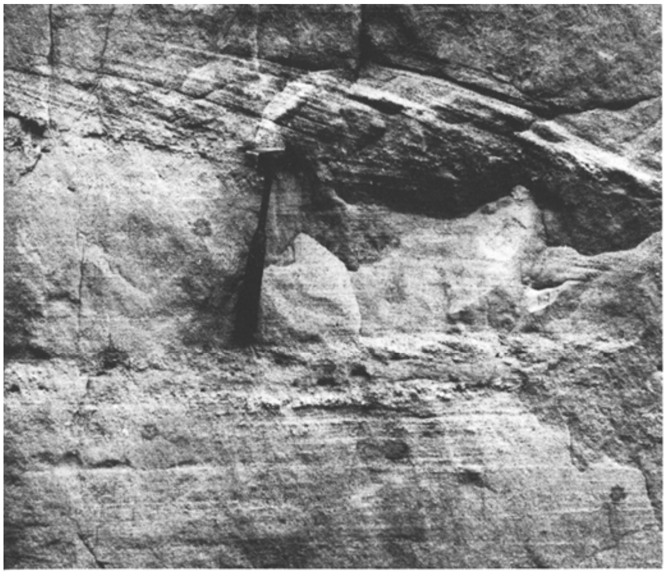

Figure 17. Convex-up foresets in upper part of lower sandstone unit at Rim Vista section marked by hammer head. Vertical dimension of hammer is 0.93 foot.

Table 1. Ratios of minerals present in shale samples from Dakota Sandstone at Highway 84 section. All samples from middle shale unit (see Fig. 4).

Q/K	Q/F	K/F	Q/C	Q/P	Q/M	Q/I	Sample	Group
1.9	147.1	82.1	0.0	0.0	0.0	0.0	M	3
0.9	82.0	87.0	0.0	0.0	0.0	0.0	L	
2.1	28.8	13.9	0.0	0.0	0.0	32.7	K	2
2.9	33.8	11.6	0.0	0.0	0.0	0.0	J	
2.8	45.1	16.0	0.0	0.0	35.6	9.4	I	
1.9	41.4	22.0	0.0	0.0	0.0	6.7	H	
2.9	51.4	17.9	0.0	0.0	8.5	0.0	G	
3.2	45.6	14.0	0.0	0.0	0.0	0.0	F	
2.2	36.3	16.2	0.0	21.1	0.0	0.0	E	
1.8	0.0	0.0	0.0	14.7	0.0	0.0	D	1
2.6	0.0	0.0	0.0	0.0	0.0	0.0	C	
1.2	0.0	0.0	129	0.0	0.0	0.0	B	
3.1	0.0	0.0	101	0.0	0.0	0.0	A	

Q = Quartz K = Kaolinite F = Feldspar C = Chlorite

P = Pyrite M = Muscovite I = Illite

thick (approximately 45 feet), dark grey, silty shales with thin sandstones present toward the top of the succession. The third mineral grouping (group 3, samples L-M) is from the dark grey to black, carbonaceous shale unit that underlies the upper sandstone unit.

Table 2 shows the results of the analysis of 13 shale samples from the Joaquin Canyon section. These samples were taken from a succession of dark grey to black carbonaceous shales; the ratios of the various minerals present are very similar overall to those of group 3 from the Highway 84 section. Although much more work needs to be done on the shales from the Dakota Sandstone, the above data indicate that lithologically similar types of shales have similar mineral percentages and that at least three types of shale are present in the Dakota of the study area.

In terms of depositional environment interpretations, the most significant factor is that the Dakota shales are highly kaolinitic, with only subordinate amounts of other clay minerals. While the authors recognize that there are two basic non-aligned philosophies concerning the significance of the distribution of various types of clay and other minerals in sedimentary rocks (Grim, 1958; Smoot, 1960; Pryor and Glass, 1961, etc.), it is possible that consistent differences within any one particular formation may be considered as valid diagnostic criteria for interpretations made relevant to that formation. This should be particularly true for the Dakota Sandstone inasmuch as the top and bottom of the formation are clearly defined by sandstone units that effectively enclose the shales. The authors also recognize the necessity of utilizing other forms of environmentally indicative evidence such as crossbedding, trace fossils, etc., along with the shale analyses.

The presence of highly kaolinitic shales within the Dakota indicates that the environment of deposition of these shales was largely fluvial and low-salinity paralic and that no offshore marine shales are present in the study area. Many other workers (Grim, 1951 and 1958; Weaver, 1958; Smoot, 1960; Pryor and Glass, 1961) have concluded that shales composed mainly of quartz and kaolinite, like the Dakota shales, are representative of fluvial environments, especially when the marine diagnostic mixed-up layer illite-montmorillonite clays are rare or absent. No mixed-layer illite-montmorillonite was identified in the study area, but small amounts do occur in the middle shale unit in the Chama basin area (Owen, 1963, p. 151).

Table 2. Ratios of minerals present in shale samples from Dakota Sandstone at Joaquin Canyon section. Samples 1-6 from carbonaceous upper part of lower sandstone unit; samples 7-11 from carbonaceous shale of middle shale unit.

Q/K	Q/F	K/F	Q/C	Q/P	Q/M	Q/I	Sample
1.8	82.9	46.5	0.0	0.0	0.0	0.0	11
1.1	0.0	0.0	0.0	0.0	0.0	0.0	10
3.3	141.3	42.2	0.0	0.0	0.0	0.0	9
1.9	0.0	0.0	0.0	0.0	0.0	0.0	8
2.8	181.9	64.0	0.0	0.0	0.0	0.0	7
2.9	202.7	71.0	0.0	0.0	0.0	0.0	6
1.8	20.7	11.8	0.0	0.0	0.0	0.0	5
2.5	162.1	65.7	0.0	0.0	0.0	0.0	4
3.5	188.4	54.4	0.0	0.0	0.0	0.0	3
6.4	485.0	75.5	0.0	0.0	0.0	0.0	2a
2.3	138.8	61.1	0.0	31.8	0.0	0.0	2
2.4	710.0	299.0	0.0	0.0	0.0	0.0	1a
2.7	273.0	101.8	0.0	0.0	0.0	0.0	1

Q = Quartz K = Kaolinite F = Feldspar C = Chlorite
P = Pyrite M = Muscovite I = Illite

SUMMARY

The Dakota Sandstone (Cretaceous), a mesa-capping formation averaging 370 feet thick in the southern Chama basin, New Mexico, consists of a lower fluvial sandstone unit, a fluvial and paralic middle carbonaceous shale unit, and an upper marine sandstone unit. The sandstones are mainly quartz are nites containing mostly nonundulose, monocrystalline quartz grains. Crossbedding, which is very abundant in the lower sandstone unit and uncommon in the other sandstone beds, is dominantly of the externally wedge-shaped, internally planar type. Shales are composed almost entirely of quartz and kaolinite. A small variety of trace fossils, especially *Thalassinoides,* are very abundant in the upper portions of the formation.

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