



## ***Correlation and paleoenvironments of the Jackpile sandstone (Upper Jurassic) and intertongued Dakota Sandstone-lower Mancos Shale (Upper Cretaceous) in west-central New Mexico***

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# CORRELATION AND PALEOENVIRONMENTS OF THE JACKPILE SANDSTONE (UPPER JURASSIC) AND INTERTONGUED DAKOTA SANDSTONE-LOWER MANCOS SHALE (UPPER CRETACEOUS) IN WEST-CENTRAL NEW MEXICO

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## INTRODUCTION

The main purpose of this paper is to summarize interpretations of the correlation and paleoenvironments of rock-stratigraphic units adjacent to the Jurassic-Cretaceous unconformity in an irregular arcuate-shaped outcrop belt between Grants and Santa Fe, New Mexico (fig. 1). The study area is somewhat complicated structurally because it includes the junction of the Colorado Plateau (San Juan Basin), Rocky Mountains (Nacimiento uplift), and Basin and Range (Rio Grande graben). Included in this area is the type area of the Jackpile sandstone and the type section of the most of the members of the Dakota Sandstone—lower Mancos Shale intertongued complex. The Jackpile is the principal host rock for uranium in the study area, the Dakota is a reservoir rock, and the Mancos a source rock for gas and oil in the San Juan Basin.

This paper is part of a larger, in-progress study of the greater San Juan Basin region encompassing the rock-stratigraphic units discussed here plus the Burro Canyon Formation (Lower Cretaceous). The Burro Canyon Formation is present to the north of the study area.

## STRATIGRAPHIC NOMENCLATURE

The reference stratigraphic section for the area is the Laguna section (fig. 2), where all the named members are present. The Jackpile sand-

stone is an informally named bed present in the uppermost part of the Brushy Basin Member of the Morrison Formation. It derives its name from the Jackpile uranium mine east of Laguna. Although the Jackpile sandstone has never been formally named, the name has been widely used in publications on the area (for example: Moench and Schlee, 1967; Santos, 1975; Owen and Siemers, 1977). A very low-angle unconformity separates the Jackpile from the overlying Dakota Sandstone.

The Dakota Sandstone and lower part of the Mancos Shale form a complex of intertongued sandstones and shales throughout most of the San Juan Basin area. The Laguna section is the type section for the lower four of these units, formally named by Landis and others (1973). In stratigraphic order, these are: (1) Oak Canyon Member of the Dakota Sandstone, (2) Cubero Sandstone Tongue of the Dakota Sandstone, (3) Clay Mesa Shale Tongue of the Mancos Shale, and (4) Paguate Sandstone Tongue of the Dakota Sandstone. Two overlying tongues were named previously and have their type locality southwest of the San Juan Basin (Owen, 1966), but they are well developed in the Laguna section (fig. 2). These are the Whitewater Arroyo Shale Tongue of the Mancos Shale and the Twowells Sandstone Tongue of the Dakota Sandstone. Where one of the alternating sandstone or shale tongues wedges out, the subjacent and superjacent tongues merge together as an undifferentiated mass (fig. 2) with no significant lithologic contrast. However, over most of the study area, few of these wedgeouts occur; rather, they are much more common north (Owen and Siemers, 1977, fig. 2) and west (Landis and others, 1973, fig. 3) of the study area.

The lower Mancos Shale above the Twowells Sandstone Tongue is not subdivided formally in the study area because the absence of the Greenhorn Limestone Member precludes recognition of the underlying Graneros Shale Member. Shale that is of the same age as these members is present, as shown by molluscan faunal studies (Cobban, 1977a, b; Hook and Cobban, 1981), but no limestone occurs.

## AGE AND FOSSILS

The age of the Jackpile sandstone is somewhat uncertain because of a lack of age-diagnostic fossils. The only fossils discovered in the Jackpile are petrified wood fragments and nonmarine insect burrow casts; both of these are distributed sparsely. The underlying Brushy Basin mudstones also lack age-diagnostic fossils. Lee and Brookins (1978) gave an age of  $146 \pm 5$  my. based on Rb-Sr dates, for sedimentation of the Jackpile sandstone in the Laguna area. This would place it in the Oxfordian or possibly as high as the Kimmeridgian Stage of the Upper Jurassic using the time scale of Van Hinte (1976a).

The Dakota Sandstone and intertongued Mancos Shale are placed entirely in the Cenomanian Stage (lowermost Upper Cretaceous) by Cobban (1977a, b) based on an abundant molluscan fauna from all six members. The Cenomanian spans the 100-92 m.y. range in the time scale of Van Hinte (1976b). The Twowells Sandstone and Whitewater

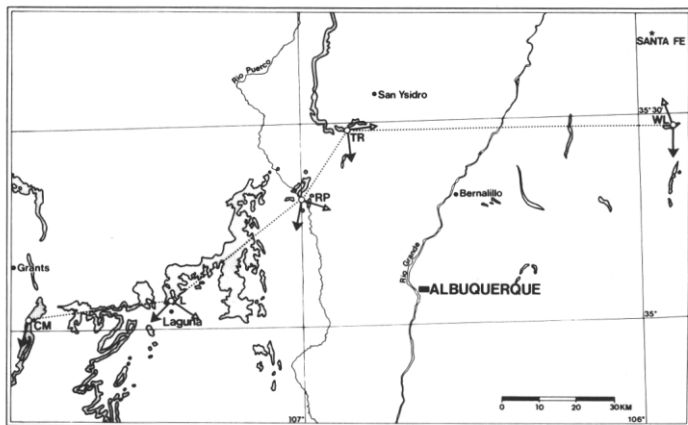


Figure 1. Map of study area with location of measured sections and paleocurrent directions. Stippled pattern is intertongued Dakota Sandstone-Mancos Shale outcrop. Open-headed arrows indicate Jackpile sandstone fluvial paleocurrents; solid-headed arrows indicate marine Dakota Sandstone paleocurrents. Following symbols show location of sections in Figure 2: CM = Cebolleta Mesa; L = Laguna; RP = Rio Puerco; TR = Tenorio Ranch; WL = West Lamy. RP is a composite section compiled from three partial sections at surrounding outcrops. The dotted line CM-WL is the line of cross section of Figure 2. Base map from Dane and Bachman (1965).

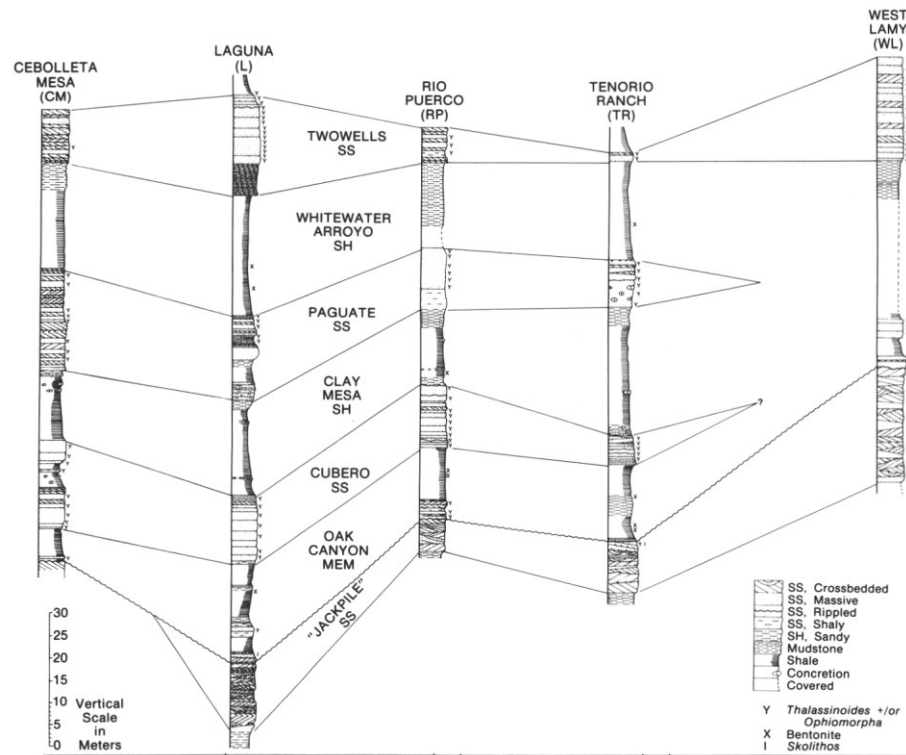


Figure 2. Correlation of rock-stratigraphic units within the upper part of the Morrison Formation, the Dakota Sandstone, and the lower part of the Mancos Shale. No horizontal scale. See Figure 1 for location of measured sections within the study area.

Arroyo Shale are upper Cenomanian, and the other four members contain middle Cenomanian faunas. The Cenomanian-Turonian boundary occurs above the Twowells in the lower Mancos Shale within the beds equivalent to the Greenhorn Limestone (Hook and Cobban, 1981). Where fluvial channel sandstones occur on the unconformity below the Dakota marine sandstones, some of these channel sandstones may be lower Cenomanian. They contain Cenomanian palynomorphs and carbonized wood fragments. Very few of these channel sandstones are present in the study area, but they are more common to the north and west. Based on the numeric time scales of Van Hinte (1976a, b), the unconformity separating the Jackpile from the Dakota could represent approximately 45 my. or more of hiatus; that is, a little more than all of Early-Cretaceous time.

In addition to body fossils, the intertongued Dakota-Mancos rocks contain abundant trace fossils, which are best seen in the sandstones. The four most common genera follow. Nondescript *Planolites* burrow fillings constitute completely bioturbated thick beds in all sandstone members. The Paguate Sandstone is completely bioturbated at many exposures. *Thalassinoides* and *Ophiomorpha*, the Y-shaped filled burrows of marine decapod crustaceans, are abundant in most members at most localities. *Skolithos*, a straight vertical filled burrow of a marine worm, is present in the lower part of the Oak Canyon Member at some localities.

#### THICKNESS AND CORRELATION

The Jackpile sandstone is present beneath the basal Dakota unconformity throughout most of the study area. The Jackpile has been removed by pre-Cenomanian erosion along this slightly angular unconformity from areas more than 15 km west of the Laguna section (fig. 1), so that it is not present at the Cebolleta Mesa section (fig. 2). The Jackpile has also been removed along this unconformity on Mesa

Gigante, 9 km east of Laguna, and at all outcrops south of Laguna (fig. 1). Locally, the Jackpile does wedge out as mapped by Santos (1975), for example just west of the Rio Puerco section (fig. 1). It ranges from near 0 to 50 m thick (Santos, 1975) and shows a general, but irregular, increase in thickness to the northeast. An average thickness is 15 m. The Jackpile is generally present at all of the outcrops shown on Figure 1 east of the Rio Grande to near Santa Fe, a fact not previously well known.

The Dakota Sandstone and intertongued Mancos Shale are present throughout the study area. They are typically about 100 m thick. Maximum thickness of 128 m occurs in the Laguna area (fig. 2). Minimum thickness occurs in the area east of the Rio Grande where some of the sandstone tongues wedge out. For example, at the West Lamy section (fig. 2), the Dakota-intertongued-Mancos thickness is only 69 m, and it is even thinner at some other nearby localities. Some older publications (Hunt, 1936) reported the Dakota locally wedging out in the study area. However, these reports reflect an older usage of the term Dakota to mean only the basal sandstone bed above the unconformity; so that where this basal sandstone is missing, they concluded that the Mancos Shale rested directly on the Morrison Formation. Also, in many older publications beginning with Hunt (1936), the sandstone tongues (now known as Cubero, Paguate, and Twowells) were erroneously called "Tres Hermanos sandstones." However, Dane (1959), Owen (1966), Marvin (1967), and Dane and others (1971) eventually corrected this mistake and worked out the correct correlations.

The Oak Canyon Member is present throughout the area, although correlation of its upper part contact to the West Lamy section (fig. 2) is difficult. It varies appreciably in thickness due to relief on the basal unconformity and development of various sandstones within it. An average thickness is 16 m in the study area.

The Cubero Sandstone Tongue is present throughout most of the

study area although it thins to the east and is probably not present at the West Lamy section (fig. 2). It averages 14 m in thickness where present.

The Clay Mesa Shale Tongue is present throughout most of the study area. However, it becomes unrecognizable at the West Lamy section (fig. 2), because it merges with the Whitewater Arroyo Shale Tongue. It varies somewhat in thickness due to an uneven development of a rather thick transition zone with the overlying Paguate Sandstone. The uneven development of this zone and the variable quality of its exposure make a consistent Clay Mesa—Paguate contact impossible to define. An average thickness of the Clay Mesa is 21 m.

The Paguate Sandstone Tongue is also present throughout most of the study area, but it thins eastward and is not present at the outcrops examined east of the Rio Grande (fig. 2). Its average thickness in the study area, where present, is 16 m, although the lower contact is difficult to define, as mentioned above.

The Whitewater Arroyo Shale tongue is recognizable throughout the part of the study area west of the Rio Grande where the overlying Twowells Sandstone Tongue is present. Like the Clay Mesa, it merges into an undifferentiated mass of Mancos Shale east of the Rio Grande. It is consistently about 24 m thick, where present, although locally it may also have a thick transition zone with the overlying Twowells (fig. 2).

The Twowells Sandstone Tongue, although present at all five measured sections in Figure 2, is rather irregularly developed in the study area. It is present throughout the western part of the study area and is quite thick (22.5 m) in the vicinity of the Laguna section where it includes remarkable cosets of unimodal crossbeds in its lower part (fig. 2). In the area of the Rio Puerco and Tenorio Ranch sections it wedges in and out, although it is shown as a continuous bed for simplicity on Figure 2. It is considerably thinner in the area where it wedges in and out as a series of lenses (8 m at Rio Puerco and 2 m at Tenorio Ranch). East of the Rio Grande, it is present along all the outcrops observed but varies in thickness up to the maximum 32 m at West Lamy (fig. 2). The Twowells is overlain by the main body of the lower part of the Mancos Shale (Graneros equivalent).

Readers interested in the extent of the individual intertongued Dakota-Mancos members outside the study area are referred to Landis and others (1973), Owen and Siemers (1977), and Hook and others (1980).

### LITHOLOGY AND SEDIMENTARY STRUCTURES

Lithologically, the Jackpile sandstone is quite distinct from the sandstones of the Dakota. The various Dakota sandstone tongues are quite similar to each other in type of sandstone. Likewise, the Mancos shale tongues differ very little in lithology between themselves or from the main body of the lower Mancos. Only brief lithologic descriptions are given here. For more detail, the reader is referred to Flesch (1974), Flesch and Wilson (1974), and Santos (1975) for the Jackpile and Landis and others (1973) and Owen and Siemers (1977) for the Dakota-Mancos.

The Jackpile sandstone is white, kaolinitic, fine- to medium-grained feldspathic quartz sandstone with a gradational, locally scoured contact with the underlying Brushy Basin mudstones. Thin lenses of variegated pale-green to pale-red mudstone, similar to that of the Brushy Basin mudstones, are locally present. Other than the generally white color, the most distinctive feature of the Jackpile is the abundant medium-scale, wedge and trough sets of crossbedding.

Sandstones of the Dakota are tan, carbonaceous, very fine- to fine-grained cherty quartz sandstones that are mostly bioturbated. A few beds that are not bioturbated show small-scale, tabular and trough sets of crossbedding. Except for basal Oak Canyon sandstones, a gradational lower contact and an abrupt upper contact are characteristic.

Shales of the Mancos tongues are dark-gray and silty with a few thin bentonite beds, especially in the Whitewater Arroyo Tongue and locally abundant zones of calcareous concretions especially in the Clay Mesa Tongue. The Mancos is a predominantly nonresistant unit so that good exposures occur only on very steep slopes. Trenching of outcrops is generally necessary to observe details, such as the thin bentonite beds which rarely exceed a centimeter in thickness.

Detailed measurements and descriptions of the crossbedding present in the Jackpile and Dakota sandstones were made at all localities where possible. A total of 89 crossbedding-dip directions at four localities were measured in the Jackpile, and 173 crossbedding-dip directions at five localities were measured in the Dakota marine sandstones. The data were subjected to true dip calculations, rotation to remove structural dip, statistical calculations including significance testing, and analysis for bimodality. Arrows indicating the direction of the statistically significant vector mean are plotted at each locality on Figure 1. The grand mean for the Jackpile of the study area is 72°, and individual locality means range from northerly through easterly to southeasterly. The grand mean for the Dakota marine sandstones of the study area is 185°. All of the individual-locality means are closely grouped around a southerly direction for the marine Dakota.

### PALEOENVIRONMENTS AND PALEOGEOGRAPHY

The Jackpile sandstone was deposited by a low-sinuosity braided-stream system, probably on the distal portion of a low-gradient alluvial fan, that flowed in a generally easterly direction. Associated playa deposits in Brushy Basin mudstones (Bell, 1981) indicate closed-basin conditions existed during some of the time. Mineralogy of associated altered tuffs (Bell, 1981) indicates an arid climate and location far from the sea. The source area was to the west and southwest of the study area and may have consisted of many stratigraphically lower Jurassic formations, as well as older rocks exposed in the distant Mogollon Highlands of Arizona, eroded during regional tilting.

A considerable hiatus, during which regional tilting to the northeast and subaerial erosion occurred, transpired after deposition of the Jackpile. During this period the erosional surface separating the Jackpile and basal Dakota was produced.

As the inland seaway approached the study area from the east, the climate became more humid, and meandering streams flowed across the vegetated coastal plain in generally easterly directions. A few of these stream-channel deposits were preserved locally in the basal Oak Canyon of the study area. The headwaters of these streams extended into the distant source areas of the Mogollon highlands of Arizona. Some sediment was derived from erosion of the Jackpile and stratigraphically lower Jurassic formations down into the Chinle Formation (Upper Triassic) closer to, but southwest of, the study area, producing the basal Dakota low-angle unconformity.

As the shoreline transgressed across the area, reworking of coastal-plain deposits occurred by waves and currents, depositing the lower part of the Oak Canyon Member. The remainder of the Oak Canyon, the Cubero, Clay Mesa, Paguate, Whitewater Arroyo, and most of the Twowells tongues were deposited as shoreface sands and offshore muds during a series of cyclic regressions and transgressions. The sandstone tongues represent temporary regressions of the shoreface due to increased sediment supply, eustatic sea-level fall, or uplift. Conversely, the shale tongues represent transgressions of the offshore zone due to decreased sediment supply, sea-level rise, or subsidence. Uplift and increased subsidence are regarded as the least likely causes of transgression and regression due to the lack of unconformities within the formations and the close timing of the cycles. Medial- and late-Cenomanian time was a period of rapid eustatic sea-level rise after an early-Cenomanian low level, according to Vail and others (1977) and Kauffman

(1979), although some minor sea-level falls could be superimposed on this overall rise. Unless these minor sea-level falls were sufficient to produce the regressive sandstone events, then increased sedimentation apparently caused progradations of the shoreface sand over the offshore mud. The overlap of the offshore mud on the shoreface sand probably was a result of the overall sea-level rise. The gradational lower and sharp upper contacts of the sandstone tongues may indicate slower regressions and faster transgressions.

Strong, southerly flowing bottom currents parallel or at a low angle to the shoreline were prevalent in the shoreface zone as indicated by the strongly oriented, south-dipping crossbedding (fig. 1). These currents brought sediment originally from the Sevier uplift of Utah into the area. Southerly bottom currents were characteristic of the western edge of the Cretaceous seaway throughout the interior western U.S. When sedimentation was slow the abundant population of burrowing organisms was able to bioturbate the sands completely, destroying the crossbedding. However, occasional periods of rapid sedimentation and/or destruction of the burrowers allowed some of the crossbedded units to be preserved.

Not all the Dakota marine sands were connected to the shoreline as shoreface sands. The principal exception in the study area is the Twowells sandstone lenses near the Rio Puerco and Tenorio Ranch sections. These sand bodies were deposited as elongate offshore sand lenses enclosed in offshore muds. They generally trend north-northwest and probably were oblique to the shoreline.

After deposition of the Twowells, the westward spread of the sea continued while the lower part of the main body of the Mancos was deposited. This seaway reached its maximum extent with deposition of part of the Greenhorn Limestone and equivalents during the high sea level of the early Turonian.

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