



Surface and subsurface stratigraphy of the Burro Canyon Formation, Dakota Sandstone, and intertongued Mancos Shale of the Chama Basin, New Mexico

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SURFACE AND SUBSURFACE STRATIGRAPHY OF THE BURRO CANYON FORMATION, DAKOTA SANDSTONE, AND INTERTONGUED MANCOS SHALE OF THE CHAMA BASIN, NEW MEXICO

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ABSTRACT.—The Burro Canyon Formation (Lower Cretaceous) and the Dakota Sandstone (Upper Cretaceous: Cenomanian), including two tongues of the Mancos Shale, are present throughout the Chama Basin. The Dakota-Mancos section is divided into 7 marine members in the Chama Basin. The entire stratigraphic section thins southward across the Chama Basin, most notably the Clay Mesa Shale Tongue of the Mancos and the Paguate Sandstone of the Dakota. Prominent sequence-bounding unconformities, K1 and K2, bound the Burro Canyon Formation. A correlative conformity equivalent to the K3 sequence-bounding unconformity occurs at the base of the Cubero Sandstone Tongue of the Dakota. A possible sequence boundary occurs at the base of the marine La Jollas bed, a local sandstone lens at the stratigraphic position of the upper Twowells Sandstone Tongue of the Dakota in the southern Chama Basin.

INTRODUCTION

The Burro Canyon Formation and Dakota Sandstone, including interbedded members of Mancos Shale, form prominent, cliff-forming outcrops along the east flank of the San Juan Basin, Rio Chama Canyon, large mesas, such as Mesa de los Viejos, across the southern Chama Basin, and the west flank of the Brazos uplift. Figure 1 shows the outcrop of the top of the Dakota Sandstone along both sides of the Rio Chama Canyon and the southern and eastern parts of the Chama Basin. The Dakota forms the caprock of most mesas in the Chama Basin. For this study, 13 stratigraphic sections were measured in the Chama Basin region. In addition, approximately 30 logs of petroleum-exploration wells and 16 published logs of uranium drill-holes (Ridgley, 1987) are available that penetrate a significant thickness of these formations in the Chama Basin region (R1-6E of T25-32N). These logs were also integrated into this study, which is part of the regional San Juan Basin study reported by Head and Owen (2005, this guidebook). All of the members of the Dakota-Mancos section were correlated into the Chama Basin through outcrops and subsurface logs from their stratotypes in the southern San Juan Basin, and the Burro Canyon Formation was traced from its stratotype in western Colorado (Stokes and Phoenix, 1948).

Previous stratigraphic work on the Burro Canyon-Dakota section in the Chama Basin includes that of McPeck (1965), Grant and Owen (1974), Saucier (1974), Ridgley (1977), Owen and Siemers (1977), Ridgley (1987), and the recent sequence-stratigraphic analysis of Varney (2001; 2005, this guidebook). The recognition of the Burro Canyon Formation in the Chama Basin has been a controversial topic. McPeck (1965) traced the Burro Canyon Formation to the western Chama Basin but, as many other early workers, included these strata in the Dakota Sandstone for mapping purposes, as did Grant and Owen (1974). Grant and Owen (1974) included it in an informal lower sandstone unit of the Dakota, which is now known to consist of the Burro Canyon Formation and the Encinal Canyon Member of the Dakota. Their middle shale unit is now known as the Oak Canyon Member

of the Dakota, and their upper sandstone unit consisted of the current Cubero Sandstone Tongue of the Dakota and the thin, yellow sandstone of the southern Chama Basin now known as the Paguate Sandstone Tongue of the Dakota. Saucier (1974) was the first to make a strong case for recognizing the Burro Canyon in the Chama Basin, and later workers have followed his lead. Ridgley (1977) correlated the Burro Canyon through the southern Chama Basin, but did not describe its lower contact with the Morrison Formation as unconformable. Owen and Siemers (1977) correlated the Burro Canyon across the Chama Basin and recognized its lower contact as unconformable on the Morrison Formation. However, Owen and Siemers (1977, fig. 2) miscorrelated the Cubero Sandstone Tongue of the Dakota to what is now known to be a thick Paguate Sandstone Tongue of the Dakota at North El Vado Dome (Heron Dam section of this paper). The

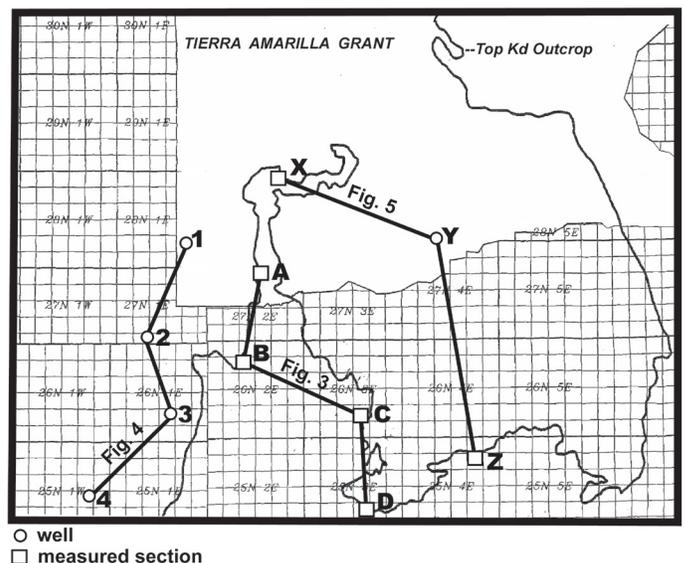


FIGURE 1. Index map of the Chama Basin with location of cross-sections (Figs. 3, 4, and 5). The Tierra Amarilla Grant is not surveyed into townships and ranges.

miscorrelation was corrected in Owen (2001, p. 32). Ridgley (1987) correlated the Burro Canyon Formation and units within the Dakota Sandstone in a series of uranium drill-hole logs to two measured sections near Heron Dam. She recognized the unconformities at the base and top of the Burro Canyon and divided the Dakota into informal units A (=Encinal Canyon Member), B (=Oak Canyon Member and Cubero Sandstone Tongue), and C (=Clay Mesa Shale Tongue of Mancos and Paguate Sandstone Tongue of Dakota). Varney (2001) proposed three sequences in the Dakota Sandstone at the Heron Dam section. Details are included in Varney (2005, this guidebook).

STRATIGRAPHY

General

The Cretaceous strata of the Chama Basin were deposited on coastal plain, shoreface, and offshore areas on the western edge of the Western Interior depositional basin, a subsiding, shallow seaway that connected the Arctic Ocean to the Gulf of Mexico during most of Late Cretaceous time (Fig. 2). The source areas for this clastic-dominated basin were the Sevier thrust-belt highlands to the west and the Mogollon highlands to the southwest. Shorelines transgressed and regressed frequently in response to eustatic sea-level changes and uplift-driven pulses of sediment from the highlands to the west and southwest. Climate was subtropical and probably semi-arid, due to the rain-shadow of the highlands during late Early Cretaceous time when the Burro Canyon Formation was deposited by braided-stream systems on a coastal plain. Climate became more humid when the fluvial and deltaic lower Dakota Sandstone strata, including floodplain coal beds, were deposited in the San Juan Basin during early Late Cretaceous (Cenomanian) time, 99.6-93.5 Ma (Gradstein and Ogg, 2004). Transgressions spread offshore Mancos marine shale tongues over shoreface sandstones in the upper Dakota of the Chama Basin, also during the Cenomanian. In the San Juan Basin, periods of subaerial erosion between periods of deposition produced three sequence-bounding unconformities, K1, K2, and K3, at the base and top of the Burro Canyon and within the Dakota. However, in the Chama Basin, the K3 unconformity grades into a correlative conformity in this more offshore location in the Western Interior seaway.

The Burro Canyon-Dakota strata are much like a scale model for the whole Cretaceous stratigraphic section in the San Juan and Chama basins. Almost all of the depositional systems of the thousands of feet of Cretaceous strata above are represented in the few hundred feet of Burro Canyon-Dakota strata.

The Burro Canyon-Dakota stratigraphy of the Chama Basin is presented in a series of three stratigraphic cross-sections, Figures 3, 4, and 5 (see Fig. 1 for location of cross-sections). Figure 3 is a 26-km long cross-section of measured sections along the Rio Chama Canyon from just below El Vado Dam to Chaves Canyon near the confluence of the Rio Gallina. The stratigraphy depicted in Figure 3 is almost continuously displayed along the upper part of the Rio Chama Canyon, best viewed with binoculars during a leisurely float down the river. Access to Burro Canyon-Dakota

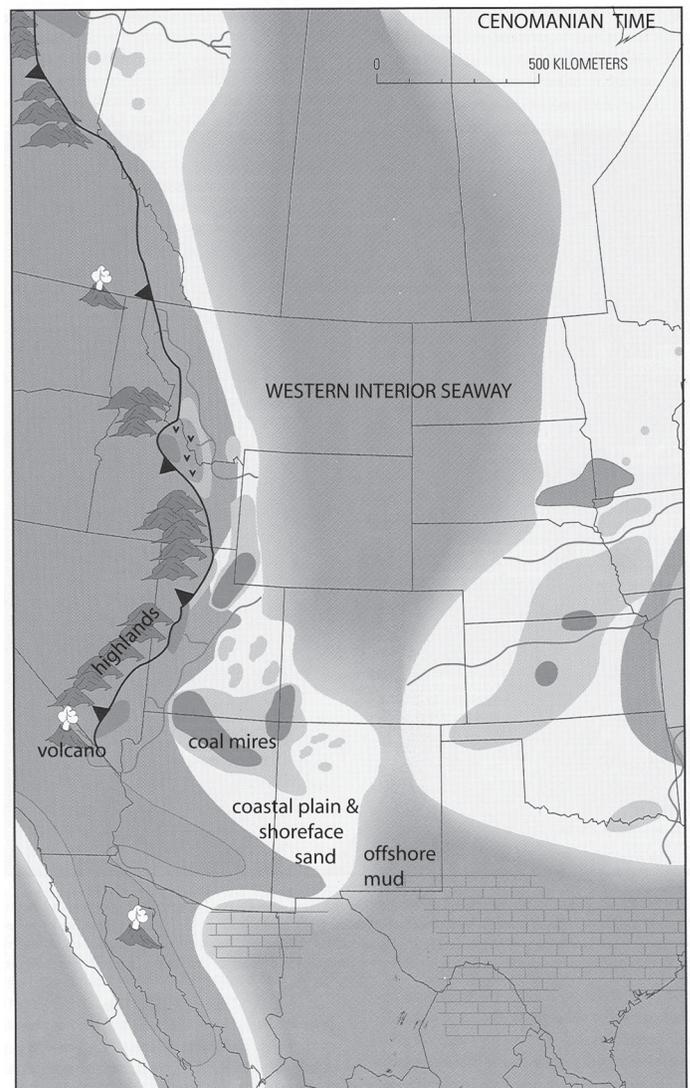


FIGURE 2. The Western Interior Seaway during Cenomanian time (modified from Roberts and Kirschbaum, 1995, p. 17). The Western Interior Seaway first connected with the Gulf of Mexico Seaway in northern New Mexico and southern Colorado during early Cenomanian time (*Neogastropilites cornutus* Biozone), according to Roberts and Kirschbaum (1995, p. 15).

cliffs on the east rim of the canyon is possible via a series of Forest Service dirt roads on the top of Mesa de los Viejos from a road junction at the top of the HW84 measured section. The Aragon Spring section (B on Fig. 3) is considered most typical of the Chama Basin Burro Canyon-Dakota stratigraphy. Figure 4 is a 28-km long cross-section of well logs along a roughly parallel line in the subsurface to the west of Figure 2. The Enre 1 Phoenix log (2 on Fig. 4) is a high-quality, modern log that is considered most typical of the Chama Basin Burro Canyon-Dakota stratigraphy. Figure 5 is a 34-km long cross-section connecting the HW84 measured section to the Heron Dam measured section by way of a well log approximately halfway between these sections. Almost all the stratigraphic units thin considerably southward in this cross-section, so the well log is at a valuable

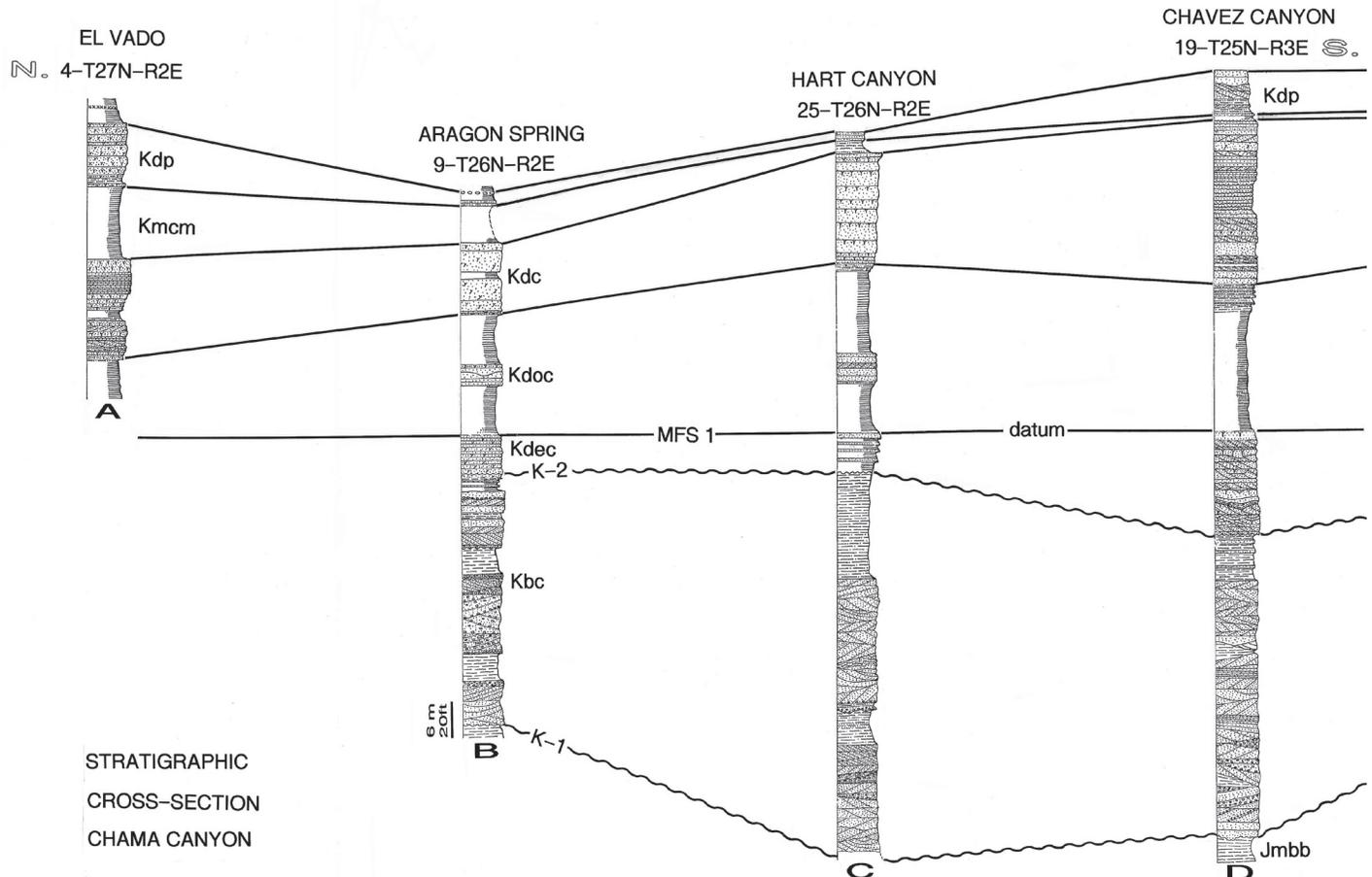


FIGURE 3. Stratigraphic cross-section, Chama Canyon. Kdp=Paguate Sandstone Tongue of Dakota Sandstone; Kmcm=Clay Mesa Shale Tongue of Mancos Shale; Kdc=Cubero Sandstone Tongue of Dakota Sandstone; Kdoc=Oak Canyon Member of Dakota Sandstone; Kdec=Encinal Canyon Member of Dakota Sandstone; Kbc=Burro Canyon Formation; Jmbb=Brushy Basin Member of Morrison Formation; MFS1=marine-flooding surface 1, the datum; K-2=K2 unconformity; K-1=K1 unconformity.

intermediate point to aid in correlation. A photograph (Fig. 6) of the Burro Canyon-Dakota section at Heron Dam shows all the exposed formal units. Figure 7, an annotated type log, shows all the stratigraphic unit boundaries and key surfaces. Details of the stratigraphy shown on these cross-sections, the photograph, and the log are presented below.

Burro Canyon Formation

The Burro Canyon Formation is present throughout the Chama Basin as a complete depositional sequence between the K1 and K2 unconformities. It is generally 35-55 m thick, but it does thin southward across the Chama Basin, reaching a minimum of 25 m at the HW84 section (Fig. 5). South of the Chama Basin, it decreases to 20 m near Gallina and 0 near Cuba. The southward thinning appears to be mainly due to regional truncation at the top of the Burro Canyon by the K2 unconformity. Many of the locally thick areas of Burro Canyon appear to be due to channeling on the K1 unconformity, for example, in the Hart Canyon and Chavez Canyon sections (Fig. 3).

The lithology of the Burro Canyon is dominated by medium- to fine-grained sandstone, much of which contains well rounded

chert and quartz pebbles above scour surfaces. Interbedded with the sandstone are layers and wedges of pale-green, locally pale red, mudstone that may be up to 20 m thick, but generally are near 5 m. Rip-up clasts of these mudstones occur locally in overlying pebbly sandstones. Fairly commonly, the uppermost preserved bed in the Burro Canyon is a mudstone (see Fig. 3 and the Enre 1 Phoenix well log in Fig. 4). Most of the sandstones are planar and trough crossbedded, but some plane-bedded sandstones exist. Paleocurrent flow directions from the crossbedding are locally variable, but average northeasterly and easterly (Grant and Owen, 1974; Owen et al., 1978).

The Burro Canyon Formation was deposited in a braided-stream system based on its lithology, geometry, and sedimentary structures. Streams flowed down the coastal plain in northeasterly to easterly directions toward the Western Interior seaway. Abandoned backwater areas accumulated thin mud deposits, but the lateral migration of the sandy braid bars deposited most of the formation. No fossils of any kind have been observed in the Chama Basin Burro Canyon. It is generally regarded as Aptian-Albian (125-99.6 Ma) in age (Gradstein and Ogg, 2004), based on Burro Canyon palynomorphs in western Colorado (Tschudy, et al., 1984), but it might be somewhat older.

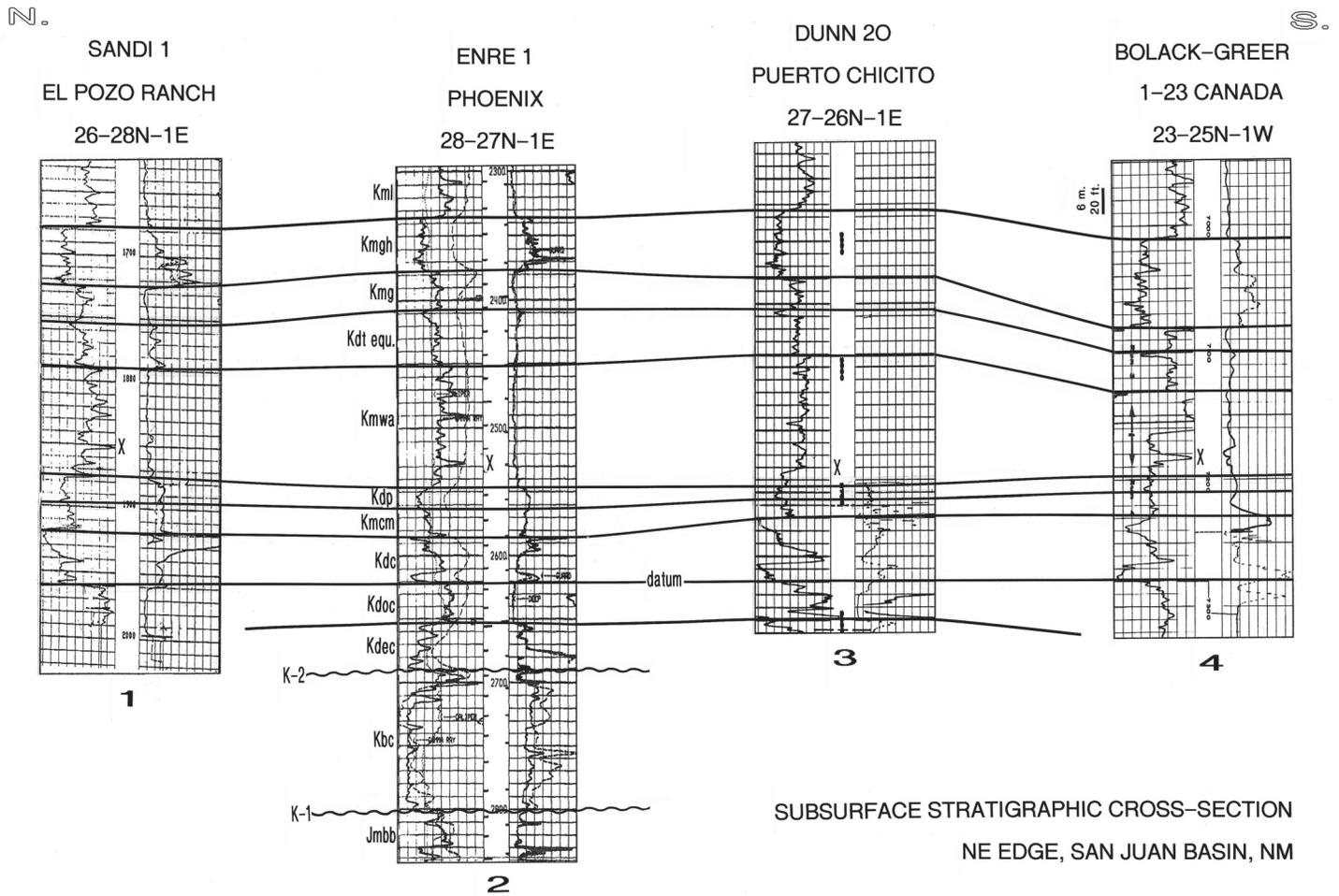


FIGURE 4. Subsurface stratigraphic cross-section, northeastern edge, San Juan Basin, NM. Abbreviations are the same as in Figure 3 plus the following additional ones: Kml=lower tongue of Mancos Shale; Kmgh=Greenhorn Limestone Member of Mancos Shale; Kmg=Graneros Shale Member of Mancos Shale; Kdt=Twowells Sandstone Tongue of Dakota Sandstone; Kmwa=Whitewater Arroyo Shale Tongue of Mancos Shale; X=X bentonite. Datum is the Oak Canyon-Cubero contact.

Dakota Sandstone and tongues of Mancos Shale

Encinal Canyon Member

The Encinal Canyon Member of the Dakota Sandstone is also present throughout the Chama Basin. It is bounded by the K2 unconformity below and the initial transgressive marine surface (MFS1) above (Fig. 7). Some low-relief channeling is present on the K2 surface in the Chama Basin, but the transgressive surface is relatively flat. Thickness averages approximately 8 m, typically ranging 3-12 m, with an extreme range of 2-24 m. It is fairly thick in the Chavez Canyon section (Fig. 3) and the Enre 1 Phoenix well (Fig. 4).

The lithology of the Encinal Canyon is overwhelmingly sandstone with only a few, thin, black shale beds. Small pebbles of chert and quartz pebbles are locally present in the basal part. The sandstone generally fines upward from medium-grained to very fine-grained. Many beds contain finely divided carbonaceous fragments. Most bedding planes are horizontal, with some beds having internal planar or trough crossbedding. Ripple marks

are present on a few bedding planes. Bases of a few beds show shallow channeling. At a measured section on the west side of Mesa del Yeso, east of the HW84 section, a large tidal-channel-fill deposit is present (location is 0.3 km east of the center of Sec. 32, T25N, R3E). It contains plant-fossil fragments and rip-up clasts of carbonaceous shale. The inclined beds on what appears to be one side of the channel contain flaser structures, ripples, and bimodal, very small-scale crossbedding indicative of tidal deposition. In the Chama Basin, unlike in most of the San Juan Basin, many beds of the Encinal Canyon have abundant trace fossils, and a few beds are bioturbated. The trace fossils are dominated by medium-to-small, smooth, planar burrow casts with no preferred orientation. These are similar to the ichnogenus *Planolites*.

The Encinal Canyon Member in the San Juan Basin, especially in the Canyon Largo area, clearly was deposited in a system of fluvial channels incised into the Burro Canyon Formation at the K2 unconformity (Fig. 7), with very thin, residual sandstones between channels. Aubrey (1988; 1989; 1992) attributed the basal Encinal Canyon incised channels in the Chama Basin to a late Albian sea-level drop, with an early Cenomanian filling with

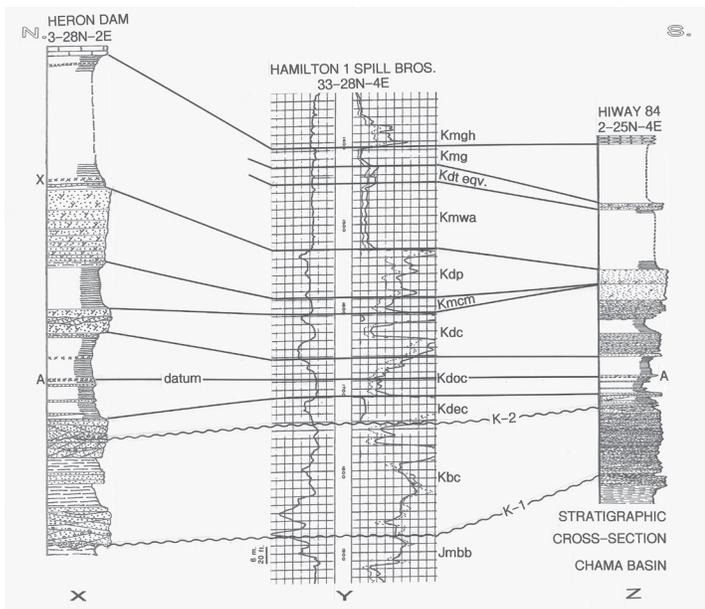


FIGURE 5. Stratigraphic cross-section, Chama Basin. Abbreviations are the same as in Figure 3 and 4. Datum is A, the A bentonite in the Oak Canyon Member of the Dakota Sandstone.

Encinal Canyon sediments. However, Aubrey (1998; 1989; 1992) miscorrelated the Encinal Canyon Member to basal Dakota channel-filling sandstones in southwestern Colorado and southeastern Utah. These basal Dakota sandstones in Colorado and Utah are in the White Rock Mesa Member of the Dakota (Owen and Owen, 2005, this guidebook), not the Encinal Canyon Member, and the unconformity they rest on is the K3 unconformity, which was cut during middle (?) Cenomanian time, after the deposition of the Encinal Canyon Member. The Encinal Canyon of the Chama Basin is far enough east to show abundant evidence of deposition in a marginal-marine environment, perhaps in somewhat protected estuaries, bays, and tidal flats along the western shoreline

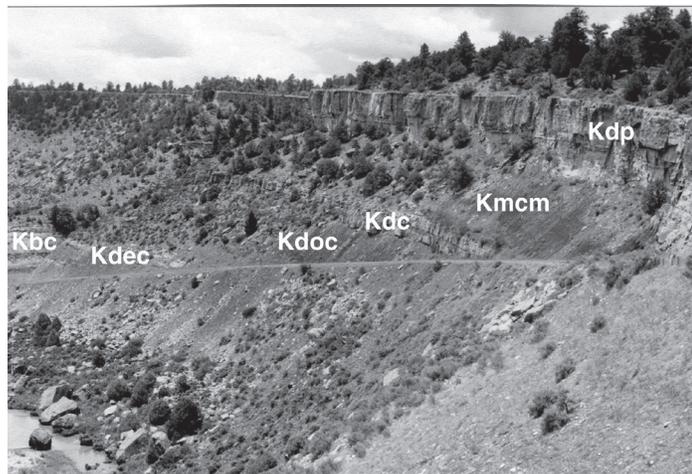


FIGURE 6. Photograph of Burro Canyon and Dakota (with Mancos Shale tongues) Sandstone at the Heron Dam measured section. Rio Chama in lower left corner. Abbreviations are the same as in Figure 3.

of the Western Interior seaway during early Cenomanian time. Therefore, the first evidence of rising relative sea-level which would begin the first Cretaceous marine transgression across the

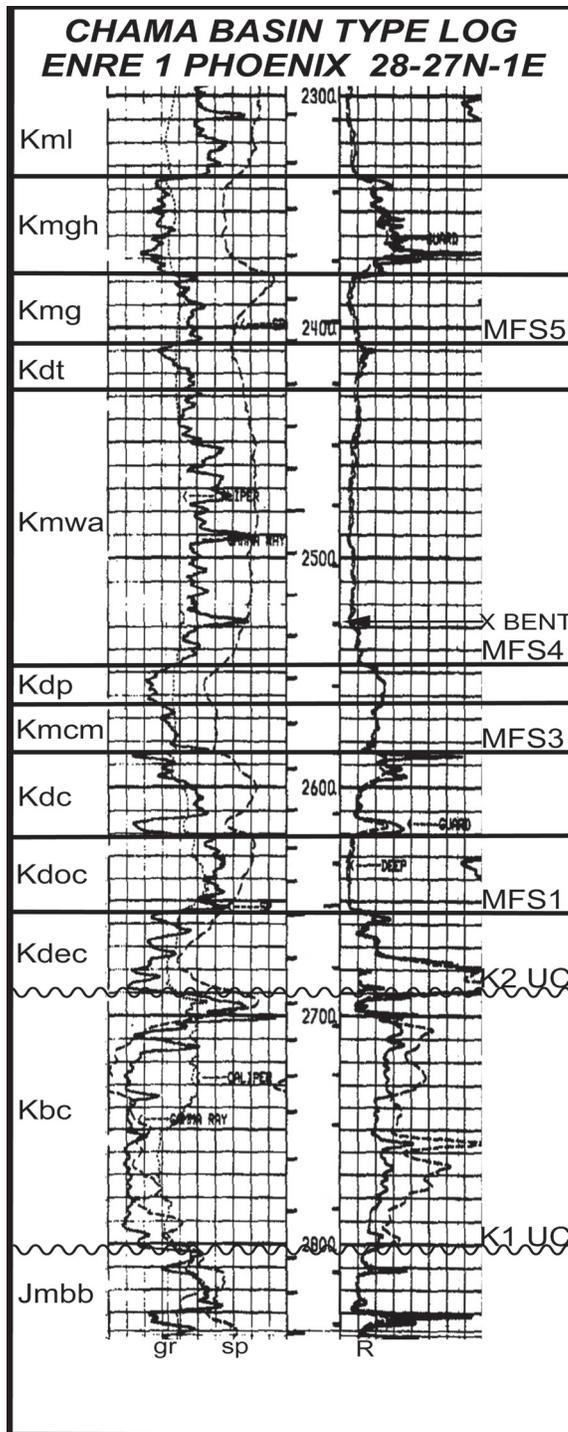


FIGURE 7. Chama Basin type log with all stratigraphic unit boundaries and key surfaces annotated. Abbreviations are the same as in Figure 3 and 4, plus UC=unconformity, MFS=marine-flooding surface, and BENT=bentonite. This well log (API 3003925357) is log 2 on Figure 4 and is located at 2 on the map of Figure 1

San Juan Basin appears in the Encinal Canyon Member in the Chama Basin.

Oak Canyon Member

Like the Encinal Canyon Member, the Oak Canyon Member of the Dakota Sandstone is present throughout the Chama Basin. Its lower boundary is the sharp transgressive surface, MFS1 (Fig. 7), mentioned above. Locally, some reworked sediment, typically sand, forms a thin veneer on this surface. Varney (2005, this guidebook) reports a possible paleosol at this surface at the HW84 section. The Oak Canyon is thicker in the northern Chama Basin, from the Heron Dam section (Fig. 5) north to Colorado, than anywhere in the San Juan Basin, averaging approximately 23 m, but reaching 32 m locally. It thins south of Heron Dam (Fig. 5), averaging approximately 15 m, but locally as little as 6 m. It has a fairly uniform thickness along the Chama Canyon (Fig. 3).

The dominant lithology of the Oak Canyon Member is dark-gray marine shale, essentially the same as the two tongues of Mancos Shale higher in the Dakota. The A bentonite, a prominent marker bed in most outcrops and logs, occurs in the lower part of the Oak Canyon. An Ar-Ar date of 98.1 ± 2.4 Ma (Peters, 2004), an early Cenomanian age, from sanidine crystals in the bentonite has recently been obtained from an outcrop of the A bentonite near San Ysidro, approximately 100 km south of the Chama Basin. A widespread coarsening-up, sandy parasequence generally occurs in the middle part of the Oak Canyon above the A bentonite in the Chama Basin (Fig. 3). This sandstone bed is so prominent in the Chama Basin that Ridgley (1987) used the top of it as the datum for her Burro Canyon-Dakota stratigraphic cross-sections in the northern Chama Basin.

The Oak Canyon was deposited in an offshore marine environment. A few marine molluscan fossils have been collected from shales in the Chama Basin, and the marine ichnogenus, *Thalassinoides*, occurs in some of the sandy beds. The Oak Canyon shales have been traced to a point nearly to Gallup, 190 km southwest of the Chama Basin, so it may contain the maximum flooding surface, which equates to maximum water depth for the whole Dakota Sandstone in the Chama Basin.

Cubero Sandstone Tongue

The Cubero Sandstone Tongue is present throughout the Chama Basin, but it generally consists of two coarsening-up parasequences of sandstone separated by a shale bed that is the fine-grained part of the upper parasequence. Thickness of the whole Cubero averages approximately 19 m, but it ranges from 9 to 30 m. The main thin area is in wells and outcrops near the Heron Dam section (Fig. 5), where the middle shale is absent due to apparent downcutting of the upper sandstone into the lower one. In the southern Chama Basin, the Cubero gradually thickens southward from Heron Dam as the overlying Clay Mesa Shale and Paguate Sandstone thin (Fig. 3). The lower contact of the Cubero is generally at a gradation zone from shale to sandstone of less than a meter. However, locally, this contact may be abrupt, as in the Enre 1 Phoenix well (Fig. 4). This contact is at the same

stratigraphic position as the K3 unconformity as close as 27 km west in the subsurface. East of this point, the K3 unconformity passes into a correlative conformity that generally shows a gradational contact, but is locally scoured (see Owen and Owen, 2005, this guidebook for additional information). Thus, the base of the Cubero could be considered a marine sequence boundary. The upper contact is marine-flooding surface, MFS3 (Fig. 7)

The lower Cubero parasequence is typically a slightly silty, very fine-grained sandstone that gradually coarsens upward. However, no medium-grained sand or coarser material has been observed. Bedding is generally flat with bioturbation or isolated burrow casts of *Thalassinoides* or a few *Ophiomorpha*. A few planar crossbedded zones are locally present. The upper Cubero parasequence is similar to the lower one, but is generally not silty, is typically fine-grained sandstone, and contains a few more crossbedded zones, such as in its basal part at Heron Dam. Cross-bedding indicates southerly to southeasterly paleocurrent flow, roughly parallel to shore, in the Cubero and higher shoreface sandstones of the Dakota. Both parasequences generally have a marine-flooding surface at their tops, the upper one designated as MFS3. The middle part of the Cubero contains the silty shale bed that separates the sandstones. This bed forms the shaly part of the upper parasequence; the upper Oak Canyon shale is the lower part of the lower parasequence.

Both Cubero parasequences were deposited as shoreface marine sands, mostly in the middle shoreface zone, but outer shoreface silty sand is more prominent in the lower parasequence. The middle shaly zone was deposited in the adjacent offshore muddy environment. No marine shelly fossils have been seen in the Chama Basin Cubero, although one might expect them to have been deposited.

Clay Mesa Shale Tongue of the Mancos Shale

A tongue of Mancos Shale known as the Clay Mesa separates the Cubero Sandstone Tongue of the Dakota from the overlying Paguate Sandstone Tongue of the Dakota. The Clay Mesa is not well exposed in the Chama Basin because it is eroded back from the rims of the mesas, which are capped by Cubero Sandstone in most of the area. However, good exposures of the Clay Mesa may be seen at the Heron Dam and El Vado sections (Fig. 5) where a cliff or Paguate Sandstone is above, and it may be measured in well logs. Maximum thickness of the Clay Mesa occurs in the northern Chama Basin where it reaches 19 m, but 12 m is typical. South of El Vado it may be seen to thin dramatically along the Rio Chama Canyon down to a few meters near Chavez Canyon (Fig. 4 and 8) and 0 at the HW84 section (Fig. 5). As it thins, it takes on a rusty yellow weathering color from iron oxide, as does the overlying Paguate Sandstone.

The lithology of the Clay Mesa is typical dark-gray Mancos Shale in the northern Chama Basin, but it becomes more silty and iron-oxide rich as it thins in the southern Chama Basin. An offshore muddy environment with slightly deeper marine water than that of marine sandstones was typical of the Clay Mesa Shale, but a shallowing-upward pattern is apparent as it gradually grades upward into the Paguate Sandstone.



FIGURE 8. Photograph of thin Clay Mesa Shale Tongue of Mancos Shale and Paguate Sandstone Tongue of Dakota Sandstone at top of Chavez Canyon measured section at rim of Mesa de los Viejos above Rio Chama Canyon. Geologist, who is 1.8 m. tall, has feet on Clay Mesa Shale and left hand on Paguate Sandstone.

Paguate Sandstone Tongue

The Paguate Sandstone Tongue of the Dakota is thick, well-developed sandstone in the northern Chama Basin, but south of El Vado, well displayed at the rim of Rio Chama Canyon (Fig. 8), it thins dramatically to a thin, poorly-developed, silty, rusty yellow weathering sandstone (Figs. 3-4). This thin Paguate may be seen in the Dunn 20 Puerto Chiquito well in T26N, 1E (Fig. 4). The Paguate thins from an 18 m-thick sandstone at the Heron Dam section in the northern Chama Basin (Fig. 5 and 6) to a 4 m-thick, very fine-grained, yellow sandstone at the HW84 section (Fig. 5), and a 3 m-thick siltstone in the Dunn well (Fig. 4). This thin, silty Paguate zone may be traced in the subsurface on a N60W trend from the Dunn well for at least 6 townships into the San Juan Basin. A similar thinning of the Clay Mesa Shale occurs in the same area, where it is only 2-3 m thick. Also, on the outcrop south of the Chama Basin, sandstone is absent in the Paguate interval for 10 townships south to the Holy Ghost Springs area south of Cuba. Therefore, the Paguate sandstone body of the southeastern San Juan, including the stratotype of the Paguate, is separated from the Paguate sandstone body of the northeastern San Juan Basin and Chama Basin by a large area of shale on the outcrop and nearby subsurface. However, the type Paguate Sandstone can be correlated with the Paguate sandstone body of this paper throughout the subsurface of the central San Juan Basin as a continuous sheet of sandstone, thus establishing the Chama Basin Paguate as continuous with the type Paguate. The X bentonite (Fig. 7), which occurs a few meters above MFS4 at the top of the Paguate is very useful in establishing its correlation, especially where Paguate sandstone is absent.

Bedding in the Chama Basin Paguate is flat to indistinct, and most of the sandstone is thoroughly bioturbated, so cross-bedding is rarely seen. A few bedding planes display ripples at some localities. The Paguate is finer-grained than the underlying Cubero; anything coarser than very fine-grained sand is rare. Identifiable trace fossils are also rare, but a few *Thalassinoides*

burrow casts have been observed. No shelly fossils have been noted in the Chama Basin, but a diverse molluscan fauna has been reported from the southeastern San Juan Basin Paguate by Cobban (1977).

The Paguate was deposited in a middle and outer shoreface environment that was well populated with burrowing organisms. The area in the extreme southern Chama Basin, as well as a large area to the south and west, was starved for sediment, especially sand.

Whitewater Arroyo Shale Tongue of the Mancos Shale, Twowells Sandstone Tongue of the Dakota Sandstone, and Graneros Shale Member of the Mancos Shale

Both the Whitewater Shale Tongue of the Mancos Shale and The Twowells Sandstone Tongue of the Dakota Sandstone were defined from stratotypes near Gallup, NM, 230 km from the Chama Basin (Owen, 1966). The Whitewater Arroyo is composed of typical Mancos-type shale, and there is little to distinguish it from the underlying Clay Mesa or overlying Graneros shales of the Mancos except stratigraphic position in relation to the X bentonite (which is in the lower part of the Whitewater Arroyo), and the Paguate and Twowells Sandstone Tongues. In the Chama Basin, the Twowells interval contains no sandstone, except for a small lens at and near the HW84 section. The upper parasequence in the Twowells that contains sandstone in the central San Juan Basin can be reliably correlated on well logs to siltstones and silty shales in the Chama Basin (see the log on Figure 5). The top of the Twowells is marked by a marine-flooding surface (MFS5); its base is gradational (Fig. 7). The Whitewater Arroyo-Twowells interval is very poorly exposed in the Chama Basin because it lacks resistant sandstone beds except for the local lens mentioned above. Only steeply sloping, fairly fresh artificial cuts, such as at the spillway on the west side of El Vado dam, generally expose this interval (Fig. 9).

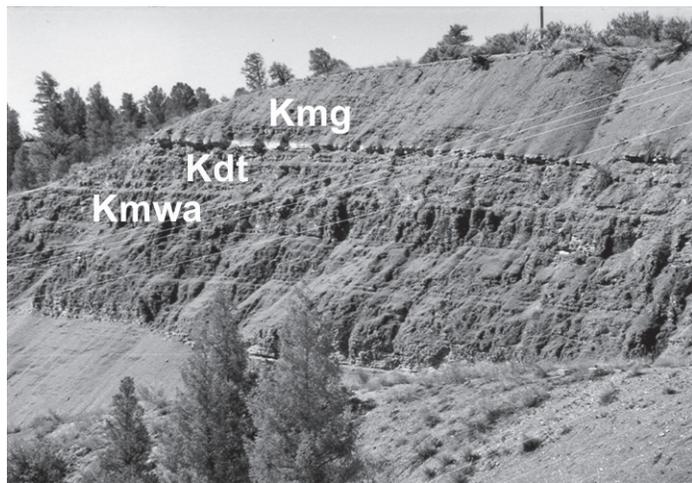


FIGURE 9. Photograph of upper Whitewater Arroyo Shale Member, Twowells Sandstone Tongue of Dakota Sandstone, and lower Graneros Shale Member of Mancos Shale at west end of El Vado Dam. Abbreviations are included in Figure 4.

It has been customary in the San Juan and Chama basins to use the term Graneros Shale Member of the Mancos for the interval between the highest Dakota Sandstone tongue (which can be the Cubero, Paguate, or Twowells, depending on location) and the Greenhorn Limestone Member of the Mancos Shale, so this practice could be followed in the Chama Basin. Alternatively, where well logs make it possible to reliably correlate the silty Twowells equivalent beds, the Whitewater Arroyo and Twowells can be recognized as lithostratigraphic units. Therefore, the Twowells equivalent beds have been recognized in this paper, but it would not be possible to map the Whitewater Arroyo and Twowells as separate units on geologic maps in the Chama Basin.

Thickness of the Whitewater Arroyo ranges from 20 to 36 m, averaging 29 m. Thickness of the Twowells ranges from 6-13 m, averaging 9 m. The X bentonite, the most widespread bentonite in the Dakota-Mancos section in the San Juan Basin, occurs approximately 3 to 6 m above MFS4 at the top of the Paguate. This bentonite is typically only 10 cm or less in thickness in the Chama Basin, but this is enough to produce a high gamma-ray spike on most well logs. (see wells 1, 2, and 4 on Figure 4).

In the Chama Basin, the Whitewater Arroyo Shale was deposited in the offshore zone well seaward of the San Juan Basin Twowells outer shoreface sands. The Twowells siltstones were deposited in a similar environment. The only sandstone lens in the stratigraphic position of the Twowells in the Chama Basin occurs in an east-west trending area from near English Tanks, 12 km west of the HW84 section, to Las Jollas at the north end of the HW84 section, to US Forest Service road 137 crossing the upper part of Lopez Canyon near the center of Sec. 33, T26N, R5E, 6 km east of the HW84 section. We refer to this sandstone informally as the Las Jollas bed. At Las Jollas, it is a 2 m -thick, medium-grained sandstone with abundant *Thalassinoides* burrow casts. Indicative of a normal marine environment. At Lopez Canyon, it is mostly poorly sorted, silty, fine-grained sandstone, but it contains a 1 m-thick bed of medium-grained sandstone with some coarse and very coarse sand grains and a few chert pebbles. Crossbedding is developed in the coarser beds. Paleocurrent readings indicate a south-southeasterly transport direction. The Las Jollas bed also contains *Thalassinoides*, *Ophiomorpha*, and molds of bivalve shells. Total thickness is 7 m. West of Las Jollas, on top of Mesa de los Viejos, the La Jollas bed thins and becomes finer grained sandstone. It could not be traced as far as the Rio Chama Canyon. The Las Jollas bed is a puzzle--one would not expect to find an isolated sand bed this coarse in an offshore area surrounded by silty shale. One possible explanation is a temporary sea-level drop that allowed enough erosion to transport fairly coarse sand offshore, where currents reworked it into sand bars, which were then burrowed, producing the La Jollas bed. Wolter (1987) documented an upper Twowells finer-grained sandstone bed that channeled into a typical shoreface lower Twowells sandstone at McCartys on the south flank of the San Juan Basin. One could envision a sequence boundary in the Twowells Sandstone that connects these two separated areas, but there is not much other evidence for such a sequence boundary in the San Juan Basin Twowells.

Above the Twowells, which is topped by MFS5 (Fig. 7), is approximately 7-9 m of the Graneros Shale Member of the Mancos Shale, which contains the prominent D bentonite near its top. Above this is the Greenhorn Limestone Member of the Mancos Shale. The Greenhorn is generally eroded back a considerable distance from the uppermost Dakota sandstone. However, an excellent, complete exposure of the 8.25 m of Graneros, including the D bentonite, and 12.8 m of Greenhorn may be seen above the Dakota at the west end of El Vado Dam.

CONCLUSIONS

Because of its seaward location on the western edge of the Cretaceous Western Interior Seaway, all of the Cenomanian Dakota Sandstone and intertongued Mancos Shale members in the Chama Basin are marine, although the basal member, the Encinal Canyon, was deposited in various coastal environments. Three prominent bentonites and numerous marine-flooding surfaces aid in intra-Dakota correlations. The Dakota Sandstone, with included Mancos Shale, averages approximately 90 m in thickness. A distinct southward thinning occurs in the Clay Mesa Tongue of the Mancos and the Paguate Sandstone Tongue of the Dakota.

The Burro Canyon Formation, which is immediately subjacent to the Dakota, averages approximately 30 m in thickness and is present throughout the Chama Basin. It was deposited by easterly to northeasterly flowing braided-stream systems on a coastal plain during late Early Cretaceous time. The K1 and K2 unconformities bound the Burro Canyon, making it a complete nonmarine depositional sequence. It also thins southward, in this case because of erosion at the K2 unconformity.

Subsurface data from well logs provide an important addition to outcrop data in correlating and in reconstructing depositional relationships and stratigraphy of the Burro Canyon and Dakota-Mancos, especially in the northern Chama Basin, where there are few outcrops.

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