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Some geological observations at Carbon Coal Company's No. 2 mine—a small but unique operation

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Introduction

Carbon Coal Company began strip mining operations on privately owned land just west of Gallup, New Mexico, near the village of Mentmore in late 1978. Although it is a relatively small operation, the company has nevertheless gained valuable experience in thin multiple-seam mining, blending, and efficient rail loadout methods. Because of deteriorating stripping ratios at this site, it was placed on inactive status in December 1984, and production was shifted to a newly opened pit 2 mi south of Gallup, near the old Catalpa mine. Production at the new site, named Carbon No. 2 (Fig. 1), was realized in January 1985. It also is a thin multiple-seam stripping operation on privately owned land; however, an important difference here is truck transportation costs. The coal is transported via highway haulers 14 mi to the rail loadout at the Mentmore mine site.

Carbon Coal Company is currently operating the No. 2 mine with a work force of about 84 employees. Production operations are scheduled 4 days per week, two shifts per day, and daily production is about 3,300 short tons, which equals an annual rate of approximately 650,000 short tons. From the rail loadout the coal is delivered by unit train to the Arizona Electric Power Cooperative near Benson, Arizona. The coal is used by the utility company at their Apache steam-electric generating station, which has 350 Mw of installed coal-fired capacity.

Geologic setting

Gallup, New Mexico, is located near the north end of the Zuni Basin, a structural sag that extends southeastward off the southwest corner of the San Juan Basin; the area is within the Navajo section of the Colorado Plateau physiographic province (Fenneman, 1931). The Zuni Basin is highly asymmetric, bounded abruptly on the northeast by the Nutria monocline (Fig. 1). The monocline, with near-vertical dips locally, provides excellent exposures of Jurassic and Cretaceous rocks along its entire length of about 32 mi. Five miles north of Gallup the Nutria monocline loses all expression, and it is at this point that the Zuni Basin merges with the larger San Juan Basin.

Upper Cretaceous rocks ranging from the Dakota Sandstone (Cenomanian) through the Gallup Sandstone (late Turonian) to the Crevasse Canyon Formation (Coniacian and Santonian) are exposed within and along the margins of the Zuni Basin. Coal occurs in all of the formations except the Mancos Shale; however, commercially important coal resources are limited to the Gallup Sandstone and to the Dilco and Gibson Coal Members of the Crevasse Canyon Formation (Fig. 2). The uppermost of these, the Gibson Coal Member, is referred to by most authors as the undivided Gibson–Cleary because at the northeast corner of the basin these two coal zones are split by a marine sandstone—the Point Lookout. At present, as has been the case historically, coal production in this area is almost entirely from the upper half of the Dilco Coal Member and the undivided Gibson–Cleary Coal Member.

Structures similar to and parallel to the Nutria monocline, but of lesser magnitude, characterize the Zuni Basin and account for the northwest-trending outcrop patterns. They are all typical Colorado Plateau monoclines in that they are narrow flexures with sinuate traces. The possibility of early or pre- ☞

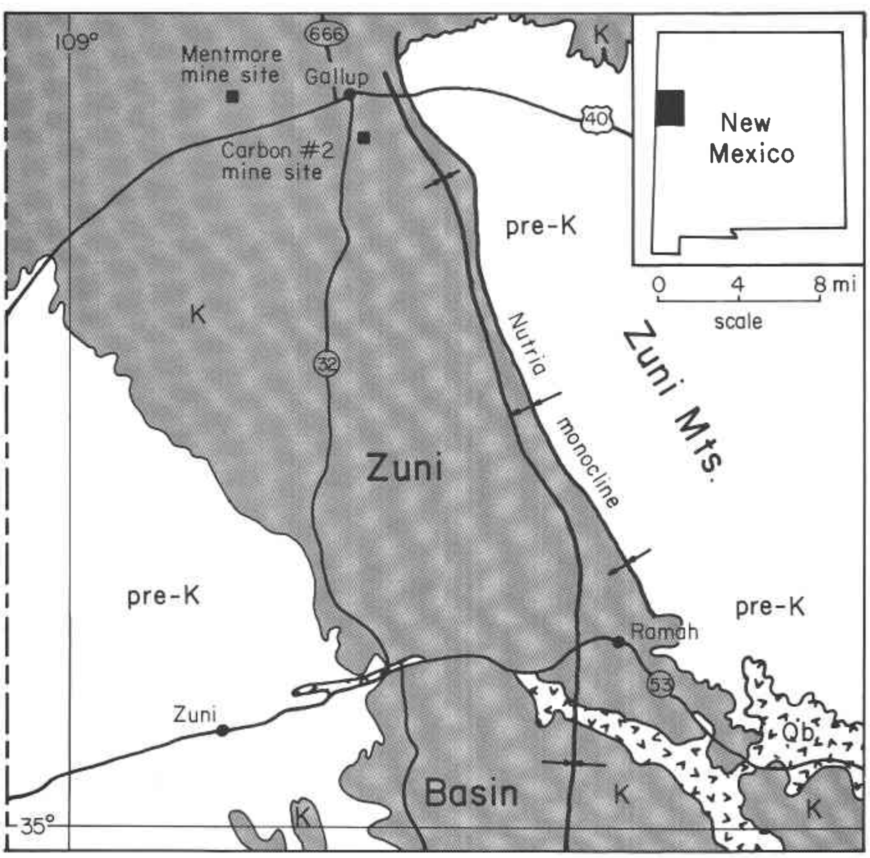

FIGURE 1—Index map of Zuni Basin showing Zuni Mountains, distribution of Cretaceous (**K**) and pre-Cretaceous (**pre-K**) rocks, and major structures; note Carbon Coal Company mines just west and southeast of Gallup.

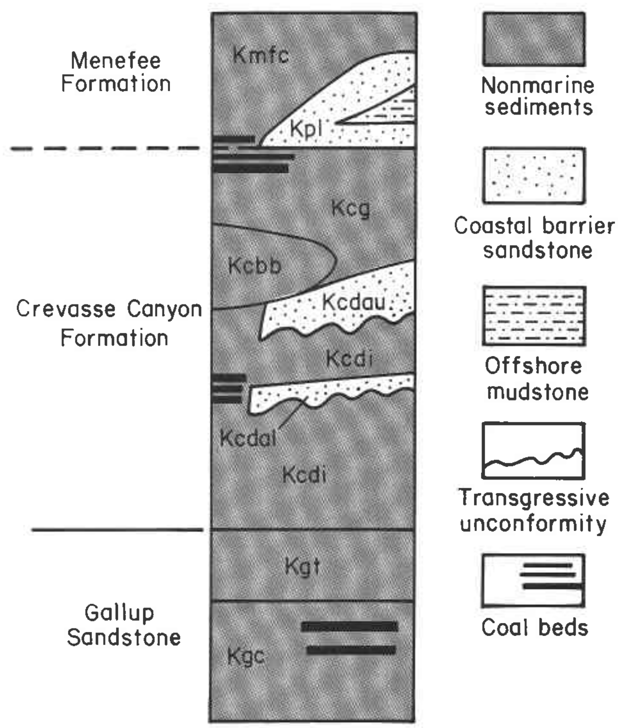

FIGURE 2—Generalized geologic section at Nutria monocline 6 mi northeast of Gallup: **(Kgc)** coal-bearing member and **(Kgt)** Torrivio Member of Gallup Sandstone; Crevasse Canyon Formation includes Dilco Coal Member **(Kcdi)**, lower **(Kcdal)** and upper **(Kcdau)** part of Dalton Sandstone, Bartlett Barren Member **(Kcbb)**, and Gibson Coal Member **(Kcg)**. Point Lookout Sandstone, undifferentiated is **Kpl**, and the Cleary Member of the Menefee Formation is **Kmfc**.

Laramide activity along the trends of some of these monoclines and the resulting influence on Cretaceous shoreline configurations and paralic coal swamps was noted by Anderson and Stricker (1984) and Stricker and Anderson (1985).

Evidence for this early tectonic activity consists of pinchouts of marine facies along the trend of modern-day monoclines. Specifically the Dalton Sandstone, deposited during the T–3 (transgression 3) cycle, and the Point Lookout Sandstone, deposited during the T–4 cycle, have their maximum landward extent at the Nutria monocline (Fig. 3). These rocks are of Coniacian and Santonian age (Late Cretaceous).

The type of deformation suggested by the field evidence as having produced the monocline or drape fold is a basement fault, probably formed in association with the low-lying Pennsylvanian Zuni uplift (Kottlowski, 1959) and reactivated during the earliest stages of Laramide compressive deformation. From Stearns (1978) we find that monoclines, or drape folds, are more likely to form over high-angle reverse faults (60° or steeper) and very high-angle normal faults (75° or steeper) than over low-angle faults. This is due in part to the fact that layered rocks will be initially put under greater extension in the low-angle regime and will therefore tend to fault rather than fold. For these reasons we contend that a high-angle reverse basement fault produced the monocline (the term basement is used here to include only those rocks that are statistically isotropic and below which no layered sequences occur; i.e., the Precambrian for this area and much of the Colorado Plateau). The utilization of a pre-existing fault or faults is what perhaps allowed such a high-angle response to compressive forces.

But whatever the nature of the basement deformation it influenced marine and coastal-plain sedimentation in the following manner: northeastward tilting of the uplifted Zuni block occurred about a northwest-trending axis and the upturned edge of this block exerted local shoreline control. Evidence for this interpretation is a slight angular unconformity at the base of the upper Dalton Sandstone (Kcdau) where it grades westward into a nonmarine unit in the north-central part of sec. 13, T16N, R18W (Fig. 3). The downwarped/downfaulted block to the southwest was then underlying the coastal-plain area, allowing slow subsidence and creating conditions favorable to the establishment of extensive paralic peat swamps. The most persistent of these swamps were, with time, developed into the coal beds of the Dilco Member, which occur opposite the maximum landward extent of the Dalton Sandstone Member; higher in the section the major coal beds of the Gibson Member were developed opposite the maximum landward extent of the Point Lookout Sandstone.

Further evidence of syndepositional tectonism can be found in the upper, nonmarine part of the Gallup Sandstone (Late Turonian). This part, including the Torrivio Member at the top, thins from a characteristic 190 ft on the downwarped/downfaulted, coastal-plain side of the Nutria monocline to less than 40 ft across the crest of the structure. Even more dramatic is the thinning of the overlying Dilco Coal Member (Kcdi) across the top of the structure; here the unit thins from a characteristic 300 ft in the basin to less than 40 ft of nonmarine sediments lying between the Torrivio Member of the Gallup (Kgt) and the lower part of the Dalton Sandstone (Kcdal; Fig. 3). The Dilco Coal Member is also barren where it is thin, which indicates that there was no extensive peat-swamp development. This is what would be expected on a slightly positive, well-drained area. Because the Dilco is by definition a coal-bearing unit, in places where it is barren it should actually be designated as the Dilco equivalent.

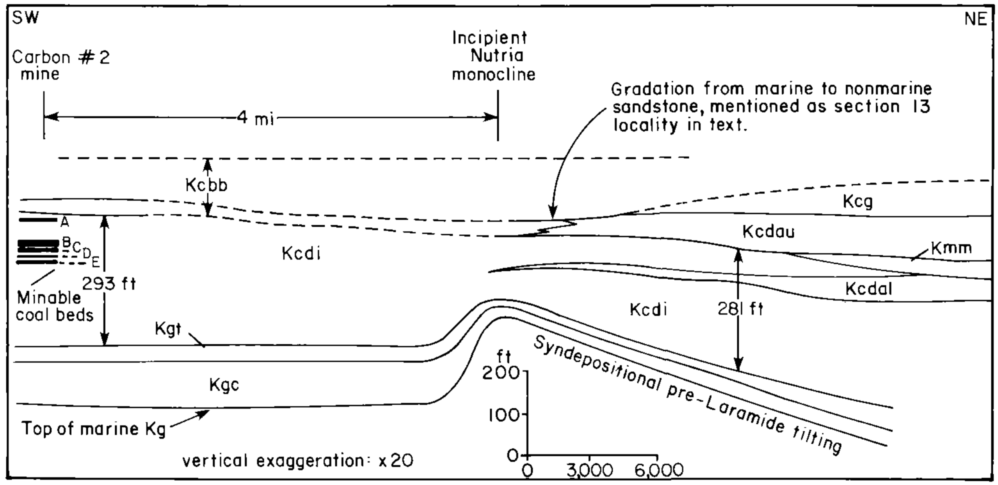

FIGURE 3—Restored cross section illustrating stratigraphic and structural relationships across the incipient Nutria monocline during time of deposition of Crevasse Canyon Formation (Coniacian). Note position of coal beds at Carbon No. 2 mine and their stratigraphic relationship to the pinchout of marine facies in the incipient Nutria monocline. Presence of Mulatto Tongue of Mancos Shale **(Kmm)** is based on Kirk and Zech (1977); other symbols are explained in Fig. 2. Dashed lines indicate section has been removed by modern erosion.

Stratigraphic sequence at Carbon No. 2 site

All the relationships described above can be seen in the Gallup area, but how does the coal-bearing sequence at the Carbon No. 2 lease fit into this stratigraphic framework?

The Carbon No. 2 mine is located on the southwest flank of the Gallup anticline in the S½ sec. 35, T15N, R18W, 2 mi south of the city of Gallup. Coal is mined from multiple seams in the upper part of the Dilco Coal Member of the Crevasse Canyon Formation. In descending order the seams are designated A, B, C, D, and E. Also present are A′, A″, AB, and AB′ seams, but these are either too thin or nonpersistent to be produced and they are usually spoiled. The B seam, which ranges from 5.5–8 ft thick, is the thickest. The other producing seams range from 1.5 to 5 ft thick; 1.5 ft is the cutoff thickness used in production planning. Total recoverable reserves at a 13:1 maximum stripping ratio are 3.2 million tons.

Overlying the coal-bearing sequence at the pit is a 30-ft-thick, yellowish gray (5Y 8/1), fine-grained, but poorly sorted, quartzose sandstone. The sandstone contains clay galls and numerous stringers of coalified peat fragments, especially in the lower 10 ft. It is a fining-upward crossbedded sequence that is characteristic of an active channel fill in the lower alluvial plain. Crossbedding is of both trough and planar type, medium angle (10–20°) with crossbed dip directions clustering about N80°E, but ranging from N85°E to N25°E.

We found this sandstone to be of significance because it is one of the thickest in the local Crevasse Canyon Formation section and can be taken as the break between the Dilco Coal Member and the Bartlett Barren Member. Of greater importance, however, is the stratigraphic position of the unit. The base is 293 ft above the top of the Gallup Sandstone (from drill hole information). Significantly, near the landward pinchout of the Dalton Sandstone, which occurs along trend of the Nutria monocline 4 mi east of the mine, the base of the massive, upper part of the Dalton is 281 ft above the top of the Gallup Sandstone (from measured section). These intervals suggest that the units are time equivalents. The 281-ft interval (the Dilco equivalent) thins considerably across the anticlinal axis of the monocline (Fig. 3), but this thinning of stratigraphic units upon approach to the monocline from either the gentle northeast side or the abrupt southwest side is further indication of syndepositional tilting rather than tectonic thinning. Although modern erosion has removed this part of the section between the No. 2 mine and the monocline the inferences and correlations are clear. The anomalously thick fluvial sandstone represents sand backing up onto the lower alluvial plain in response to the approach of the epicontinental sea to within 4 mi of the present mine site (Fig. 3).

Below the fluvial channel buildup is up to 5 ft of laminated silty clay, which may indicate a period of lacustrine sedimentation just landward of the transgressive maxima. However, we are inclined to think that the laminated clays were deposited in a brackish water lagoon because of the high sulfur content of the immediately underlying A coal bed. This coal bed, which is the uppermost in the sequence being mined, has a sulfur value of 1.65% (Table 1). The others all range from 0.54 to 0.86% sulfur with the mine-run coal averaging much closer to the lower value (Table 1). The sulfur values in the A bed strongly suggest marine influence in the immediately overlying rocks. Thus, we interpret that a short-lived brackish-water lagoon existed before the deposition of the thick fluvial sand, an event that initiated increased sedimentation in the coastal-plain enviroment at the onset of deposition of the Bartlett Barren Member. The time-equivalent rocks in a seaward direction are represented by the Dalton Sandstone, a thick, regressive coastal-barrier sequence; the Dalton reaches a maximum thickness of more than 100 ft locally (Beaumont, 1971), which indicates increased sediment supply to this portion of the seaway. This increase in sediment supply plus the local tectonic tilting along the trend of the Nutria monocline resulted in a significant seaway regression (the R–3 regression of Molenaar, 1983) during which no significant peat-swamp development occurred.

Actually, the thickest coal in the sequence, the B coal bed, occurs 50 ft below the high-sulfur A bed. The B bed and some of the lower beds may have been deposited nearly as close to the strandline as the A bed because Kirk and Zech (1977) recognized, as we do, the presence of a thin, lower Dalton Sandstone. We, however, recognize it about 60–70 ft below the massive, upper part, whereas Kirk and Zech (1977) showed about 200 ft of nonmarine sediments between the upper and lower parts. We believe that their interval is exaggerated. In addition, they show the Mulatto Tongue of the Mancos Shale to be present, thinning from about 75 ft (a figure we believe is also exaggerated) to 0 ft in less than a mile as the monocline is approached. The landward pinchouts of all marine facies occur abruptly at the monocline, and a very effective coastal-barrier system was in place to prevent any marine influence from reaching the accumulating B, C, D, and E coal beds (Fig. 3).

TABLE 1—Average core quality of Dilco coals from Carbon No. 2 mine.

Seam	Typical thickness	As received				Comments
		BTU/lb	% Ash	% Sulfur	% Moisture	
A	2.0	10,169	17.57	1.65	9.91	
B	5.3	11,110	9.79	0.60	11.11	
C	3.3	10,982	10.02	0.54	12.51	excluding parting
D	2.0	10,877	11.70	0.67	11.54	
E	5.2	9,987	16.80	0.86	12.11	excluding parting

Coal quality at Carbon No. 2

The coal currently being produced from the Dilco Coal Member at the Carbon No. 2 mine is of high-volatile C bituminous rank. The heating values range from about 9,990 to 11,100 BTU/lb (in place). The in-place coal quality of the five beds being mined is given in Table 1. The variability in sulfur and ash content require that some blending be done to meet the quality specifications in the contract, which are: deliver a coal that has a minimum of 10,000 BTU/lb, a maximum of 16% ash, with no more than 0.65% sulfur.

One of the problems encountered in the mining of a thin, multiple-bed reserve is the quality reduction of the coal caused by dilution with waste material inevitably taken at the upper and lower contacts. At Carbon No. 2 the mine run coal has an ash content 30–100% higher than the in-place, or core, values. This causes a corresponding reduction in caloric value of up to 10%, and, consequently, some washing is required. In particular, the A and E beds require washing because they are the lowest in quality. The problem is compounded in the case of the A bed because it is also one of the thinner beds, and therefore dilution is high.

Fortunately for the operation the thickest coal bed (B), which ranges up to 8 ft in thickness, is one of the better quality beds, and because of this there has been no problem in delivering coal that meets contractual specifications. The company has been able to keep costs to a minimum by following an operational policy of maximum blending and minimum washing.

Washing, however, is very beneficial in that it not only lowers the ash content significantly, but it also lowers the sulfur content in coals with a high pyritic to total sulfur ratio. This ratio is not high at Carbon No. 2; typically it is slightly more than 1:1 (just over 50% pyritic sulfur). Washing removes about 50% or more of the pyritic sulfur, which results in a 25–30% reduction of total sulfur in the delivered coal. Washing does not appear to reduce the content of organic or sulfate sulfur, nor is there any program aimed at reducing this fraction because the product is initially low in sulfur.

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