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Edward C. Beaumont and Gretchen K. Hoffman

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INTERRELATIONSHIPS BETWEEN THE UPPER COAL MEMBER OF THE MENEFEE FORMATION, THE LA VENTANA TONGUE, AND THE LEWIS SHALE IN THE SOUTHEASTERN SAN JUAN BASIN, NEW MEXICO

E. C. BEAUMONT[1] and G. K. HOFFMAN[2]

[1]E. C. Beaumont, Inc., Albuquerque, New Mexico; [2]New Mexico Bureau of Mines and Mineral Resources, Socorro, New Mexico 87801

Abstract—The La Ventana Tongue of the Cliff House Sandstone has been the subject of several studies in the northwest and central San Juan Basin, in particular for oil and gas potential. The lack of drill-hole data in the southeastern San Juan Basin had restricted detailed studies in this area to outcrops and a few oil and gas test logs. Logs from the New Mexico Bureau of Mines and Mineral Resources coal-quality drilling program (1985–1988), additional oil and gas drilling completed since the late 1970s, together with the older data provide sufficient subsurface data for detailed interpretations of stratigraphic relationships in the southeastern San Juan Basin. A 27-km cross section based on 24 geophysical logs was constructed north-northeastward from the outcrop area, 8 km east of Torreon Trading Post. The cross section transects the upper coal member of the Menefee, the La Ventana Tongue and the Lewis Shale. The maximum development of the La Ventana Tongue is clearly seen on the cross section, as is the relationship of the La Ventana to the coals within the upper coal member sequence. After a sudden landward shift of the shoreline that terminated the La Ventana buildup, a secondary stacking of barrier beach sandstones developed further inland. This unit is informally referred to in this report as the Chacra Mesa tongue. The intertonguing between the upper coal member of the Menefee and the La Ventana Tongue can be related to the principle of stratidynamics. This concept assumes continuing subsidence in a depositional environment and deals with transitional units, such as the upper coal member and the La Ventana, between the nonmarine and marine. The variables introduced are rate of subsidence and rate of shoreline shift. The La Ventana–upper coal member sequence developed during a time of minimal shoreline movement, with minor oscillations and variable sediment supply. Not only did this environment allow for a massive sandstone buildup, it also created an environment for numerous relatively thick coals to develop in the back barrier swamps.

INTRODUCTION

In 1971, Beaumont stated that there was a lack of data for more than a generalized interpretation of the intertonguing relationship between the La Ventana Tongue and the Menefee Formation on the southeastern side of the San Juan Basin. The widely spaced oil tests and the difficulty of distinguishing coal from other lithologic types, and the nonmarine from the marine sandstones, in these geophysical logs were two reasons cited as a hinderance to correlating these units. Beaumont (1971) also noted that the extensive burned coal or clinker on the surface in the southeastern San Juan Basin, particularly in the vicinity of Torreon Trading Post, stimulated his interest in the area. This indication of coal in the upper Menefee plus the considerable thickness of the marine La Ventana Tongue would suggest the potential for a significant coal resource in this area, but more subsurface data were needed to verify the extent and thickness of the coals.

The opportunity to obtain more data came about with the funding of a coal-quality program by New Mexico Research and Development Institute (NMRDI) at the New Mexico Bureau of Mines and Mineral Resources (NMBMMR). In 1986 and 1988 drill holes at 23 sites were completed in the Chacra Mesa–La Ventana coal areas (Fig. 1). Each drill site produced a set of data, including geophysical logs, lithologic descriptions of cuttings and coal cores, and chemical analyses. Using several of the geophysical logs from these drill sites and both recent and older oil and gas logs, a 27-km cross section was constructed, approximately perpendicular to the depositional strike of the La Ventana Tongue. The cross section transects the maximum development of the La Ventana and the established relationships provide a foundation for discussing the intertonguing relationships between the upper coal member of the Menefee Formation, the La Ventana Tongue of the Cliff House Sandstone and the Lewis Shale. These intertonguing relationships can then be related to the rate of shoreline shift with respect to time and distance, referred to as the principle of stratidynamics.

PREVIOUS WORK

Several investigators have worked in the La Ventana–Torreon area over the past 90 years. A few studies have focused on the Menefee

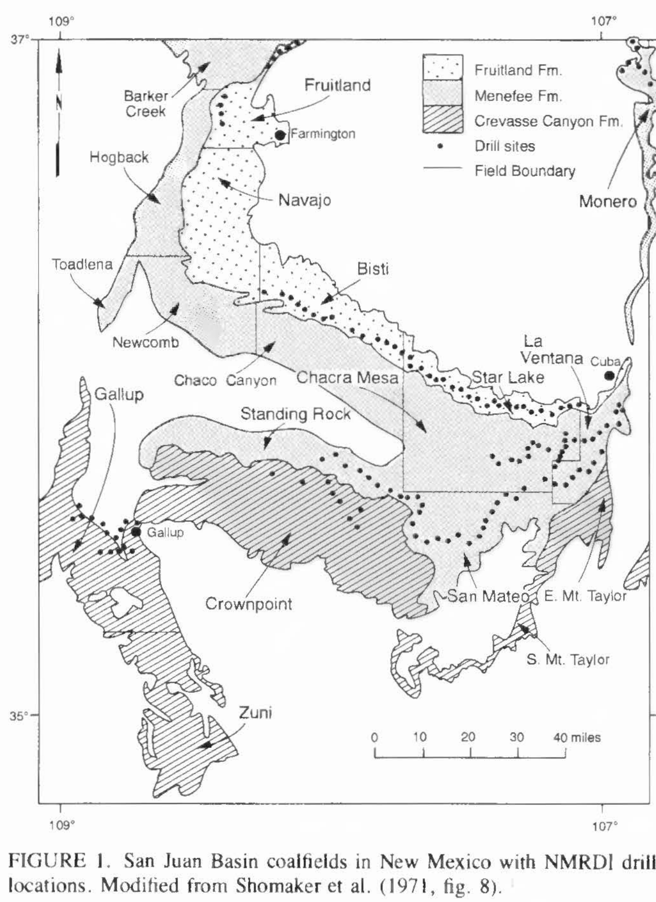


FIGURE 1. San Juan Basin coalfields in New Mexico with NMRDI drill-site locations. Modified from Shomaker et al. (1971, fig. 8).

coal beds, in particular the thickness and resource potential. Most recent investigators have been interested in the depositional environment of the La Ventana Tongue, especially as it pertains to its oil and gas potential. A brief discussion of the work relevant to this study follows.

Gardner (1910), in his reconnaissance investigation of the coal between San Mateo and Cuba, New Mexico, noted the presence of a 0.91-m coal bed 4 to 6 km west of Torreon Trading Post. His map (pl. XXII) indicates observations of coal at two other localities in what is now called the upper coal member of the Menefee Formation, but the emphasis of his investigation was on the Cleary Coal Member of the Menefee Formation and on the Fruitland Formation.

Dane's (1936) detailed investigation of the La Ventana–Chacra Mesa area included geologic mapping of the Mesaverde Formation with emphasis on the coal resources. Dane was the first to recognize the intertonguing relationship between what is now called the Menefee Formation, the Cliff House Sandstone and the Lewis Shale, and the significant buildup of marine sandstones of the La Ventana Tongue. Dane's (1936) nomenclature preceded the use of the Mesaverde Group in this part of the San Juan Basin. The Mesaverde Group nomenclature scheme (Fig. 2) was first defined by Beaumont et al. (1956).

In discussing the stratigraphy of the strippable coals of the San Juan Basin, Beaumont (1971) described the transgressive and regressive sequences recognized in the San Juan Basin. He relied on exposures on the west side of the San Juan Basin to describe the Cliff House transgression and the intertonguing of the marine and nonmarine units, because of insufficient subsurface data for the southeastern San Juan Basin. In the same publication, Shomaker (1971) and Speer (1971) described the outcropping units, coal thicknesses, and estimated the resources of the Chacra Mesa and La Ventana areas.

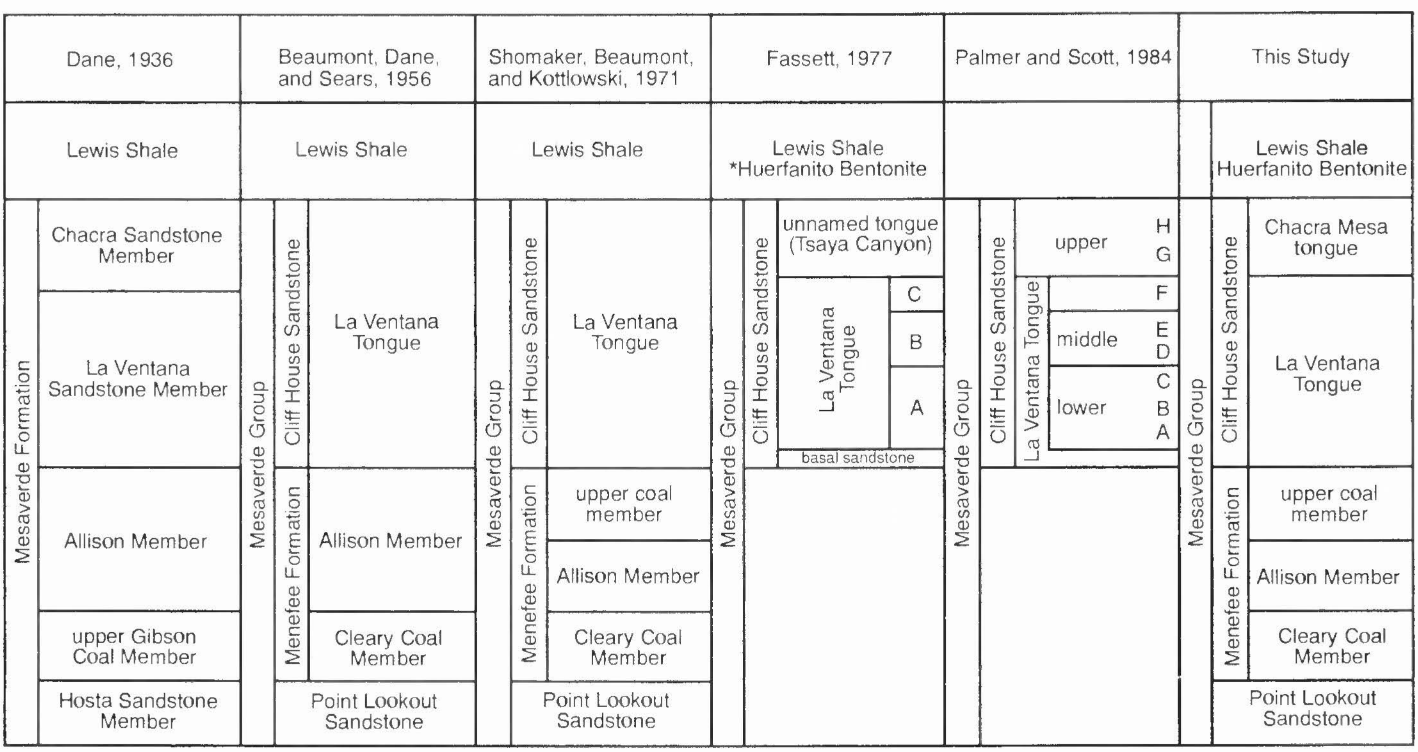
Beaumont and Shomaker (1974) made a first attempt to illustrate the intertonguing relationships of the Menefee–Cliff House–Lewis Shale sequence in the Torreon area using the available geophysical logs. They also dealt with the coal resources of the upper coal member and the Cleary Coal Member of the Menefee, and the past mining in the La Ventana–Chacra Mesa area. Shomaker and Whyte's (1977) investigation of the deep coal resources of the San Juan Basin encompassed the upper Menefee coals, in particular those landward of the La Ventana Tongue.

Mannhard (1976) examined surface exposures of the La Ventana Tongue in the southeastern part of the San Juan Basin. From his observations and measurements, he described the intertonguing La Ventana sandstones as stacked constructional and destructional sands deposited during a time of delicate balance between sediment supply and subsidence.

Fassett (1977) discussed the subsurface geometry of the Cliff House Sandstone and how it related to the depositional environment. He also reviewed the nomenclature problems of the Cliff House Sandstone and defined three sandstone units; the basal Cliff House, the La Ventana Tongue and the unnamed tongue of the Cliff House Sandstone (Fig. 2). Fassett suggested the name "Tsaya Canyon" for the uppermost unnamed tongue, because this unit is well exposed in Tsaya Canyon, in the southwestern San Juan Basin. He felt the three sandstones represented three distinctive events. The basal sandstone was deposited during a fairly rapid transgression, followed by a stabilization of the shoreline with minor oscillations that allowed the thick barrier sandstone buildup of the La Ventana Tongue. This was curtailed by a rapid but brief transgression, followed by a period of stabilization that allowed the unnamed or Tsaya Canyon tongue barrier sandstones to develop.

Tabet and Frost (1979a) discussed the coal geology and depositional environment of the Menefee and the overlying La Ventana Tongue and Cliff House Sandstone. They agreed with Siemers (1978), who developed a model for the Menefee as a continental, fluvial plain adjacent to a delta-plain deposit. Tabet and Frost's (1979b) geologic map delineated the members of the Menefee in the Torreon area, as well as the coal outcrops. The La Ventana Tongue of the Cliff House is geographically differentiated from the Cliff House Sandstone on their map.

McCubbin (1982) included the La Ventana in his case studies of barrier island and strand-plain facies. He referred to the La Ventana Tongue as an interdeltaic barrier chain. By studying the outcrop and geophysical logs along the trend of the La Ventana Tongue, McCubbin divided this thick buildup of sandstone into an upper and a lower interval. He described the upper interval, which included the interton-



*defined in Fassett and Hinds, 1971

FIGURE 2. Stratigraphic nomenclature for the upper Mesaverde Group in the southeastern San Juan Basin since 1936.

guing with the Menefee, as an extensive stacked barrier-island and associated lagoonal system. McCubbin considered the lower interval of the La Ventana Tongue to be a shoreline sandstone.

Palmer and Scott (1984) studied geophysical logs along the La Ventana Tongue trend from T19N, R3W, to T29N, R15W. Most of their work focused on the northwest part of this trend, where there is a greater density of data. The depositional model they developed for the La Ventana sandstones was that of a wave-dominated shoreline, probably with southeast-flowing currents, with widely spaced cuspate deltas flanked by interdistributary strand plains and coastal barriers.

GEOLOGIC SETTING

Structure

The Torreon area is in the southeastern San Juan Basin, where the gently north-dipping (2–5°) Cretaceous beds are broken by scattered normal faults. Most of these faults have throws of a few meters, but several are known to have displacements of between 30 and 60 m at the surface (Fig. 3). The dominant fault trend is north-northeast, although northwest- and west-trending faults are not uncommon. The presence of faulting in the Torreon area compounds the difficulty of mapping geologic units having limited lateral extent and similar lithology.

Stratigraphy

The Cretaceous rocks exposed in the study area represent the last two regressive (R-4, R-5; Molenaar, 1983) phases and the intermediate transgressive (T-5; Molenaar, 1983) phase along the western margin of the Late Cretaceous seaway. The nature of Cretaceous sedimentation was such that the lower coastal plain, paludal and fluvial environments shifted landward and seaward through time, leaving an almost unbroken record of transgressive and regressive deposits. Most of these units are part of the Mesaverde Group, beginning with the basal marine to paralic Point Lookout Sandstone and ending with the paralic Cliff House Sandstone. The Point Lookout is a regressive barrier-beach deposit, 31 to 61 m thick in the southeastern San Juan Basin. It is overlain by the nonmarine, coal-bearing sequence, the Cleary Coal Member of the Menefee Formation.

The Cleary Coal Member of the Menefee consists of 31 to 61 m of mudstone, silty sandstone and thin to moderately thick coal. Overlying this coal-bearing unit is the Allison Member of the Menefee Formation. The Allison Member makes up the majority of the nonmarine Menefee, and consists of approximately 183 m of continental mudstone, siltstone and silty sandstone. The Allison is both a regressive and a transgressive sequence. Although Dane (1936, p. 95–96) modified Sears' (1925, p. 18) definition of the Allison as a barren unit to include the coal in the upper part of the Menefee, we prefer to use the informal term "upper coal member" as used by Beaumont (1971, fig. 6) for the equivalent section on the west side of the San Juan Basin (Fig. 2). The upper coal member of the Menefee is part of the transgressive sequence that intertongues with the paralic Cliff House Sandstone, and specifically in this area, the La Ventana Tongue. The upper coal member, where it does not intertongue with the La Ventana, is very thin, 15 to 23 m, but this unit is correspondingly thicker, up to 137 m, when it is landward of the La Ventana Tongue buildup.

The La Ventana Tongue of the Cliff House Sandstone is a thick succession of nearshore marine and barrier-beach sandstones deposited during a period of relatively stable shoreline conditions. The balance between subsidence and sediment supply was such that the strandline remained close to the same position, with minor transgressive and regressive oscillations. The thickness of the La Ventana Tongue ranges from 8 m at the north end of the cross section shown in Fig. 4, to about

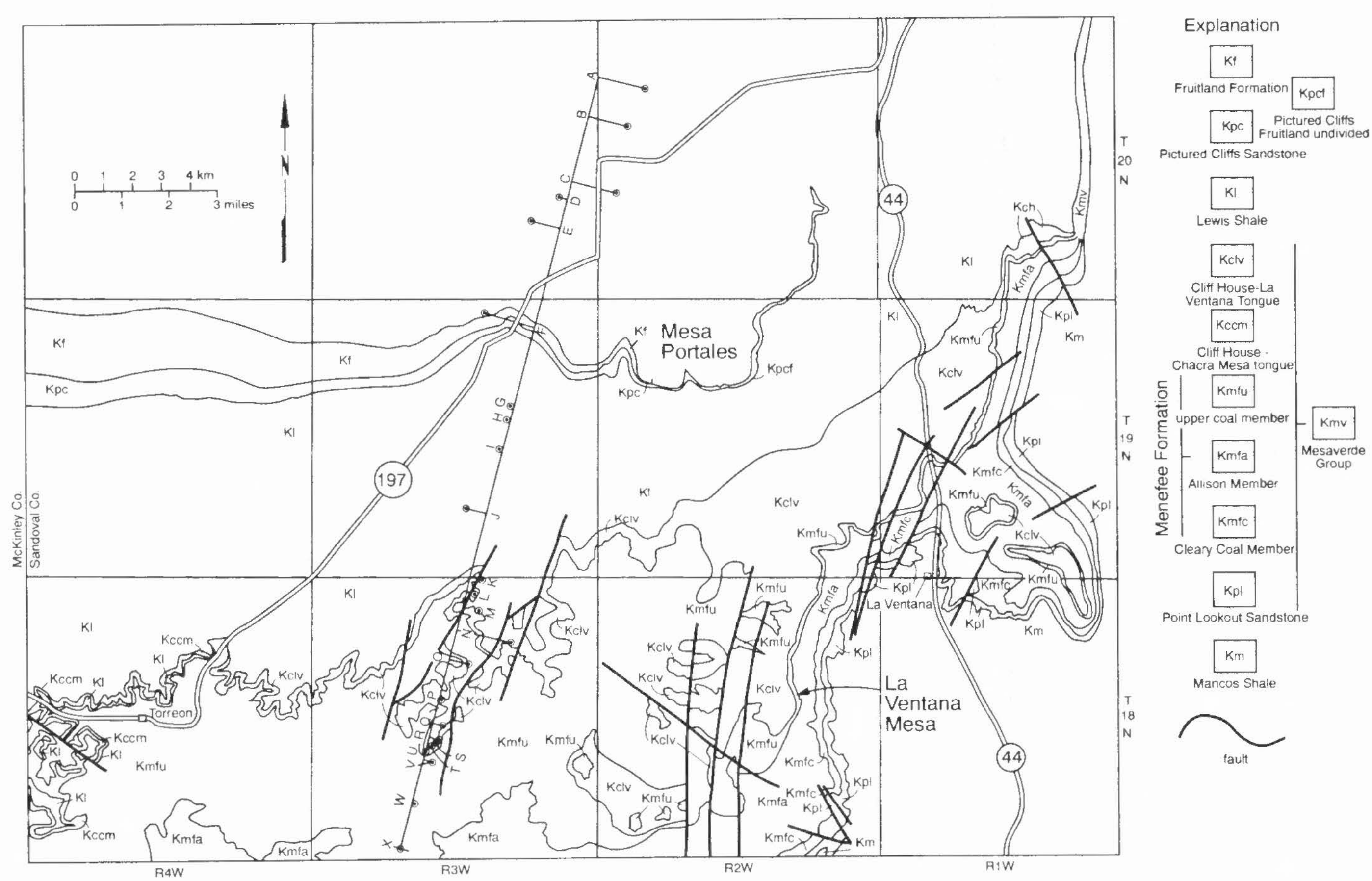


FIGURE 3. Geologic map of the Torreon–La Ventana area in southeastern San Juan Basin, New Mexico, with line of cross section in Fig. 4. Modified from Tabet and Frost (1979b).

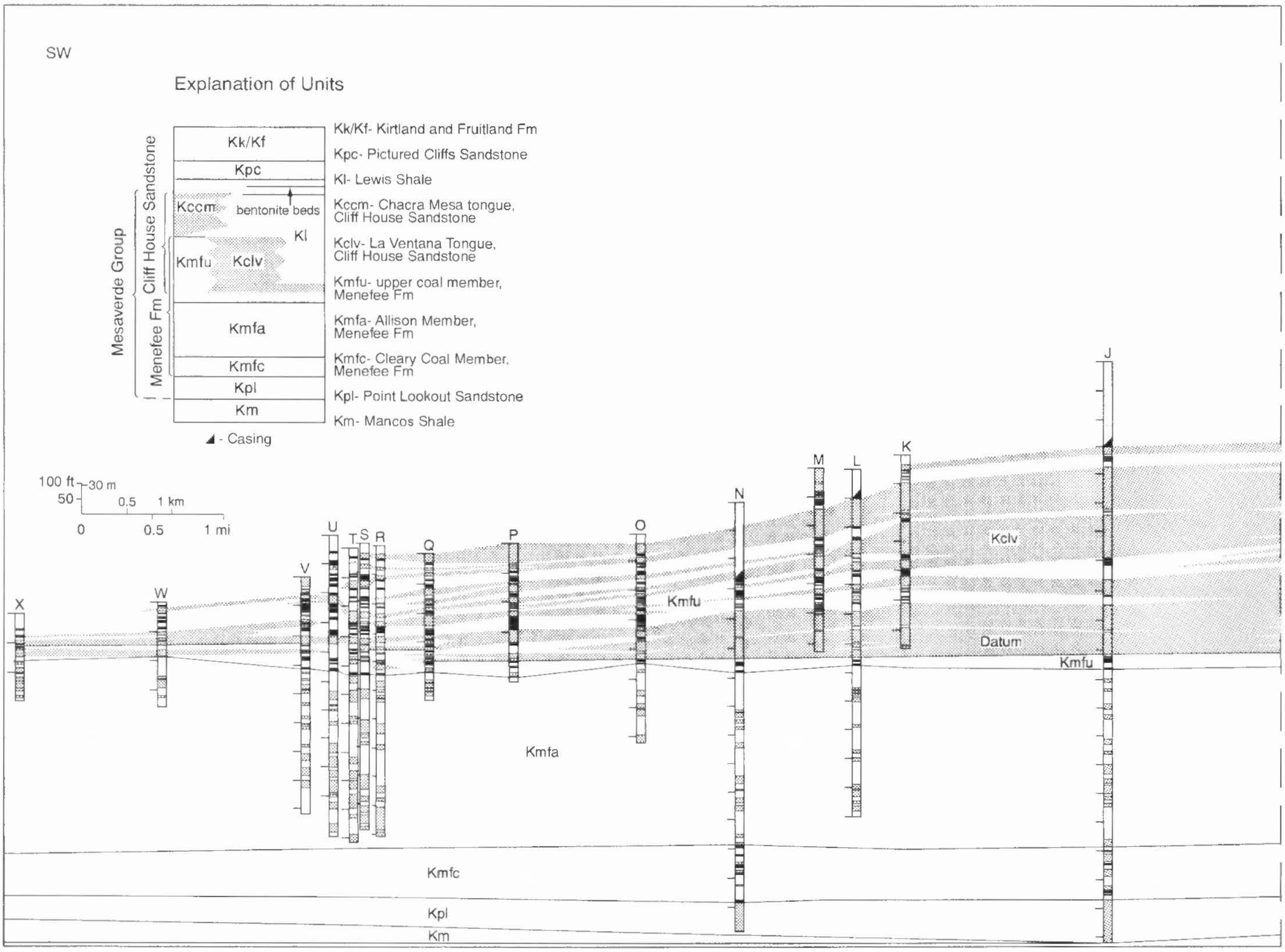


FIGURE 4. Detailed cross section of Torreon–La Ventana area, southeastern San Juan Basin, New Mexico.

229 m in the area of maximum sand development. The La Ventana Tongue intertongues seaward with the Lewis Shale. The Lewis Shale is a thick section, up to 457 m, of silty and sandy marine shales that also intertongue with tongues of the Cliff House Sandstone, and locally is in contact with the Menefee Formation.

The upper part of the Lewis Shale is part of the final regressive cycle in the San Juan Basin and is overlain by and intertongues with the Pictured Cliffs Sandstone. This coastal barrier sandstone is approximately 31 m thick near Mesa Portales, southwest of Cuba (T19N, R2W, Fig. 3), and intertongues with the overlying coal-bearing Fruitland Formation. Both the Fruitland and Pictured Cliffs thin greatly on the southeast San Juan Basin from their thicknesses on the northwest side of the basin. The Fruitland is a regressive nonmarine unit characteristically containing several coal beds, particularly at the base. The nonmarine barren beds above the Fruitland belong to the Kirtland Shale. At Mesa Portales, the Fruitland and Kirtland range from 31 to 91 m thick and consist of mudstone, siltstone and silty sandstone, with thin coal beds, which attain a maximum thickness of 1.4 m (Fassett, 1966).

ANALYSIS OF CROSS SECTION

Introduction

This study is the outgrowth of an investigation of the quality of the potentially surface-minable coal in the San Juan Basin. It is concerned primarily with the Torreon area, and the downdip equivalents of the exposed sections of coal-bearing rocks in the vicinity of Torreon. Although the data are imperfect, drilling of oil and gas tests in recent years, coupled with the drilling of NMBMMR coal-test holes in this area provide sufficient data to permit a fairly complete and detailed analysis of the Menefee–La Ventana–Lewis stratigraphic relationships along a line oriented nearly normal to the depositional strike (Fig. 3). Of the 24 data points used to compile the nearly 27-km-long cross section, the farthest projection of well data is about 1.6 km. All drill-hole data in the deeper, northeastern part of the cross section are from oil and gas tests, whereas both oil and gas logs and coal logs are intermixed in the southwestern part of the cross section (Table 1). The quality of the oil and gas tests varies from marginal to excellent; thus the interpretation of lithologies from these logs is of variable quality. The obvious advantage of the oil and gas tests is that they were drilled deeper than the coal tests, and penetrated the entire Mesaverde section in most instances. The logs from the coal tests are generally excellent for interpreting coal and associated lithologies. For construction of the cross section the writers relied on bulk density, gamma, and resistivity logs to determine the coal and sandstone thicknesses and to pick formational boundaries. This study deals principally with the upper coal member of the Menefee–La Ventana–Lewis relationships; therefore, no detailed lithologic correlations are shown for the other stratigraphic units on the cross section (Fig. 4).

Description of cross section drill logs

The northeast end of the cross section (Fig. 4) is the most basinward position. The entire Lewis Shale interval, from the base of the Pictured Cliffs Sandstone to the top of the basal La Ventana Tongue sandstone

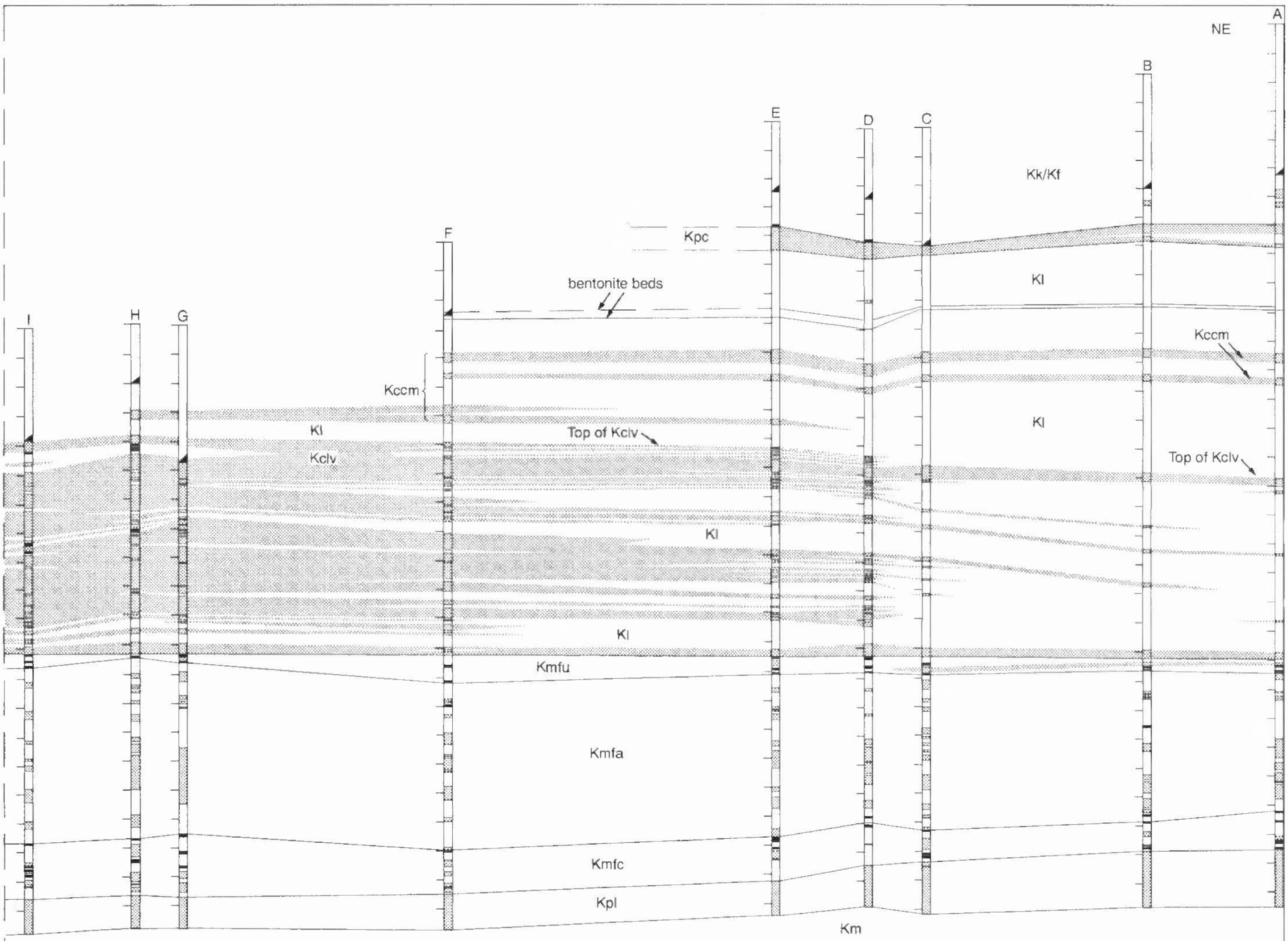


TABLE 1. List of drill holes used in cross section, Fig. 4.

Cross Section Designation	Operator	Well Name	Location
A	Filon	Federal 7-1	T20N, R2W, Sec. 7
B	Filon	Federal 18-1	T20N, R2W, Sec. 18
C	Filon	Federal 19-1	T20N, R2W, Sec. 19
D	Gary Williams	San Isidro 24-13	T20N, R3W, Sec. 24
E	Gary Williams	San Isidro 26-7	T20N, R3W, Sec. 26
F	Atlantic Refining Co.	Torreon #2	T19N, R3W, Sec. 3
G	Magnolia Petroleum	Harvey Federal #1	T19N, R3W, Sec. 14
H	Fluid Power	Fluid Power Pump #1	T19N, R3W, Sec. 14
I	Wiley & Fluid Power	Federal-Media #6	T19N, R3W, Sec. 22
J	Rijan Oil	Federal 2-27	T19N, R3W, Sec. 27
K	NMBM&MR Coal Quality	18N3W3-1	T18N, R3W, Sec. 3
L	Cannedy	Cass Goodner #1 Federal	T18N, R3W, Sec. 3
M	NMBM&MR Coal Quality	18N3W3-2	T18N, R3W, Sec. 3
N	Tesoro Petroleum	San Luis Federal #1	T18N, R3W, Sec. 11
O	NMBM&MR Coal Quality	18N3W10	T18N, R3W, Sec. 10
P	NMBM&MR Coal Quality	18N3W16	T18N, R3W, Sec. 16
Q	NMBM&MR Coal Quality	18N3W21	T18N, R3W, Sec. 21
R	Noel Reynolds	Torreon #1	T18N, R3W, Sec. 21
S	Noel Reynolds	Torreon #4A	T18N, R3W, Sec. 21
T	Noel Reynolds	Torreon #2	T18N, R3W, Sec. 21
U	Noel Reynolds	San Luis Federal #1	T18N, R3W, Sec. 21
V	NMBM&MR Coal Quality	18N3W21-A	T18N, R3W, Sec. 21
W	NMBM&MR Coal Quality	18N3W28	T18N, R3W, Sec. 28
X	NMBM&MR Coal Quality	18N3W32	T18N, R3W, Sec. 32

unit, is 439 m thick. This interval is largely silty and sandy shale with several discrete sandstone units ranging in thickness from 1.5 to 9 m. An 8-m sandstone, about 174 m above the base of the Lewis, is interpreted to be the upper sand in the La Ventana Tongue. The total thickness of the La Ventana Tongue equivalent at locality A is about 187 m, and of this total, approximately 9 percent is sandstone.

Two sandstone units above the La Ventana sand are correlated with a later buildup of barrier sands, similar in origin to the La Ventana Tongue. These sands belong to the stratigraphic unit variously known as the Chacra Sandstone Member of the Mesaverde Formation of Dane (1936), the unnamed tongue of the Cliff House Sandstone or the Tsaya Canyon of Fassett (1977), and the upper interval of the La Ventana Tongue of Palmer and Scott (1984) (Fig. 2). For this report, and for reasons explained in a later section, we have chosen to use Chacra Mesa tongue of the Cliff House Sandstone.

To the southwest, the La Ventana interval remains about the same thickness (183 m), with a gradual increase in the percentage of sand to 21 percent at locality C, a distance of 3.7 km. However, between the two oil tests represented by localities C and D (Fig. 4) there is an abrupt increase in the amount of sand in the La Ventana section from 21 percent to 54 percent in a projected cross-sectional distance of less than 0.6 km. This abrupt change may be somewhat deceptive because the actual distance between these two oil tests is about 2.0 km. If these data points were projected to the cross section line parallel to the depositional strike, the abrupt change in percentage of sandstone would be partially eliminated as the plotted positions on the cross section would then be 1.3 km apart.

La Ventana Tongue sandstones increasingly dominate the sequence to the extent of composing 80 percent of the La Ventana interval at locality F and 89 to 90 percent at localities H and I. Locality G is estimated to contain 90 percent sand, although the uppermost 27 to 31 m of the La Ventana interval is masked by surface casing.

It is at locality H that the first indications of nonmarine Menefee sediments are detected in the oil-test logs. We interpret a 10-m-thick shaly interval beneath the upper 11-m-thick La Ventana sandstone bed to be the uppermost and the most basinward tongue of the back-barrier upper coal member of the Menefee Formation. Also, the lowermost Lewis tongue is thinning at locality H, and its final presence at locality I indicates that it reached farther landward than the subsequent Lewis tongues intertonguing with the La Ventana (Figs. 4, 5). This combination suggests that the initial transgressive surge took the shoreline to its maximum southwestern position during La Ventana time. There is a suggestion of a slightly regressive component in the La Ventana as subsequent oscillating shoreline shifts reached progressively farther seaward.

The area of maximum sand development (about 90 percent) in the vicinity of localities G, H and I is also the area of thickest La Ventana in the subsurface, about 229 m at locality H. As the nonmarine, coal-bearing tongues of the Menefee become more dominant in the section to the southwest, the total sequence begins to thin. The thickness of the upper Menefee–La Ventana is reduced to 201 and 191 m at L and M, respectively. Southward from locality M, erosion has removed the upper part of the La Ventana, but lithologic correlations within the unit are attributed to increasingly greater compaction to the south as the nonmarine sequence continues to increase and the sand fraction decreases.

Updip, toward the outcrop, the increasing proportion of softer Menefee beds has resulted in a greater degree of erosion. Also, in the thinner part of the cross section, the data are more definitive, for it is in this area of relatively abundant and shallow coal occurrence that several holes were drilled in connection with the NMBMMR coal-quality project.

In the area of outcropping La Ventana and its intertonguing with shore-marginal swamp and floodplain deposits, coal beds occur in much greater numbers and are present through a greater interval than is the case to the north. For example, at locality G the only coal in the upper member is at the base in a thin coal-bearing interval immediately beneath the basal La Ventana Tongue.

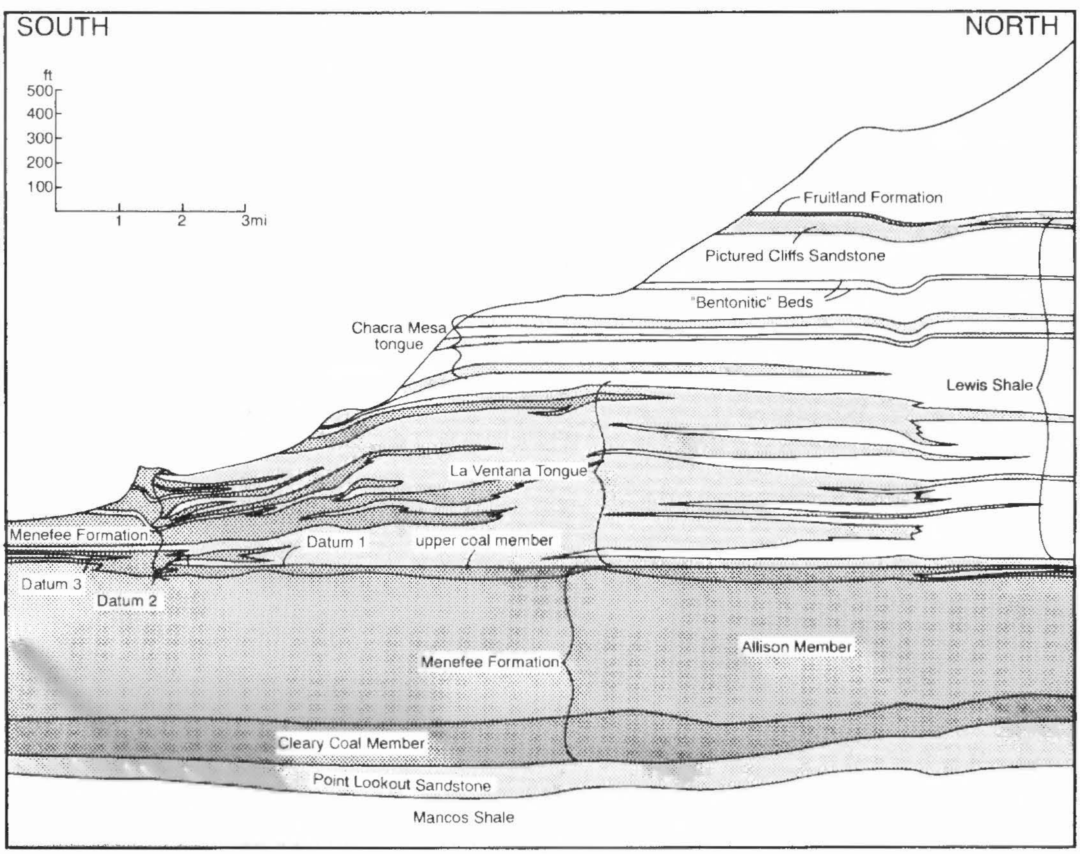


FIGURE 5. Generalized cross section of Torreon–La Ventana area.

Dane (1936) noted the presence of coal in his Allison Member (Fig. 2) of the Mesaverde along the east-facing escarpment that flanks the physiographic feature identified by the U.S. Geological Survey as La Ventana Mesa (see Fig. 3; not the La Ventana Mesa of Dane's usage, pl. 39). At several localities this coal was mined and thicknesses of 1.4 to 2.2 m were observed by Dane (1936, pl. 54) in a distance of about 8 km in T18 and 19N, R1 and 2W. NMBMMR's drill hole 18N2W3, located approximately on the trend of the maximum development of the La Ventana, penetrated a 2.4-m-thick coal about 7.6 m below the base of the lowermost La Ventana sandstone. As the basal sandstone of the La Ventana pinches out southwestward to signal the start of shoreline stabilization and the intertonguing between the coal-bearing strata and the barrier-beach sands, the thickness of the upper Menefee increases until the preserved portion of the unit is 137 m thick (locality T). Some La Ventana Tongue sands are present within this interval, but it is mostly the upper coal member. Because of the discontinuous nature of the lithologic units, there is considerable distortion due to differential compaction, as indicated on Fig. 4.

We can identify (Fig. 5) five major coal-bearing tongues of upper Menefee intertonguing with a corresponding number of La Ventana tongues. All but the upper one of these upper-member tongues can be subdivided into from two to four subunits.

Distribution of coal in the upper coal member, Menefee Formation

The vertical and lateral distribution of coal and the thicknesses of individual coal beds vary with respect to their occurrence within the depositional framework. In the San Juan Basin, especially in regressively deposited coal units, it is common to find the thickest and most extensive coal beds closest to the barrier beach–nearshore sand unit. This relationship is less likely to be true if there is extensive intertonguing between the back-barrier and the barrier environments.

Landward from the immediate back-barrier depositional environment, fluvial conditions favorable for peat deposition in the coastal plain existed, but the resulting coal beds are usually thinner and less extensive, although possibly more numerous. Conditions for the deposition of peat cease to exist away from the coastal plain, and thus the coal tends to occur in a relatively narrow band near the barrier sand units.

The La Ventana–upper coal member relationship is marked by extensive intertonguing, and the distribution of the coal with respect to thickness and proximity to the barrier sand is not readily apparent. Another complication is the greater susceptibility of the updip, nonmarine strata to later erosion. As a result, only the lower part of the upper coal member of the Menefee is preserved southward beyond the zone of intertonguing, and the La Ventana–upper coal member relationship is not fully preserved. However, in the area where the section is preserved, the zone of intricate intertonguing between nonmarine and marine units, the coal-quality drilling program has clearly shown that maximum coal bed thickness tends to be developed in the relatively thin sequences of nonmarine strata lying within the dominantly marine sequence. Locality J (Rijan Federal 2-27) appears to have encountered moderately thick coal in a locality where 90 percent of the La Ventana–upper coal member sequence is marine sandstone. The nature and scale of the oil and gas logs is such that it is impossible to quantify them, but NMBMMR drill hole 18N2W5, which would project into the line of the cross section at about locality J, contains two coal beds totaling 5.4 m of coal in a 6.7-m-thick upper Menefee tongue.

At locality K, the next data point to the south (landward) of locality J, a 2.7-m-thick coal bed containing a single 0.15-m parting is contained within a 6.4-m nonmarine section overlain and underlain by massive marine sandstone 10.7 and 10.4 m thick, respectively. At this locality the La Ventana–upper coal member interval is 78 percent La Ventana sandstone. Continuing in a landward direction, the proportion of barrier sandstone in this interval further decreases. At locality O, 2.74 km south of locality K, the La Ventana Tongue sandstone is reduced to about 50 percent of the 137-m-thick nonmarine-marine interval of intertonguing. There are, however, more coal beds; eight with thicknesses equal to or greater than 0.9 m. These coals have an aggregate thickness of 10.6 m.

Farther landward, at locality Q, the portion of the 123-m interval assigned to the La Ventana is about 35 percent sandstone, and there are five coal beds 0.9 m or more thick, with a total thickness of 4.7 m. Another 1.3 km landward at locality V, the preserved La Ventana–upper coal member section is reduced to about 91 m, and the La Ventana sandstone portion is only about 11 m thick, or 12 percent of the section. Coal beds are abundant, with 18 percent in an interval of about 73 m. However, most are thin, with only three being thicker than 0.6 m and one thicker than 0.9 m. The thicker sequence with thinner coals is to be expected as the coal environment becomes more fluvial landward from the shoreline. Landward from locality V, the preserved section is reduced to the degree that there is no significance in estimating the relative proportions of upper coal member and La Ventana Tongue sandstone. In that portion of the upper coal member that is preserved, the coal beds are few in number and reduced in thickness.

DISCUSSION

Geographic extent of the La Ventana Tongue

Although Palmer and Scott (1984), and to a lesser extent McCubbin (1982), have defined the La Ventana in the subsurface, their interest has been largely from the point of view of origin with respect to oil and gas potential; although the focus may be different, these studies serve to show the geographic distribution of the La Ventana throughout the San Juan Basin. Palmer and Scott's net isopach map (1984, fig. 3b) shows a trend for the La Ventana Tongue of N55°W, and the maximum thickness (152 m) of the La Ventana at the southeast end of their map area closely compares with the maximum thickness (205 m) shown in our cross section (Fig. 4, H, I). Wiegand's map (in McCubbin, 1982, fig. 50) of the "upper interval" of the La Ventana agrees with this orientation, and Shomaker and Whyte (1977, fig. 12) showed a total coal isopach orientation similar to that for the La Ventana Tongue. The outcrop of the strata dealt with in their paper is on the northwest side of the San Juan Basin, near Hogback Mountain and somewhat farther to the south, a distance of nearly 161 km from the area of study for this paper. It is not the purpose of this paper to establish or confirm these relationships.

Post–La Ventana deposition

Two thin sandstone units occur in the Lewis above the uppermost La Ventana sandstone tongue. These upper sands, about 8 and 9 m thick, occur 290 and 303 m above the base of the Lewis, respectively. The uppermost of these sands is about 46 m below the Huerfanito Bentonite (Fassett and Hinds, 1971) at locality A. These units remain fairly constant in thickness and position, and can be traced by log correlation nearly to their outcrop position to the southwest. A third sandstone is picked up in locality E and again in F where it is more than 15 m thick. The bottom of this third sand is 25 to 21 m above the top of the La Ventana Tongue at locations E and F, respectively, and the total interval of Lewis through which the three sands occur is 73 m.

These three sandstones are correlated with a sequence of stacked sandstone units that is younger than the La Ventana and about half as thick. Mapped by Dane (1936) as the Chacra Sandstone Member of the Mesaverde Formation, the unit culminates in the massive sandstones that form Chacra Mesa; the southeast end of this northwest-trending unit lies about 5 km southwest of Torreon Trading Post. Dane (1936) measured a maximum thickness for the Chacra Sandstone of about 110 m. One of the NMBMMR drill holes (18N5W26) which spudded in the "Chacra Sandstone," some 49 m below the top of the mesa and therefore below the top of the Chacra, encountered a minimum of an additional 83 m of "Chacra Sandstone," putting the total thickness of this unit at more than 144 m.

The name "Chacra" was abandoned in the course of revising the Cretaceous nomenclature in the San Juan Basin (Beaumont et al., 1956), and the unit is identified simply as Cliff House Sandstone (Fig. 2). Fassett (1977) referred to it as an "unnamed tongue" of the Cliff House, and it would appear that he, like the present writers, would have favored a resurrection of the name "Chacra." But, as Fassett further noted, a deterrent for the reapplication of "Chacra" is the adoption of the name for a subsurface producing interval by the New Mexico Oil Conservation Commission (OCD Order No. R5459). Unfortunately this OCD unit, which includes producing sands for an interval of 229 m below the Huerfanito Bentonite, encompasses the upper 53 to 76 m of La Ventana equivalent strata. The name Tsaya Canyon tongue of the Cliff House Sandstone was proposed by Fassett (1977) for exposures in Tsaya Canyon, about 88 km to the northwest. The "Tsaya Canyon" designation had not been formalized at the time of this writing; thus, we have chosen the informal name Chacra Mesa tongue to refer to this interval, because of its prominence in this geographic feature.

The subsiding, but nearly stationary position of the shoreline that produced the stacked sands composing the Chacra Mesa tongue was on the order of 19 to 21 km southwest of the maximum development of the La Ventana Tongue, and there appears to have been an abundance of sediment supplied to the system. The Chacra Mesa shoreface sandstones can be traced seaward a greater distance from the primary buildup of the La Ventana Tongue. Although this paper is concerned principally with the La Ventana Tongue, the La Ventana–Chacra Mesa relationships are important to the extent that the younger stacked sandstone unit, the Chacra Mesa, might be considered a continuation of the conditions that produced the La Ventana with a temporary, albeit rather severe, interruption that resulted in a rapid shift to the southwest of the center of maximum sand buildup.

Although the detailed portion of Palmer and Scott's (1984) study area is some 97 km northwest of our cross section (Fig. 4), they presumably included the Chacra Mesa sand units in the upper La Ventana Tongue (Fig. 2). They recognized the transgressive shoreline shift following the deposition of their lower and middle La Ventana units and further suggested either an increase in the rate of basin subsidence or eustatic rise in sea level.

In several sections of the Chacra Sandstone Member (Chacra Mesa tongue of this report) measured by Dane (1936, p. 104–107), he noted that an erosional conformity was present at the bottom at most places. Dane (1936, p. 103) described the basal contact as sharp and as having a relief of a few inches to a few feet. He further recognized that there is no unconformity between the Chacra Sandstone and the underlying Allison Member (upper coal member of the Menefee Formation, this report). Dane cited an example of intertonguing between the basal Chacra Sandstone and the Allison Member, whereby the Chacra is reduced in thickness by about 12 m.

In a discussion between Dane and Beaumont regarding the nature of events that might have caused the rapid landward shift of the shoreline between La Ventana and Chacra Mesa deposition, Dane (personal comm. 1960) said that he suspected structural unrest accompanied by earthquake activity. This discussion was the result of Beaumont's asking Dane whether he had encountered disturbed Cretaceous strata like those found in the upper Menefee a few kilometers east of Newcomb, New Mexico, where intraformational angular discordance is common. The erosional disconformity of the base of the Chacra Mesa is not particularly significant since minor erosional loss between the back-barrier and the barrier deposits can be observed elsewhere in transgressive conditions in the San Juan Basin.

Whatever the cause for the landwrd shift, the La Ventana–Chacra Mesa deposition can be considered as a single depositional event temporarily interrupted by a sudden change in sea level. During this period of time, in excess of 335 m of barrier-beach sandstone was deposited along a narrow northwest-trending band about 24 km wide.

The coal that occurs in the upper part of the Menefee beneath and interbedded with the Chacra Mesa tongue is genetically related to the upper coal member of the Menefee. The coal-bearing interval at the top of the Menefee is essentially eliminated as a result of the rapid landward shoreline shift at the end of La Ventana deposition. The reestablishment of shoreline stability resulted in a resumption of the back-barrier paludal environment and intertonguing between the Chacra Mesa barrier sand and the shore-marginal upper coal member of the Menefee. Because the Chacra Mesa is stratigraphically younger, and thus physiographically higher than the La Ventana, the interval has been exposed to more erosion, and for the most part only the core of the stacked barrier sandstones remains. Dane (1936, p. 103) noted the presence of interbedded coal-bearing material in the Chacra, and he observed the particular abundance of coal at a place about 34 km west of Torreon. At this locality, the southwesternmost preserved position with respect to the strandline orientation, Dane recognized that the marine Chacra Mesa is grading laterally to nonmarine rocks.

Principles of stratidynamics

The Late Cretaceous deposits of the San Juan Basin provide many opportunities for the application of the principles of stratidynamics (Beaumont et al., 1971). This concept relates thickness of transitional facies to rate of either transgressive or regressive shoreline shift. Transitional facies are those that are between nonmarine on the landward side of the shore and those that are wholly marine in the seaward direction. The principal transitional facies found in the San Juan Basin are the back-barrier lacustrine and lower floodplain deposits, as characterized by the upper coal member of the Menefee, and barrier-beach and nearshore sands belonging to the La Ventana Tongue of the Cliff House. The Allison Member of the Menefee and the Lewis Shale would be classified as wholly nonmarine and wholly marine, respectively.

Fig. 6 diagrammatically expresses the concept of stratidynamics. First, continuing subsidence and deposition is assumed. Time is represented on the vertical axis and the amount of lateral movement or shoreline shift is represented on the horizontal axis as "distance." Three parallel curves will define the two principal transitional facies: the shore-marginal and lower-floodplain paludal facies, and the nearshore and barrier-beach sand facies. The slopes of the curves, which are a function of rate of shoreline shift, will determine the thickness of these transitional units. If the rate of transgressive shoreline shift is relatively slow (Fig. 6, position A), the slopes of the curves will be steep and the distance between the defining curves will be relatively wide, and the transitional units will be correspondingly thick. If the rate of transgressive shift increases (Fig. 6, position B), the slope of the defining curves decreases and the transitional units are consequently decreased in thickness. Coal beds deposited in areas of relatively rapid shoreline shift are thin because the nearly stationary conditions required for the accumulation of thick peat deposits do not exist. If, as is expressed in the central part of the diagram (Fig. 6, position C_1), there is an essentially instantaneous lateral shift, the curves flatten and merge along a horizontal plane and the transitional facies are eliminated. In this region the wholly nonmarine and the wholly marine are in contact. Also, in the early part of this rapid shift, at position C_2, the barrier-beach facies is gone but the paludal (coal-bearing) facies is still present, though thinning, and in direct contact with the marine sequence. Likewise, at

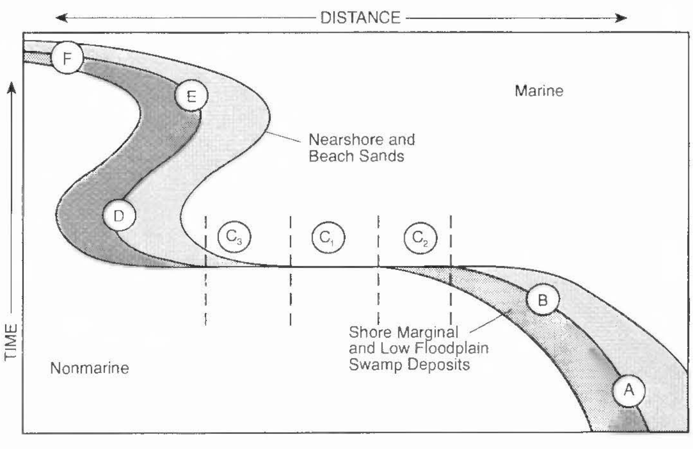


FIGURE 6. Relations of time and distance to deposition of transitional facies; a diagrammatic sketch of the principle of stratidynamics.

the end of this phase, totally nonmarine beds may be directly overlain by the barrier-beach deposits as at position C_3.

If conditions develop during deposition that cause the overall transgressive phase to be interrupted by a temporary regressive movement, as is expressed at position D, the transitional facies may be well developed and sediments deposited in both the transgressive and the regressive modes may be present in a continuous sequence. On a relatively small scale, these reversals may result in intertonguing relationships. On a major scale such as is found in areas of major reversal of direction of shoreline shift, the relationships are the same but on a grander scale. In either instance such reversals are good sites for the development of coal resources.

If an absolute balance between subsidence and sediment supply existed, the shoreline would be stable, and consequently the transitional facies would have their maximum development. It is more likely that there would be factors causing minor oscillations of the shoreline during periods of relative stability. Thus, a more-or-less vertical accumulation of the transitional facies would likely result, but with jagged boundaries representing intertonguing relationships between the adjacent facies. In a very simplified way, this is represented as occurring between positions D and E. If the transgressive mode is once again reestablished and the rate of shoreline shift in the landward direction becomes increasingly rapid, the defining curves will become flatter and therefore the transitional facies thins, as is represented between positions E and F.

Illustrations of stratidynamics principles

All of the conditions described above are manifested in the Late Cretaceous stata in the San Juan Basin. Several of these are visible in the sedimentary sequence in the Torreon area. Within the Mesaverde Group, the sequence of events and their positions within the diagrammatic illustration of stratidynamic principles (Fig. 6) is described in the following paragraphs.

Point Lookout Sandstone–Cleary Coal Member deposition

These transitional units were deposited under regressive conditions. The rate of shoreline shift appears rather steady, with no apparent intertonguing, and relatively rapid with little time for the development of thick coal beds, although some minable coal has been developed within the Cleary near the line of the cross section. These conditions are approximated on Fig. 6 at position B.

Upper coal member–La Ventana Tongue deposition

The upper coal member of the Menefee Formation and the La Ventana Tongue of the Cliff House Sandstone should be considered as two separate sedimentary phases. Initially the shoreline advanced from a position of maximum seaward retreat during Mesaverde time in southern Colorado. A short distance west of the cross section (Fig. 4) the rate of transgression appears to have been sufficiently rapid to have resulted in an interruption in the deposition of the transitional Cliff House Sandstone and the adjacent upper coal member. Near the north end of the cross section (Fig. 4), the rate of advance slowed somewhat and the lower sand unit belonging to the La Ventana Tongue of the Cliff House was deposited, along with one or two shore marginal coals. This is analogous to conditions on Fig. 6 at locality F.

The advance of the sea came nearly to a standstill and was followed by a period during which subsidence and sediment supply continued, although perhaps both at variable rates. This resulted in oscillatory shoreline movement, with the La Ventana and the upper coal member being deposited in an irregular, intertonguing stacked configuration. This continued as 213 m of barrier sand constituting the La Ventana was deposited in a narrow band. This is illustrated in a much simplified way between positions D and E on Fig. 6.

Upper coal member–Lewis Shale deposition

The abrupt termination of the period of imperfect balance between sediment supply and subsidence that had produced the La Ventana sand buildup resulted in a sudden shift landward, which locally eliminated at least one of the transitional units. Just west of Torreon Trading Post the upper coal member is in contact with the Lewis Shale. This is roughly analogous to position C_2 on Fig. 6.

Upper coal member–Chacra Mesa tongue deposition

The rapid landward shift following La Ventana time ceased with apparent abruptness, the oscillating shoreline conditions were reestablished, and the Chacra Mesa transitional barrier sands were deposited to a thickness of about 122 m. The shore-marginal paludal deposits presumably accumulated landward from the barrier strand, although remnants of this transitional facies are presently preserved only in isolated tongues of coal-bearing nonmarine strata within the marine sandstone. The Chacra Mesa tongue is also represented in a simplified form on Fig. 6 by the interval between D and E.

The concept of stratidynamics does not attempt to consider all of the factors of sedimentary deposition. It is applicable only in conditions of subsidence and the variable rates of subsidence. The concept does not take into account variations in sediment supply versus variations in rate of subsidence, variations in the factors affecting rates of peat production, width of the coastal plain, or current variations. However, the concept of stratidynamics does explain some of the major conditions of sedimentary rock accumulation in conditions like or similar to those found in the Upper Cretaceous of the San Juan Basin.

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