Coal Geology of Torreon Wash area, southeast San Juan Basin, New Mexico

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Discussion:

INTRODUCTION

1 The Torreon Wash area basically consists of a series of three north-sloping, sandstone-capped mesas, each one stepping successively up to the north. From south to north these mesas are formed by the Point Lookout Sandstone, the sandy middle member of the Menefee Formation, and the Cliff House Sandstone. The intermittent Chico Arroyo and Torreon Wash, two main tributaries of the Rio Puerco, traverse the area from west to east and north to south respectively. The area has been deeply dissected by these two main washes and their tributaries. In the southern part of the area extensive erosion has exhumed various volcanic necks around the lava-capped Mesa Chivato. At 8,091 ft above sea level, Mesa Chivato is the highest point in the area; Chacra Mesa in the north is the second highest point, reaching 7,078 ft. The lowest point is along the Chico Arroyo in the south at 5,940 ft above sea level.

2 NM-197 connecting Cuba and Crownpoint passes through the northwest corner of the area and NM-44 runs north-south 9 mi from the eastern edge of the area. Federal, county, utility, and ranching concerns maintain numerous dirt roads providing good access to the whole area. Torreon, comprising a trading post, mission school, and various Indian houses and hogans on part of the Eastern Navajo Reservation, is the only sizable development in the area; Cuba, 30 mi to the northeast, is the closest major town.

3 Various workers have studied all or part of the Torreon Wash project area. Dutton (1885), who conducted the first reconnaissance examination through the Torreon Wash area, outlined the geology and emphasized the volcanic rocks. Schrader (1906) and Gardner (1909, 1910) traced the Upper Cretaceous coal-bearing rocks around the San Juan Basin south from Durango, Colorado, and east from Gallup, New Mexico, and described selected coal exposures. Hunt (1936) and Dane (1936) made more detailed examinations of the coal beds in the southern part of the San Juan Basin and attempted to correlate some of the thicker beds in an effort to classify the coal resources on public land. Shomaker and others (1971) included some general information about the study area in their discussion of low-sulfur strippable coal resources for the entire San Juan Basin. Beaumont and Shomaker (1974) gave a short summary of the geology and deep-coal resources of the Cuba–La Ventana–Torreon area, and the deep-coal resources of the area were discussed at length in Shomaker and Whyte (1977). Mannhard (1976) measured two stratigraphic sections of the La Ventana Tongue of the Cliff House Sandstone and associated Menefee Formation through part of the Torreon Wash area and discussed the sedimentology of these rocks.

4 ACKNOWLEDGMENTS—Several people provided information that was essential to understanding the stratigraphy and coal geology of the Torreon Wash area. Howard Nickelson, formerly supervising mining engineer with the U.S. Geological Survey Conservation Division Office in Farmington, New Mexico, allowed access to the expired coal-lease and prospect files for the study area. Ray N. Warren of Pioneer Nuclear, Incorporated, Albuquerque, New Mexico, Dennis G. Storhaug of Tenneco Oil Company, Denver, Colorado, and Thomas Drought, agent for the H. P. Drought Company, San Antonio, Texas, all kindly released drill-hole information for use in this report. Certainly most important to the completion of this project was the funding provided by the U.S. Geological Survey, Conservation Division, under grant number 14-08-0001-448, and the cordial working relationship that developed with Marvin Millgate, Wayne Lambert, and Norman Wingard of the Conservation Division.

REGIONAL STRATIGRAPHY

5 The Torreon Wash area strata comprise Upper Cretaceous marine and nonmarine rocks that have locally been intruded and/or overlain by Tertiary volcanic rocks related to the Mount Taylor center to the southwest. Coal is found in the Menefee Formation, which is composed of the basal coal-bearing Cleary Member, the middle Allison Member (a sandy unit essentially devoid of coal), and an upper unnamed coal-bearing member. In the southern part of the area, the Menefee Formation lies conformably on the Point Lookout Sandstone; to the east and northeast it intertongues with the La Ventana Tongue of the Cliff House Sandstone, and to the northwest it is overlain by the Cliff House Sandstone.

Mancos Shale

6 Two tongues of the Mancos Shale, the Mulatto and the Satan, are exposed in the southeastern part of the Torreon Wash area in parts of T. 16 N., R. 4 W. and T. 17 N., Rs. 3 and 4 W. These shales are the

lowermost Upper Cretaceous rocks exposed in the area. They consist of medium-gray, silty, laminated marine shale. The lower Mulatto and upper Satan Tongues are separated by distal sands of the Hosta Tongue of the Point Lookout Sandstone. The Hosta Tongue thickens to the southwest. The main body of the Point Lookout Sandstone conformably overlies the Satan Tongue.

Point Lookout Sandstone

7 The regressive marine Point Lookout Sandstone has an alternating sand-shale transitional lower contact with the Satan Tongue of the Mancos Shale. The contact between these two units is characterized by a series of sand beds and intervening shales in which the sand beds increase gradually in thickness upward until only a massive cliff- forming sand exists. For the sake of mapping, this contact was drawn where sand predominates over shale. The Point Lookout crops out in a belt that runs southwestward through the southern part of T. 17 N., R. 3 W. and T. 17 N., R. 4 W. This belt turns sharply south midway through the latter township and extends southward through the central part of T. 16 N., R. 4 W. along the east edge of Mesa Chivato.

8 Outcrops of Point Lookout Sandstone are very pale orange to light gray for the most part, although exposures may be very light gray to white toward the top. Bedding toward the base of the unit is generally less than 3 ft thick and has planar lamination; bedding toward the top is thicker and has cross-lamination.

9 Sand grains in the Point Lookout are subangular to subrounded and vary from very fine to fine grained. A general increase in grain size occurs from the base to the top of the formation (Shetiwy, 1978). Quartz is the dominant mineral in the Point Lookout Sandstone, especially in the finer grained sandstones. Detrital grains of chert, feldspar, rock fragments, and organic debris are more common in the coarser sandstones of the upper Point Lookout (Sabins, 1964). Body fossils are not common in the Point Lookout although the trace fossil *Ophiomorpha* may be common in places.

10 Examination of well logs from the Torreon Wash area shows that the thickness of the Point Lookout Sandstone ranges from 75 to 260 ft. The Point Lookout thickens and thins in a systematic way to form a series of west-northwest-trending ridges and troughs.

Menefee Formation

11 The Menefee Formation consists of interbedded shales or mudstones, siltstones, sandstones, and coals. The three members of the Menefee mapped in the Torreon Wash area were essentially divided on the basis of the presence or absence of coal. In ascending order these members are the coal-bearing Cleary Member, the sandy Allison Member, and an upper unnamed coal-bearing member, formerly considered part of the Allison Member. The upper coal member underlies or intertongues with the Cliff House Sandstone and includes the Hogback Mountain tongue of Shomaker and Whyte (1977). The Hogback Mountain tongue was defined as one or more Menefee tongues that are laterally (to the south) equivalent and in part enclosed by the La Ventana Tongue of the Cliff House Sandstone.

12 These three members represent the gradational succession of depositional environments from a coastal swamp to a floodplain and back to a coastal swamp. Because the succession is gradational, the contacts between units are gradational and not easily defined and so they are dashed on the maps. The contact between the Cleary and Allison members is drawn at the base of a thick, cliff-forming channel-sandstone sequence that overlies the uppermost major coal horizon of the Cleary. The upper contact of the Allison Member with the overlying upper coal member is not well defined. This contact is drawn where coals and brown to black carbonaceous shales, rarely found in the Allison Member, once again begin to predominate over drab-gray and tan mudstones.

13 CLEARY MEMBER—The basal Cleary Member of the Menefee Formation has a conformable, transitional contact with the underlying Point Lookout Sandstone. This unit, composed of paludal deposits, is generally 200-300 ft thick. The Cleary Member crops out in a northeast-trending belt running through most of T. 16 N., R. 5 W., the west half of T. 16 N., R. 4 W., the southern part of T. 17 N., R. 4 W., and the central part of T. 17 N., R. 3 W.

14 Lithologically the Cleary Member is dominated by finer grained paludal deposits composed of silt-clay-sized particles and abundant organic debris. At various horizons, more commonly in the lower half of the Cleary, organic debris accumulated to form coal beds. Occasional lenticular channel sandstone deposits and related splay and levee sandstone deposits make up a minor portion of the Cleary Member. These sands increase in abundance toward the top of the unit. Iron-rich

concretionary layers or nodules composed of siderite are often associated with organic-rich shales or mudstones. Abundant plant impressions and fragments ranging up to sections of logs are found along bedding planes, but no macroinvertebrate fossils are found. The random orientation of the plant debris and the occasional presence of an upright stump indicate that most of the organic debris accumulated in place. The coal is characterized by medium bands of vitrain with bits of amber along horizontal cleats.

15 ALLISON MEMBER—The Allison Member, composed of channel sandstones and barren silty mudstones and shales, overlies the Cleary Member with an irregular but conformable contact. This unit crops out mainly in the northern third of T. 17 N., R. 3 W. and the northern half of T. 17 N., R. 4 W. Small areas of exposures occur in the southern parts of the two northern townships and cap the higher mesas of the two southern townships. The Allison is roughly 400–550 ft thick.

16 Unlike the Cleary Member, rocks of the Allison Member are composed primarily of sand-silt-sized particles and very little organic debris. Directly above the Cleary, the basal part of the Allison consists of a 200-ft-thick, multistory sequence of stacked channel sandstones. Above this basal sequence, channel-sand units are common but do not occur in thick, stacked sequences. The channel-sand units are characterized by sharp scour bases containing numerous clay clasts and wood fragments. A major part of these units has large sets of high-angle cross-stratification. The cross-sets generally decrease upward in size and thickness, then change to trough cross-sets and finally to ripple lamination. Grain size in the channel units decreases generally upward from medium to very fine sand. In cross section the channel sandstones are thick lenticular units with a flat upper surface and a concave (upward) lower surface.

17 Laterally associated with the thick channel-sand units are thin (usually less than 3-ft) tabular bodies of fine, silty sand. These bodies commonly have ripple lamination and numerous root tubes along the upper surface and represent splay and levee deposits marginal to the channels and extending into the floodplain deposits.

18 The floodplain deposits interstratified with the channel and marginal channel deposits are light-gray or tan silty claystones and shales. These claystones and shales contain little organic material, probably as a result of an oxidizing, well-drained depositional environment. Locally thin coals and some brown humic shales occur, but they generally compose less than 5 percent of the Allison Member.

19 UPPER MEMBER—The upper unnamed member composes as much as 650 ft of the Menefee Formation. It has a gradational lower contact with the Allison Member and intertongues and is overlain by sand bodies of the the Cliff House Sandstone. The upper member is lithologically similar to the Cleary Member. Most of the thicker coal beds occur in the upper part of the upper member between sandstone tongues of the La Ventana Tongue of the Cliff House Sandstone. The upper coal member thins somewhat to the west, grading laterally into the Allison Member.

Cliff House Sandstone

20 The Cliff House Sandstone proper and the stratigraphically lower La Ventana Tongue of the Cliff House overlie and intertongue with the Menefee Formation in T. 18 N., Rs. 3 and 4 W. Lack of detailed mapping or stratigraphic data caused earlier workers (Dane, 1936; Shomaker and others, 1971; and Beaumont and Shomaker, 1974) to postulate that the Menefee Formation in this area is directly overlain by the Lewis Shale. Thin marine sandstones of the Cliff House are found between the Menefee Formation and the Lewis Shale at all exposures. The stratigraphy in this area is particularly complicated because only thin lenses of Cliff House extending seaward (northeast) and thin lenses of the La Ventana extending landward (southwest) are found overlying most of the Menefee. The Lewis Shale, which intertongues with the thin Cliff House sands, pinches out rapidly to a knife edge at Chacra Mesa in sec. 30, T. 18 N., R. 4 W.

21 LA VENTANA TONGUE—The La Ventana within the Torreon Wash area consists of several laterally persistent lenses of marine sandstone up to 40 ft thick that are interstratified with paludal deposits of the upper Menefee member. The uppermost lens of La Ventana separates the Menefee from the Lewis Shale through T. 18 N., R. 3 W. and the eastern half of T. 18 N., R. 4 W. The lower La Ventana lenses, which occur in T. 18 N., R. 3 W., thin and intertongue with the Menefee Formation to the southwest and thicken toward the main buildup of the La Ventana to the northeast.

22 The La Ventana sandstone lenses are characterized by sharp, generally planar to slightly undulatory upper and lower contacts with the brown humic shales or coals of the upper Menefee. Load deformational structures and some reworked clasts of Menefee lithology are found along the lower contacts of these lenses. Internally, horizontal to very low angle, planar cross-stratification may also be present. Ironoxide-stained, knobby-walled *Ophiomorpha* trace fossils are sparse to very abundant and a key indicator of marine conditions for the La Ventana sands. The quartzose sands composing the La Ventana units are tan to light gray, fine to very fine grained, and moderately well sorted.

23 CLIFF HOUSE SANDSTONE, MAIN BODY—The main body of the Cliff House Sandstone in this area was originally named the Chacra Sandstone by Dane (1936) for Chacra Mesa, which it caps, extending westward from T. 18 N., R. 4 W. The name Chacra was dropped by Beaumont, Dane, and Sears (1956) in favor of the name Cliff House, when more work showed the continuity of this sandstone around the San Juan Basin. The name Chacra Tongue has been informally used for the portion of the Cliff House that caps Chacra Mesa (Shomaker and others, 1971; Beaumont and Shomaker, 1974; Beaumont and others, 1976; and Shomaker and Stone, 1976). We prefer to use the term Cliff House until further work and formal naming clearly warrant the use of a different name.

24 Dane (1936) measured 310 ft of Cliff House Sandstone on Chacra Mesa in T. 18 N., R. 4 W. This thick, cliff-forming unit undergoes radical changes just a short distance to the northeast. Surface exposures show a rapid seaward (northeast) thinning of the Cliff House and a significant increase in intertonguing with the marine Lewis Shale. Within the space of 3 mi, from Chacra Mesa northeastward to near the Torreon Trading Post, the Cliff House changes from a 310-ft-thick sandstone to an interval composed of upper marine sandstone approximately 45 ft thick, a medial tongue of Lewis Shale roughly 165 ft thick, and a lower marine sandstone up to 25 ft thick.

25 The quartzose sands of the Cliff House are tan to light gray, very fine grained, well cemented with occasional carbonaceous shale laminae. Sorting in these sands is generally poor to fair. Hollenshead and Pritchard (1961) list an average petrographic description from Cliff House core samples taken from 19 wells scattered across the San Juan Basin: quartz, 60 percent; feldspar, 10 percent; rock fragments, 5 percent; clay, 5 percent; and calcareous cement, 15 percent.

Lewis Shale

26 Marine Lewis Shale overlies the uppermost La Ventana sandstone tongue in the northeast part of the Torreon area and interfingers with the main Cliff House Sandstone in the northwest. Good exposures of the Lewis Shale are sparse and it was not studied in great detail. The Lewis generally consists of gray to olive-gray, silty shale with common thin interbeds of silty sandstone. A persistent fossiliferous, thin, calcareous, silty sandstone occurs about 40 ft above the uppermost La Ventana sand in T. 18 N., R. 3 W. The Lewis contains numerous gastropods, bivalves, and ammonites, including *Placenticeras intercalare.* Thickness varies considerably over the area and generally thickens to the north and east from the Chacra Mesa area.

Tertiary igneous rocks

27 Tertiary igneous rocks related to the Mount Taylor volcanic center intrude and overlie the Upper Cretaceous rocks of the Torreon Wash area. A series of thick columnar-jointed basaltic flows caps Mesa Chivato in the south. Abundant basaltic rubble forms talus along the northern slopes of the mesa, obscuring the underlying Cretaceous rocks. Erosion has exposed several basaltic necks or plugs (such as Bear's Mouth and Cerro Parido) around the northern end of Mesa Chivato. Some smaller plugs are associated with north-south- trending dikes in the southwestern part of the area in T. 16 N., R. 5 W. A series of en echelon dikes extends from T. 16 N., R. 5 W. through T. 17 N., R. 4 W., and into T. 18 N., R. 5 W. to the edge of Chacra Mesa. The dikes are generally 1 ft thick or less, yet can be traced along strike over a considerable horizontal distance. These igneous rocks have had little or no metamorphic effect on the enclosing strata.

GEOLOGIC STRUCTURE

28 The structure of the Torreon Wash area is basically a gentle northwest-dipping block. The regional orientation of the strata has a northeasterly strike and a dip of 4-5 degrees to the northwest. Dips greater than 5 degrees are generally the result of primary depositional slopes or disturbances along faults. Complicating the general picture of the northwest-dipping block are a series of northeast-trending normal faults, usually with the east side of the fault raised relative to the west side. These faults have relatively small amounts of displacement, generally only a few tens of feet, with a maximum displacement of 150

ft along the more predominant faults. Often the amount of displacement is dispersed northward along the faults as they splay into several lesser strands. Faulting is most prominently displayed along the Point Lookout escarpment across the southern part of the Torreon Wash area. The successive stepwise rise of the fault blocks to the east is probably related to the sharp uplift of the eastern edge of the San Juan Basin along the Nacimiento front.

29 Basaltic dikes in the area also reflect the same northeast-trending fracture pattern. An en echelon series of thin dikes occurs along a discontinuous line 11 mi long from Coal Spring in sec. 15, T. 16 N., R. 5 W. northeast to the east edge of Chacra Mesa in sec. 29, T. 18 N., R. 4 W.

30 Folding in the area is relatively minor. A structure contour map on the top of the Point Lookout Sandstone shows a small domal structure in the southeastern part of T. 18 N., R. 3 W. This dome extends off a gentle north-plunging anticlinal flexure in T. 17 N., R. 3 W. Another gentle north-plunging anticlinal flexure occurs in T. 16 N., R. 5 W. Small amounts of folding also occur within 100 ft of some faults as a result of drag along the fault surface.

COAL GEOLOGY

Description of surface exposures

31 T. 16 N., R. 4 W.—The Mancos Shale crops out in the central and eastern parts of this township. The Hosta and Point Lookout Sandstones cap the mesas in the eastern half of the township. The Cleary Member of the Menefee Formation crops out in the low-lying area in secs. 4–8, 17–20, and 30. Exposures of the coal beds in the Cleary are good throughout this area. These beds range in thickness from 1 to 4 ft, with an average of 2.5 ft. Parallel faults roughly spaced ⅓ mi apart splay from the south, disrupting this area. Coal in secs. 28, 29, and 31–34 of the township occurs on the steep slopes of Mesa Chivato. These slopes are formed by the Cleary and Allison Members of the Menefee Formation and a thick basaltic flow at the top. Volcanic debris from the flow capping the mesa covers much of these slopes, leaving poor to fair exposures of the Cleary coal beds. Continuity of these beds is fair, with an average thickness of 2 ft.

32 T. 16 N., R. 5 W.—This township has good exposures of the Cleary Member throughout. In secs. 1–12 the coal beds are well exposed and show an average thickness of 2.8 ft. Secs. 13–20 are underlain by coal with only a few outcrops exposing the coal beds for short distances. The upper portion of the Cleary Member is exposed in secs. 21–25. Exposures of the barren Allison Member of the Menefee Formation crop out along the highest slopes in secs. 26–36.

33 T. 17 N., R. 3 W.—A north-facing dip slope of the Point Lookout Sandstone crosses the southern part of this township. Coals of the Cleary Member crop out in a roughly east-west belt to the north. Two coal zones are traceable across the township approximately 0 and 70 ft above the Point Lookout Sandstone. The lower of these zones contains good coal beds that are persistent but show a high degree of lenticularity; these lower coals average 2.5 ft in thickness. The higher zone has beds averaging 2 ft in thickness. The northern two thirds of this township are covered by the Allison Member; no coals occur there.

34 T. 17 N., R. 4 W.—No coals exist in the Allison Member, which crops out in most of this township. This member consists of thick-bedded, light-colored sandstones and interbedded siltstones and shales forming north-dipping cuestas and mesas. The massive basal sand sequence creates a rugged terrain in the southern part of the township. The southeastern quarter of this township, however, has good to excellent coal exposures of the Cleary Member. In secs. 22–27 and 34–36 the coal beds are continuous, with a variation in thickness from 1.5 to 3.5 ft. Three separate beds crop out in these sections. A small amount of burned coal occurs in secs. 27 and 34. In sec. 34 the Tochias coal mine operated on two 2-ft beds from 1933 to 1935. The northern half of this township has no coal exposures except in secs. 3 and 4. In these two sections the upper unnamed member of the Menefee Formation begins to crop out. The coals are continuous with an average thickness of 1.7 ft

35 T. 18 N., R. 3 W.—The La Ventana sandstone, Cliff House Sandstone, and the Lewis Shale crop out in the northern half of this township. Tracing and correlating these units is difficult because of the lenticularity of the sandstones and the presence of faults. Good exposures of six coal beds of the upper unnamed member of the Menefee Formation occur in the southern half of the township. The beds are continuous throughout the southern half of the township and range in thickness from 1.3 to 3.6 ft. Some burned coal occurs in secs. 11–15, 19–26, 29, 30, 35 and 36.

36 T. 18 N., R. 4 W.—Exposures of the La Ventana sandstone, Lewis Shale, and Cliff House Sandstone cover the northern half of this township. They form a series of gently north dipping mesas. The upper unnamed member of the Menefee Formation occurs in the southern half of this township. Coal occurs in four horizons within this unit in T. 18 N., R. 4 W. Persistent burned coal horizons mask much of the outcrops in this area, making coal thicknesses unobtainable. Good exposures of coal are found in the southern part of this township. Visible coal beds range in thickness from 1.2 to 1.9 ft and are quite continuous.

Coal analyses

37 The analyses given in this report (table 1) are from core samples and drill cuttings. Moisture ranges from 4.64 to 13.66 percent with 11.74 percent being the average. The rank of the coal based on heating value is subbituminous C to subbituminous B. The range of heating value for these coals is 7,405–11,828 Btu per pound,

with an average near 10,360 Btu per pound. Table 2 lists the locations of all drill holes on table 1 and on the map.

38 The ash content is present as discrete partings or material intimately mingled with the coal itself. The samples contain 3.2–33.8 percent ash, averaging 14.6 percent. Sulfur content ranges between 0.42 and 2.47 percent, averaging about 0.8. Volatile matter ranges between 28.7 and 38.2 percent, averaging 34.7; fixed carbon ranges between 30.6 and 48.2 pecent, averaging 41.0.

Coal prospects and mines

39 One small prospect occurs in NW¼NW¼ sec. 34, T. 17 N., R. 4 W. This prospect was operated by Rudolf Tochias from 1933 to 1935 under federal coal-prospecting permit SF-065988. USGS Conservation Division records show that Mr. Tochias sold 88 tons of coal from the prospect.

40 The underground workings consist of two parallel tunnels with a joining crosscut. Both tunnels are badly caved, and no attempt was made to enter them. An inspection report of the USGS Mining Division made in 1935 states that the prospect workings were dry and flat.

41 T. 16 N., R. 5 W. and the western third of T. 16 N., R. 4 W. of the study area were recently nominated by Arizona Public Service Company in response to a U.S. Bureau of Land Management request for company nominations of tracts of interest for leasing. This request was made to assess the suitability and impact of leasing federal coal lands in preparation for the establishment of a federal coal-leasing policy.

42 In January 1978, a permit to surface-mine coal was granted by the New Mexico Coal Surface Mining Commission to Mr. Albert J. Firchau of Seattle, Washington, for an area 2 mi east of the study area in N½ sec. 16, T. 17 N., R. 2 W. The proposed Arroyo #1 mine would have extracted coal from the Cleary Member of the Menefee Formation or the first coal interval overlying the Point Lookout Sandstone. The mine plan called for an annual production of 200,000 tons for six years. The permit was cancelled when the required bond was not posted.

43 West of the study area, in T. 16 N., R. 6 W., the Santa Fe Railroad conducted an exploration drilling program in 1972–73 to test reserves on their holdings. The coal interval drilled was the lower Menefee Formation. No plans for the development of this coal have been announced.

Coal resources

44 The coal resources calculated for the Torreon area are based on field measurement of coal outcrops and drill-hole information. All resources are calculated for coal beds 14 inches (1.2 ft) or greater in thickness. An acre-foot of coal was assumed to weigh 1,770 tons. Guidelines modified from those set forth in USGS Bulletin 1450–B are used (U.S. Bureau of Mines and U.S. Geological Survey, 1976); measured resources are not identified. Because of the extreme lenticularity of the coal beds, the data-point spacing is insufficient for precise quantitative determination of measured resources. The resources calculated fall into two classes, indicated and inferred.

45 Indicated resources are based on the following criteria:

> The points of observation are ½ mi (0.8 km) to 1½ mi (2.4 km) apart or closer. Indicated resources are projected to extend as a ½ mi (0.8 km) wide belt from the outcrop or in a ¼ mi radius around a drill hole.

46 Inferred resources are based on the following criteria:

> The points of observation are 1½ mi (2.4 km) to 6 mi (9.6 km) apart. Inferred resources are projected to extend as a 2¼ mi (3.6 km) wide belt that lies more than ½ mi (0.8 km) from the outcrop or ¼ mi from a drill hole.

47 The resources are further divided into two depth categories: shallow, from 0 ft to 250 ft; and deep, from 250 ft to 3,000 ft (coal deeper than 3,000 ft does not occur in study area). Using these criteria, the study area contains 115,590,257 tons of indicated resources and 389,566,363 tons of inferred resources within 250 ft of the surface. The shallow indicated resources are listed by section and township in table 3. The 250–3,000–ft class contains 200,955,000 tons of indicated resources and 712,477,000 tons of inferred resources.

REFERENCES

Beaumont, E. C., Dane, C. H., and Sears, J. D., 1956, Revised nomenclature of Mesaverde Group in San Juan Basin: American Association of Petroleum Geologists, Bull., v. 40, p. 2149–2162

Beaumont, E. C., and Shomaker, J. W., 1974, Upper Cretaceous coal in the Cuba–La Ventana–Torreon area, eastern San Juan Basin, New Mexico: New Mexico Geological Society, Guidebook 25th field conference, p. 329–345

Beaumont, E. C., Shomaker, J. W., and Stone, W. J., eds., 1976, Guidebook to coal geology of northwest New Mexico: New Mexico Bureau of Mines and Mineral Resources, Circ. 154, 58 p.

Dane, C. H. 1936, The La Ventana–Chacra Mesa coal field: U.S. Geological Survey, Bull. 860–C, p. 81–161

Dutton, C. E., 1885, Mount Taylor and the Zuni Plateau: U.S. Geological Survey, 6th Annual Rept., 1884–85, p. 105–198

Gardner, J. H., 1909, The coal field between Gallina and Raton Springs, New Mexico: U.S. Geological Survey, Bull. 341–C, p. 335–351

——, 1910, The coal field between San Mateo and Cuba, New Mexico: U.S. Geological Survey, Bull. 381–C, p. 461–473

Hollenshead, C. T., and Pritchard, R. L., 1961, Geometry of producing Mesaverde sandstones, San Juan Basin, *in* Geometry of sandstone bodies, J. A. Peterson and J. C. Osmond, eds.: American Association of Petroleum Geologists, Symposium, p. 98–118

Hunt, C. B., 1936, The Mount Taylor coal field: U.S. Geological Survey, Bull. 860–B, p. 31–80

Mannhard, G. W., 1976, Stratigraphy, sedimentology and paleoenvironments of the La Ventana Tongue (Cliff House Sandstone) and adjacent formations of the Mesaverde Group (Upper Cretaceous), southeastern San Juan Basin, New Mexico: Ph.D. thesis, University of New Mexico, 182 p.

Sabins, F. F., Jr., 1964, Symmetry, stratigraphy, and petrography of cyclic Cretaceous deposits in the San Juan Basin: American Association of Petroleum Geologists, Bull., v. 48, no. 3, p. 292–316

Schrader, F. C., 1906, The Durango–Gallup coal field of Colorado and New Mexico: U.S. Geological Survey, Bull. 285–F, p. 241–258

Shetiwy, M. M., 1978, Sedimentologic and stratigraphic analysis of the Point Lookout Sandstone, southeast San Juan Basin, New Mexico: Ph.D. thesis, New Mexico Institute of Mining and Technology, 262 p.

Shomaker, J. W., Beaumont, E. C., and Kottlowski, F. E., eds., 1971, Strippable low-sulfur coal resources of the San Juan Basin in New Mexico and Colorado: New Mexico Bureau of Mines and Mineral Resources, Mem. 25, 189 p.

Shomaker, J. W., and Stone, W.J., 1976, Availability of ground water for coal development in San Juan Basin, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Circ. 154, p. 43–48

Shomaker, J. W., and Whyte, M. R., 1977, Geologic appraisal of deep coals, San Juan Basin, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Circ. 155, 39 p.

U.S. Bureau of Mines and U.S. Geological Survey, 1976, Coal resource classification system of the U.S. Bureau of Mines and U.S. Geological Survey: U.S. Geological Survey, Bull. 1450–B, 7 p.

TABLE 2—LOCATION OF DRILL HOLES.

Drill site	Section	Township	Range	Ground level (ft)
C5	SE¼NW¼NW¼ sec. 5	16 N.	4 W.	6,110
R23	NW¼SW¼SW¼ sec. 6	16 N.	4 W.	6,230
R21	SE¼SE¼SE¼ sec. 18	16 N.	4 W.	6,415
R24	SW¼SE¼NE¼ sec. 2	16. N.	5 W	6,305
C6	NE¼NE¼NW¼ sec. 17	16 N.	5 W.	6,390
R12	NW¼NW¼NE¼ sec. 21	16 N.	5 W.	6,510
R13	SW¼NW¼NW¼ sec. 26	16 N.	5 W.	6,630
R11	SE¼NE¼NW¼ sec 29	16 N.	5 W.	6,530
R43	NE¼SW¼NW¼ sec. 4	17 N.	3 W.	6,465
R41	NW¼SE¼SW¼ sec. 13	17 N.	3 W.	6,480
R42	SW¼SE¼NW¼ sec. 17	17 N.	3 W.	6,235
C3	NW¼SE¼NE¼ sec. 29	17 N.	3 W.	6,390
R33	SW¼SW¼NW¼ sec. 31	17 N.	3 W.	6,325
R32	NE¼NW¼SE¼ sec. 23	17 N.	4 W.	6,170
C4	NW¼SE¼NW¼ sec. 27	17 N.	4 W.	6,240
R31	SW¼SW¼SW¼ sec. 29	17 N.	4 W.	6,280
R63	NW¼NE¼SW¼ sec. 4	18 N.	3 W.	6,560
R62	SE¼NW¼NE¼ sec. 11	18 N.	3 W.	6,730
C1	NW¼NW¼SW¼ sec. 20	18 N.	3 W.	6,530
R61	NW¼SW¼SE¼ sec. 21	18 N.	3 W.	6,650
R52	SE¼NW¼SW¼ sec. 11	18 N.	4 W.	6,400
C2	NW¼SE¼NE¼ sec. 18	18 N.	4 W.	6,620
R53	SE¼NE¼NE¼ sec. 28	18 N.	4 W.	6,440
R51	NE¼NW¼NE¼ sec. 32	18 N.	4 W.	6,460

TABLE 1—COAL ANALYSES (as received); drill holes are marked on maps; exact locations listed in table 2.

		Proximate				Ultimate						
Drill hole	**Depth of sample (ft)**	**Moisture**	**Ash**	**Volatile matter**	**Fixed carbon**	**H**	**C**	**N**	**O**	**S**	**Ash**	**Btu/lb**
C1	46–49, 54–55	11.31	8.09	38.25	42.35	4.53	61.99	1.45	11.98	0.65	8.09	11,030
C1	57–60, 60–61	11.46	16.00	34.61	37.93	3.76	55.56	1.16	9.59	2.47	16.00	9,858
C1	67–67	10.42	24.42	32.23	32.93	3.52	49.41	1.09	8.96	2.18	24.42	8,596
C1	154–158	11.12	6.21	36.81	45.86	4.44	65.17	1.36	11.20	0.50	6.21	11,357
C1	158–164	13.66	3.17	36.63	46.54	4.32	66.75	1.41	10.25	0.44	3.17	11,542
C1	164–168	12.27	4.90	36.52	46.31	3.75	65.68	1.39	11.58	0.43	4.90	11,423
C2	117–118, 119–121	11.35	16.49	35.34	36.82	4.04	57.22	1.35	8.81	0.74	16.49	9,783
C3	221–224	6.72	8.68	36.38	48.22	4.66	67.43	1.33	10.49	0.69	8.68	11,828
C4	171–175	9.55	9.84	35.03	45.58	4.44	64.63	1.36	9.75	0.43	9.84	11,270
C5	14–18	7.52	31.33	29.38	31.77	3.71	44.58	1.04	20.15	0.42	31.33	7,405
C5	97–99	6.90	33.80	28.71	30.59	4.09	46.63	1.06	14.51	0.47	33.80	8,244
C5	123–127	7.89	11.46	35.17	45.48	5.26	63.81	1.13	17.70	0.64	11.46	11,412
R33	80–85	4.64	15.91	36.55	42.90	4.91	62.44	1.32	14.75	0.78	15.91	10,927

Abbreviations:

C1—Core hole #1
R33—Rotary hole #33
N—Nitrogen
O—Oxygen
S—Sulfur
H—Hyrdrogen
C—Carbon

TABLE 3—Shallow indicated resources; see paragraph 45 for definition.

T.16 N., R.4W.

Sec.	Tons	Sec.	Tons
1	0	19	1,470,836
2	0	20	230,602
3	1,797,683	21	19,505
4	1,219,043	22	0
5	1,997,171	23	0
6	1,819,304	24	0
7	249,498	25	0
8	0	26	0
9	0	27	76,393
10	0	28	780,305
11	0	29	910,219
12	0	30	1,180,135
13	0	31	0
14	0	32	0
15	0	33	0
16	0	34	3,845,675
17	1,061,211	35	0
18	605,988	36	0

Total: 17,263,568 tons

T.16 N., R.5 W.

Sec.	Tons	Sec.	Tons
1	1,565,265	19	1,397,836
2	1,815,244	20	1,300,313
3	1,243,422	21	2,113,009
4	1,917,972	22	1,343,430
5	0	23	598,970
6	0	24	143,009
7	0	25	292,570
8	915,696	26	449,421
9	1,292,192	27	1,412,465
10	219,428	28	0
11	5,284,038	29	0
12	889,078	30	0
13	1,170,282	31	0
14	1,976,653	32	1,183,285
15	1,914,839	33	0
16	1,599,488	34	0
17	1,759,575	35	0
18	617,649	36	0

Total: 34,415,129 tons

T.17 N., R.3 W.

Sec.	Tons	Sec.	Tons
1	0	19	0
2	0	20	24,381
3	0	21	195,047
4	0	22	1,344,225
5	0	23	1,111,768
6	0	24	2,015,435
7	0	25	0
8	0	26	113,776
9	0	27	2,045,572
10	0	28	832,343
11	0	29	1,547,263
12	0	30	162,486
13	715,172	31	3,445,689
14	71,517	32	1,472,386
15	0	33	637,168
16	0	34	165,789
17	214,552	35	195,047
18	97,523	36	48,762

Total: 16,455,901 tons

T.17 N., R.4 W.

Sec.	Tons	Sec.	Tons
1	0	19	0
2	0	20	0
3	0	21	0
4	0	22	0
5	0	23	1,887,079
6	0	24	1,048,337
7	0	25	731,578
8	0	26	580,265
9	0	27	2,629,694
10	0	28	0
11	0	29	0
12	0	20	0
13	0	31	0
14	0	32	0
15	0	33	0
16	0	34	0
17	0	35	1,799,028
18	0	36	4,021,286

Total: 12,697,267 tons

T.18 N., R.3 W.

Sec.	Tons	Sec.	Tons
1	0	19	4,557,154
2	534,246	20	6,712,769
3	0	21	5,639,908
4	1,782,936	22	47,121
5	0	23	432,354
6	0	24	58,495
7	0	25	250,310
8	0	26	0
9	0	27	357,586
10	0	28	1,078,220
11	1,177,209	29	1,062,995
12	19,498	30	105,645
13	0	31	29,247
14	1,441,789	32	19,505
15	1,084,136	33	38,996
16	0	34	0
17	0	35	0
18	2,145,537	36	175,542

Total: 28,751,198 tons

T.18 N., R.4 W.

Sec.	Tons	Sec.	Tons
1	0	19	0
2	0	20	19,505
3	0	21	434,856
4	0	22	591,143
5	0	23	65,016
6	0	24	0
7	260,063	25	0
8	0	26	117,028
9	0	27	928,226
10	0	28	929,101
11	0	29	377,606
12	0	30	0
13	0	31	0
14	0	32	755,211
15	24,381	33	0
16	0	34	0
17	232,090	35	414,475
18	574,050	36	284,443

Total: 6,007,194 tons