Geology of Pueblo Viejo Mesa quadrangle, Socorro and Cibola Counties, New Mexico

by JoAnne Cima Osburn, 1984

INTRODUCTION

Pueblo Viejo Mesa quadrangle is located approximately 30 mi northwest of Magdalena, New Mexico, in northwest Socorro and southeast Cibola Counties (Fig. 1). Access is by NM–52 from the south and the unpaved Acoma–Sky City road from the north. Dirt roads and tracks are present throughout the area.

The study area lies in the Datil–Mogollon subprovince, a transition zone between the Basin and Range province and the Colorado Plateau province (Hawley and Love, 1981). The landscape of Pueblo Viejo Mesa quadrangle is dominated by basalt-capped mesas and broad alluvial valleys. Upper Cretaceous rocks that crop out as small sandstone-capped hills in flat areas and as gentle cliffs on the slopes of basalt-capped mesas are commonly buried by talus or piedmont deposits throughout the study area. The entire Upper Cretaceous sequence is exposed within a broad, southward-plunging anticline in Pueblo Viejo Mesa quadrangle.

Published reports on the area date back to 1900 when Herrick published a reconnaissance map and report with measured sections of western Socorro and (then) Valencia Counties. The oil and gas potential of the area was examined in reports by Wells (1919) and Winchester (1921). Winchester extensively examined the coal-bearing Cretaceous rocks in the upper Rio Salado drainage basin and measured numerous sections in the Datil Mountains during 1913 and 1914.

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STRUCTURE

Folding and faulting affect all but the youngest rocks in the area. A broad-scale anticline/syncline pair is a prominent feature in the quadrangle. The axes of these structures trend north to northeast and plunge to the south. Folds affecting the Cretaceous rocks in the Datil Mountains have been interpreted as being related exclusively to Laramide compressional tectonics in central New Mexico (Robinson, 1981; Mayerson, 1979). However, some of these folds warp both Cretaceous and Tertiary rocks and hence, are post-Cretaceous features. Recent work (Osburn and Laroche, 1981) approximately 15 mi to the south of Pueblo Viejo Mesa quadrangle in the Lion Mountain area revealed broad-scale folds with similar trends in the Oligocene volcanic section. This work suggests that all folding in the area is not necessarily associated with the Laramide uplift.

A major fault in the southeast part of the quadrangle abuts the Twowells Tongue of the Dakota Sandstone against the Crevasse Canyon Formation, a minimum displacement of 700 ft (213 m). However, most faults in Pueblo Viejo Mesa quadrangle are normal faults with displacements of less than 100 ft (30 m).

STRATIGRAPHY

Chinle Formation –$\mathcal{T}_{\mathrm{RC}}$

The oldest rocks exposed in the Pueblo Viejo Mesa quadrangle are assigned to the Chinle Formation (Triassic). The unit is a slope former and is usually talus covered except in stream cuts. The best exposures of the Chinle Formation in the Datil Mountains are located east of Pueblo Viejo Mesa quadrangle along the Rio Salado. The Chinle is easily recognized in the field and on aerial photographs by its characteristic red color and the resistant Dakota Sandstone caprock that lies unconformably above it.

The Chinle Formation consists of red, purple, and gray mudstones, siltstones, and claystones with lesser amounts of lenticular, conglomeratic, crossbedded sandstones. Only the upper 30–50 ft (9–15 m) of the Chinle Formation is exposed in Pueblo Viejo Mesa quadrangle. Tonking (1957) divided the Chinle into lower and upper units that reach thicknesses of 300 ft and 800 ft (91 m and 243 m) respectively, in exposures approximately 7 mi east of Pueblo Viejo Mesa quadrangle. Cross sections included in this report were prepared using a maximum thickness of 1,900 ft (579 m) based on two petroleum test wells drilled just north of Pueblo Viejo Mesa quadrangle.

A floodplain environment is indicated for the Chinle by the predominance of fine-grained sediments. Lentils of conglomerate and discontinuous, crossbedded sandstones suggest channel deposits of streams that were flowing on the floodplain in Triassic time.

Approximately 1,900 ft (579 m) of Upper Cretaceous rocks crop out in Pueblo Viejo Mesa quadrangle. These rocks represent open marine, paralic, and continental-fluvial paleoenvironments. Five formations are represented: the Dakota Sandstone, Mancos Shale, Tres Hermanos Formation, Gallup Sandstone, and Crevasse Canyon Formation, in ascending order. These units, with the exception of the Tres Hermanos Formation, have been described in other New Mexico basins, including the San Juan Basin and Zuni Basin, and have been extended into the Datil Mountains area. Recent work in west-central New Mexico by members of the U.S. Geological Survey and the New Mexico Bureau of Mines and Mineral Resources has resulted in extensive revision of the lithostratigraphic nomenclature used in this area (Landis and others, 1973; Hook and others, 1980; Hook and others, 1983).

Dakota Sandstone

The Dakota Sandstone lies unconformably on the Chinle Formation. Three units are recognized on Pueblo Viejo Mesa quadrangle: the lower part of the Dakota Sandstone *(Kdl),* the Paguate Tongue *(Kdp),* and the Twowells Tongue *(Kdt).*

The lower part of the Dakota Sandstone exposed in the area is generally an upward-fining sequence of resistant, fine to very fine grained, well-sorted quartzose sandstone containing conglomeratic lenses at the base and intercalated shales in the uppermost part. In the best exposures in Pueblo Viejo Mesa quadrangle, the lower part of the Dakota is composed of 8-cm-thick, bioturbated beds with vertical burrows 1 cm in diameter alternating with 8 cm-thick structureless beds. Many thin horizontal burrows are present on bedding planes between the bioturbated beds and the burrowed beds. The base of the Dakota Sandstone is typically erosional and is made up of a weathered gravel of well-rounded quartzite, chert pebbles, and siltstone chips derived from the top of the Chinle Formation. This lag gravel is best exposed in outcrops on the east side of Tres Hermanos Mesa. The contact of the lower part of the Dakota Sandstone with the overlying Mancos Shale is gradational and is placed where thin shales first appear intercalated with a slightly fining-upward sand sequence typical of the Dakota.

The Paguate Tongue forms a dip slope in the northernmost portion of Pueblo Viejo Mesa quadrangle on the west side of Victorino Mesa. This outcrop appears to be the southeast limit of the Paguate in the Datil Mountains. The unit consists of a yellowish-brown, fine-grained, slightly upward-coarsening argillaceous sandstone with intense bioturbation and minor cross-stratification. The Paguate Tongue reaches a maximum thickness of 30 ft (9 m) in Pueblo Viejo Mesa quadrangle. The Paguate Tongue of the Dakota Sandstone lies stratigraphically between two open-water marine tongues of the Mancos Shale and appears to represent an offshore-bar complex.

The Twowells Tongue of the Dakota Sandstone is a 10–20 ft (3–6 m) thick, medium-gray to yellowish-brown, fine to very fine grained sandstone occurring between the lower part of the Mancos and the Rio Salado Tongue of the Mancos Shale. The unit is well exposed in Pueblo Viejo Mesa and Table Mountain quadrangles, but pinches out to the southeast in Indian Spring Canyon quadrangle. The Twowells contact with the underlying lower part of the Mancos Shale is gradational and is mapped where the grain size becomes consistently very fine grained sandstone and where mudstone partings become rare. The Twowells typically contains abundant planar laminations and small-scale, low-angle cross-stratification near the top of the unit. Ripples and small impact marks are present at the top of the Twowells. The upper contact of the Twowells with the Rio Salado Tongue of the Mancos Shale is usually covered but appears conformable and sharp in sec. 5, T. 4 N., R. 7 W.

Mancos Shale

The Mancos Shale is split into multiple tongues in the San Juan, Zuni, and Acoma Basins in New Mexico. Recent workers have identified faunal marker beds in the Mancos tongues that serve as useful stratigraphic correlation tools (Hook and others, 1978, 1979, 1980, 1983; Molenaar, 1974; Landis and others, 1973).

Three Mancos units were mapped in Pueblo Viejo Mesa quadrangle: in ascending order, the lower part of the Mancos *(Kml)* between the lower part of the Dakota and the Paguate Tongue of the Dakota (or the Twowells Tongue of the Dakota if the Paguate is absent); the Rio Salado Tongue *(Kmr)* between the Twowells Tongue of the Dakota and the Tres Hermanos Formation; and the D-Cross Tongue *(Kmd)* between the Tres Hermanos Formation and the Gallup Sandstone. In addition, the Whitewater Arroyo Tongue (Hook and Cobban, 1978) is also present between the Paguate Tongue and the Twowells Tongue where the Paguate is present but does not crop out in Pueblo Viejo Mesa quadrangle because of thick talus cover and erosion.

In this report, the lower part of the Mancos consists of a series of medium- to dark-gray shales and thin, silty sandstones between the lower part of the Dakota and the next stratigraphically higher tongue of the Dakota present at a given location. At most places in the study area, the lower part of the Mancos grades up into the Twowells Tongue of the Dakota. In the extreme northern part of the study area, the lower part of the Mancos Shale grades vertically into the Paguate Tongue of the Dakota Sandstone. Thickness of the lower part of the Mancos Shale thus ranges from 70 to 280 ft (21 to 85 m), depending on local presence of the Paguate Tongue of the Dakota Sandstone.

The lower part of the Mancos Shale exposed in Pueblo Viejo Mesa quadrangle was deposited in a low-energy environment as an offshore-shelf mud. Thin, silty sandstones present throughout the lower part of the Mancos probably represent storm sedimentation. The offshore-mud sequence of the lower part of the Mancos Shale grades vertically into lower shoreface sandstones that comprise the Twowells or Paguate Tongues of the Dakota Sandstone.

The Rio Salado Tongue of the Mancos Shale consists of shales that conformably separate the Twowells Tongue of the Dakota Sandstone from the Atarque Sandstone Member of the Tres Hermanos Formation (Hook and others, 1983). The Rio Salado Tongue is named for exposures along the Rio Salado near Puertecito on the Alamo Indian Reservation, southeast of Pueblo Viejo Mesa quadrangle. The Rio Salado Tongue is typically a medium- to brownish-gray, silty mudstone that can be conveniently split into a calcareous lower part, ranging from 140 to 160 ft (42 to 49 m), and a noncalcareous upper part from 70 to 110 ft (21 to 34 m) thick. The lower part of the Rio Salado is a medium-gray mudstone containing brownish-gray nodular limestones that have been identified as the Bridge Creek Limestone beds (Hook and others, 1983). Within a few feet above the basal contact with the Twowells, the Rio Salado contains *Sciponoceras gracile,* a standard zone ammonite of the Cretaceous of the Western Interior (Cobban and Scott, 1972). An oyster, *Pycnodonte newberryi* (Stanton), also occurs in the *S. gracile* zone, and serves as a marker fossil because it is confined to light-gray, calcareous shales and limestones in the basal Rio Salado Tongue. In addition, the ammonite *Mammites depressus* has been found in the lower Rio Salado (Cobban and Hook, 1979). The upper part of the Rio Salado Tongue is a noncalcareous, brownish-gray mudstone in Pueblo V ejo Mesa quadrangle. Ammonites collected in Pueblo Viejo Mesa quadrangle include *Collignoniceras woollgari woollgari* (Mantell) and *Tragodesmoceras socorroense* Cobban and Hook (Cobban and Hook, 1979). The color change from medium gray to brownish gray is often coincident with the change from calcareous to noncalcareous mudstones, although sometimes the color change occurs stratigraphically below the change in carbonate content. Crystals of secondary gypsum are common throughout the unit.

The D-Cross Tongue of the Mancos Shale was defined by Dane and others (1957) as the shale body between the lower part of the Gallup Sandstone and the Gallego Sandstone (now recognized as Tres Hermanos Formation and Gallup Sandstone, respectively). The type locality is at D Cross Mountain, approximately 5 mi west of Pueblo Viejo Mesa quadrangle. The D-Cross Tongue is Late Turonian in age (Hook and Cobban, 1979). Hook and Cobban collected the same fossils in the lower part of the D-Cross Tongue as those present in the Juana Lopez Member of the Mancos Shale in the San Juan Basin. Hence, they consider the lower part of the D-Cross Tongue and the Juana Lopez Member to be time-equivalents.

The D-Cross Tongue is a slope-forming unit ranging from 78 to 133 ft (24 to 41 m) in thickness on Pueblo Viejo Mesa quadrangle. The D-Cross can be conveniently divided into lower and upper parts. The lower part is a medium-gray, bioturbated, slightly calcareous to noncalcareous, silty shale containing many fossil-bearing concretions. Fossils identified by Robinson (1981) at D Cross Mountain and by Hook and Cobban (1979) at Puertecito in the lower part of the D-Cross include *Prionocyclus novimexicanus, Scaphites ferronenis, Coilopoceras inflatum,* and *Schaphites whitfieldi.* The upper part of the D-Cross is generally more silty than the lower part. In addition, several sandstone beds less than one foot thick are present in the upper part of the D-Cross. At least one of these sandstone beds appears to be mappable in exposures both in Pueblo Viejo Mesa and Table Mountain quadrangles. Fossils identified from the upper part of the D-Cross at Puertecito include *Lopha sannionis, Prionocyclus novimexicanus,* and *Baculites yokoyami* (Hook and Cobban, 1979). The contact of the D-Cross Tongue with the underlying Fite Ranch Member of the Tres Hermanos Formation is gradational over approximately 15 ft, but is usually masked by alluvium in Pueblo Viejo Mesa quadrangle. The upper contact of the D-Cross with the overlying Gallup Sandstone is also gradational. Following the convention of Robinson (1981), the base of the Gallup Sandstone is placed at the base of the first sandstone bed thicker than one foot.

Robinson (1981) assumed a shallow, nearshore, transition zone between shoreface sands and clean offshore muds for the environment of deposition of the D-Cross Tongue. Evidence supporting this conclusion includes the silty nature of the shales and the abundance of fossils in the unit.

Tres Hermanos Formation

The name "Tres Hermanos" was first used by Herrick (1900) to describe Cretaceous rocks that crop out east of the intrusive Tres Hermanos Peaks along the Rio Salado on the Alamo Indian Reservation. Since that time, the name has been applied to many different sandstones in the Upper Cretaceous section (Dane and others, 1971; Hook and others, 1983). Hook and others (1983) have redefined the unit and have elevated the Tres Hermanos to formation status. The Tres Hermanos Formation comprises a basal coastal sandstone, a middle paludal to continental sequence, and an upper, coastal-marine sandstone. Hook and others (1983) have defined the limits of tne Tres Hermanos Formation based on their interpretation of Herrick's original descriptions and have defined members corresponding to the aforementioned lithologic breaks. Three members are recognized: in ascending order, the Atarque Sandstone Member *(Kta),* the Carthage Member *(Ktc),* and the Fite Ranch Sandstone Member (Ktf).

The Atarque Sandstone Member consists of 20–70 ft (6–12 m) of yellowish-gray, fine to very fine grained, upward-coarsening, thin- to medium-bedded sandstone. The Atarque found in Pueblo Viejo Mesa quadrangle caps small hills of Rio Salado Shale. Planar bedding is the dominant stratification type in the unit, but locally, low-angle herringbone cross-stratification, ripple laminations, and medium-scale trough crossbeds are present. Locally, shaly beds contain abundant fossil fragments. No formal fossil collections were made in Pueblo Viejo Mesa quadrangle, but Cobban and Hook (1979) have identified the following fossils from outcrops west of Pueblo Viejo Mesa at D Cross Mountain: *Collignoniceras woollgari woollgari, Baculites yokoyami, Proplacenticeras pseudoplacenta,* and *Spathites rioensis*. The Atarque Sandstone Member is interpreted as a regressive-shoreface sand that prograded into the Mancos seaway (Hook and others, 1983).

The Carthage Member is a sequence of paludal shales and thin, calcareous sandstones. Petrified wood and large pelecypods are common on the east side of Tres Hermanos Mesa. Sandstones in the Carthage Member are typically crossbedded and have sharp bases scoured into the underlying mudstones. Thin coals, less than 1.2 ft (37 cm) thick and usually lenticular, are present in the upper part of the member. The Carthage Member probably represents sedimentation on a marshy coastal plain.

The Fite Ranch Sandstone Member consists of 10–50 ft (3–15 m) of fine to very fine grained sandstone in Pueblo Viejo Mesa quadrangle. This sandstone generally coarsens upward, is bioturbated, burrowed, and in some places contains medium-grained, fossiliferous sandstone lenses. The contact between the underlying Carthage Member and the Fite Ranch Sandstone Member is gradational through an interval about 10 ft thick. The contact of the Fite Ranch with the overlying D-Cross Tongue of the Mancos Shale is masked by alluvium in the quadrangle, but appears sharp where exposed. Like the Atarque Sandstone Member, the Fite Ranch Sandstone Member probably represents coastal barrier and shoreface deposits.

Gallup Sandstone – Kg

The Gallup Sandstone in the study area is a cliff-forming, 30–85-ft-(9–26-m-) thick sandstone that conformably overlies the D-Cross Tongue of the Mancos Shale. Winchester (1921) originally named this interval the Gallego Sandstone for exposures in Pueblo Viejo Mesa quadrangle.

The contact of the Gallup with the underlying D-Cross Tongue of the Mancos Shale is gradational and is placed at the base of the first resistant sandstone more than one foot thick in the D-Cross. The sharp Gallup contact with the overlying Crevasse Canyon Formation represents the boundary between the upper shoreface/foreshore sands of the Gallup and the finer grained, lagoonal sediments of the lower part present in the Crevasse Canyon Formation.

The Gallup Sandstone is a generally coarsening upward sequence of fine- to medium-grained sandstones. The lower part of the Gallup contains abundant horizontal laminations, planar crossbeds, and burrow mottling. This lower part of the Gallup represents a transition zone between offshore muds of the D-Cross Tongue and lower shoreface sands found in the lower part of the Gallup. The guide fossil *Lopha sannionis* occurs in abundance in the Gallup in dark-colored, massive, thin, medium-grained sandstone layers within the basal part of the unit. In the middle part of the Gallup, the sandstones are bioturbated and then, higher in the section, intensely burrowed, representing deposition in lower shoreface environments. In contrast, the upper part of the Gallup is characterized by stacked planar crossbeds that are only moderately burrowed, a typical feature of upper shoreface deposits.

Crevasse Canyon Formation – Kcc

Allen and Balk (1954) first used the Crevasse Canyon nomenclature to describe a coal-bearing sequence between the Gallup Sandstone and the Point Lookout Formation on the western flank of the San Juan Basin. Tonking (1957) first extended the terminology into the Datil Mountains area.

The Crevasse Canyon Formation crops out in Pueblo Viejo Mesa quadrangle around the perimeter of the broad anticline that dominates the landscape. On the west side of the quadrangle, the unit is overlain unconformably by Tertiary gravels, while on the east side of the quadrangle, the Crevasse Canyon is covered by Quaternary landslide debris. Isopach maps prepared in the central Datil Mountains area suggest that the unit reaches thicknesses of at least 1,100 ft (335 m) approximately 6 mi (10 km) southeast of Pueblo Viejo Mesa quadrangle (Osburn, 1982b).

The Crevasse Canyon Formation is made up of a sequence of generally fine grained sediments and associated coals. The unit can be effectively divided into three parts: a lower coastal-swamp sequence approximately 400 ft (122 m) thick; a middle coastal-plain sequence approximately 300 ft (91 m) thick; and an upper freshwater-swamp sequence that may be as much as 400 ft (122 m) thick in the quadrangle. Thin channel sandstones occur in the lowest part of the formation and sandstones up to 40 ft thick occur in the highest portion of the formation exposed in the area.

The lowest part of the formation is a coastal-swamp or lagoonal sequence. This part of the formation typically comprises interbedded mudstones, coals, and siltstones, with lesser amounts of slightly calcareous, thin sandstones. The thickest coals that occur in the study area are present in the interval from about 60 to 400 ft (18 to 122 m) above the Gallup Sandstone. This coal zone probably is the stratigraphic equivalent of the Dilco Coal Member (Molenaar, 1973) that is present in the Zuni Basin.

The middle part in the Creavasse Canyon Formation is composed of approximately 300 ft (91 m) of interbedded siltstone and very fine grained sandstones with thin dolomite and limestone layers. Lenticular pods of siltstones and sandstones suggest deposition on a flat coastal plain by an anastomosing stream system. Coals in the middle part reach a maximum thickness of 3 ft and are more lenticular than coals in the lower part of the Crevasse Canyon. Drilling in the central Datil Mountains encountered silty sandstone aquifers capable of producing 10–20 gallons/minute in this part of the Crevasse Canyon Formation (Osburn, 1982 a,b).

The upper part of the Crevasse Canyon Formation, better known from subsurface data than from outcrop data, crops out south of Pueblo Viejo Mesa on the west side of the Table Mountain quadrangle. The upper part has an estimated thickness of 400 ft (122 m) and is largely composed of a series of very fine grained sandstones, siltstones, and mudstones, with thin coals making up about 40% of the upper unit. Coals present in this interval range in thickness from 6 inches to 2 ft (15 to 61 cm). These coals are not as thick, continuous, or numerous as coals present in the lower part of the Crevasse Canyon Formation. Distribution of the coals suggests deposition in isolated, freshwater swamps adjacent to fluvial channels on the upper coastal plain. Palynologic studies of coals from this portion of the Crevasse Canyon Formation show angiosperm pollen and no marine- or brackish-water flora indicators, thus supporting a lack of marine influence during the deposition of the upper interval (Chapin and others, 1979).

Tertiary rocks present in Pueblo Viejo Mesa quadrangle document a time of basaltic volcanism, intrusion of igneous dikes, widespread erosion, and sedimentation. Some of these processes acted simultaneously within short distances as shown by the intertonguing of basalt flows and gravels exposed on the west side of Tres Hermanos Mesa.

Mafic intrusives – Tid

Dikes of mafic igneous rocks appear in Pueblo Viejo Mesa quadrangle. The dikes are typically tabular structures less than 8 ft wide and only a few to a few tens of feet long. Where unaltered, the dikes are sugary textured, aphanitic, olive green to dark gray, and porphyritic.

Basalt flows – Tbf

Pueblo Viejo Mesa quadrangle is included within the boundaries of the Lucero volcanic area. A minimum of three vertically stacked flows are present on Victorino and Tres Hermanos Mesa. These flows are clearly interbedded with Tertiary gravels on Tres Hermanos Mesa and become younger in age to the east based on stratigraphic relationships. Recent work by Scott Baldridge at Los Alamos National Laboratory (personal communication, 1983) dates these flows at 3.3–4 million yrs. B.P. Field examination of these flows shows several features common to all flows present: ropey flow structures, porphyritic textures, oxidized, vesicular tops and brecciated bases of individual flow units. Chemically, these flows are alkalic basalts, ranging from basanites to mugearites (Scott Baldridge, personal communication, 1983). Abundant mantle xenoliths contained in these basalts suggest differentiation of these rocks in mantle magma chambers.

Several features associated with volcanic vents are present in the basalts on Tres Hermanos Mesa. The most interesting of these is a maar on the east side of the mesa. This structure is essentially a large, alluvium-floored depression about 1,000 ft (305 m) across, rimmed with basaltic blocks that dip steeply outward in a radial fashion. This type of volcanic feature is formed when lava encounters the water table while erupting, thus causing an explosive eruption. In addition to the maar, several spatter cones and small shield-type cones mark more quiescent eruptions.

Tertiary piedmont gravels – Tpg

Gravels of Tertiary age cover broad areas west and south of the Crevasse Canyon outcrop belt in Pueblo Viejo Mesa quadrangle. These sediments are made up of clasts of Oligocene volcanic rocks in a silty sand matrix. These gravels are primarily piedmont deposits formed by coalescing alluvial fans formed on the flanks of the Gallinas Mountains. The gravels are of multiple ages and were deposited on a deeply eroded, northward-sloping surface underlain by the Crevasse Canyon Formation of the Rio Grande valley. The oldest gravels are probably equivalent to the Popotosa Formation. Paleocurrent measurements based on pebble imbrications measured on Pueblo Viejo Mesa quadrangle are north in the lowest part of the gravels, indicating transport by water in that direction. This suggests that the gravels were in part being deposited prior to the establishment of the Rio Salado drainage system. In contrast, paleocurrent measurements taken on younger sediments included in this unit clearly indicate drainage southward to the Rio Salado.

Quaternary deposits

Quaternary sediments in the area have been differentiated by both relative age and type of deposit. All deposits with minor or no soil development are classified as young deposits. These deposits include sediments deposited in active stream channels, young valley alluvium, slope wash, wind-blown sands infilling behind slump blocks *(Qvy)*, and undissected piedmont-slope deposits *(Qpy)*. Those alluvial deposits with appreciable soil development, often in the form of soil carbonate, are mapped as older alluvium. These deposits include older valley alluvium *(Qvo)* and dissected piedmont deposits *(Qpo)*. Talus and colluvium occupy extensive surface areas on the sides of hills and mesas. Talus and colluvium have been split into map units that comprise mainly basaltic clasts *(Qbt)*, such as those on Tres Hermanos Mesa, and those that mainly comprise Cretaceous sandstone that slid downslope on underlying shales *(Qtc)*.

ECONOMIC GEOLOGY

Pueblo Viejo Mesa quadrangle lies within the boundaries of the Datil Mountains coal field (Winchester, 1921). Coal can be observed in outcrops at several places in the quadrangle including a small pit west of Pueblo Viejo Mesa near an abandoned dwelling. A hole, drilled in NE¼ sec. 30, T. 4 N., R. 7 W. during a coal reconnaisance-drilling program conducted by the New Mexico Bureau of Mines and Mineral Resources, encountered a 4-ft thick coal bed within strippable depth (Frost and others, 1979). This discovery prompted detailed mapping of the quadrangle and more exploratory drilling in the area.

Five exploratory holes were drilled in the quadrangle as part of a larger drilling program covering the central Datil Mountains coal field. Drillhole summaries of these holes are included in Appendix I of Osburn (1982b). Three of the holes on Pueblo Viejo Mesa quadrangle contained enough coal to merit twinning of the holes to obtain coal samples for proximate, ultimate, BTU, and forms-of-sulfur analyses (Table 1). Pronounced lenticularity of the coal beds was observed during core drilling. Two seams greater than 2-ft thick were not present in the twinned corehole located 20 ft from the rotary hole. In place of the coal were fine to very fine grained, crossbedded sandstones with abundant coal fragments in the lower part. The presence and physical characteristics of these sandstones suggest that the coals were cut out by migrating fluvial channels.

Coal resources for Pueblo Viejo Mesa quadrangle were tabulated by section (Table 2). Approximately 25.80 million tons of demonstrated coal resources are present in the quadrangle. All known coal resources in the quadrangle occur within 150 ft of the surface, although drilling reached 350 ft. Approximately 32% of the coal has a stripping ratio of less than 10:1; the remaining resources have stripping ratios in excess of 20:1.

Coal beds in the Crevasse Canyon Formation in Pueblo Viejo Mesa quadrangle are typical of coals deposited in environments with strong fluvial influence. Coals are thin and discontinuous over a few thousand feet. The heating values of these coals are among the highest in the state; however, small tonnages, structural complications, lack of transportation facilities, and thick overburden will likely prohibit large-scale mining. The lower 400 ft (122 m) of the Crevasse Canyon Formation contain the thickest coals in the formation in the study area. The resource potential of the upper part of the formation in the study area is unknown at this time because of poor exposures and a lack of subsurface information. Inasmuch as the environment of deposition for the upper part of the formation was an upper coastal plain, any coals present would be discontinuous because abundant fluvial channels would probably erode coal deposits.

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TABLE 1—PROXIMATE, ULTIMATE, AND BTU DATA FOR PUEBLO VIEJO MESA QUADRANGLE (as received, Hazen Research Co., Golden, Colorado, in August, 1981)

Drill-hole number	030705-1	030705-1	040730-2	040730-2	040730-2	040730-3	040730-3	x, std. dev (ó)
Depth interval analyzed	146–148 ft	175–177 ft	36.5–37.5 ft	54–55.5 ft	60–62 ft	65.5–67.5 ft	125–128 ft	—
Volatile matter	34.08	38.09	35.03	34.46	39.41	39.91	38.69	37.09 ± 2.48
Fixed carbon	39.19	42.74	45.12	39.54	43.28	42.11	46.70	42.67 ± 2.73
Water	8.94	9.19	5.25	5.31	2.94	3.86	7.31	6.12 ± 2.43
Ash	17.79	9.98	14.60	20.69	14.37	14.12	7.30	14.12 ± 4.48
Carbon	57.51	63.35	63.42	57.27	65.94	65.37	68.36	63.03 ± 4.21
Hydrogen	4.36	4.92	4.62	4.53	5.07	5.29	5.15	4.84 ± 0.34
Nitrogen	0.77	0.95	1.00	0.95	0.91	0.92	1.22	0.96 ± 0.14
Sulfur	0.63	0.58	0.54	0.71	0.73	0.49	0.65	0.62 ± 0.08
Oxygen	10.00	11.03	10.57	10.54	10.04	9.95	10.01	10.30 ± 0.41
BTU	10,186	11,264	11,248	10,293	11,731	11,941	12,162	11,260 ± 773

TABLE 2—DEMONSTRATED COAL RESOURCES OF PUEBLO VIEJO ESA QUADRANGLE (Coal resources were tabulated by thickness categories as established in U.S. Geological Survey Bulletin 1450-B (1976; table 1) in millions of short tons; all values rounded; 1,800 short tons/acre-ft used in calculations; maximum depth, 350 ft; only sections with data reported; only portion of sections within study area reported; township totals tabulated at the end of each township.)

Location			Measured Thickness of coal bed (ft)			Indicated Thickness of coal bed (ft)			Demonstrated
T.	R.	sec.	1.2–2.3	2.3–3.5	>3.5	1.2–2.3	2.3–3.5	>3.5	measured & indicated
3N.	7W.								
		4	0.36	—	—	0.80	—	—	1.16
		5	0.26	—	—	1.27	—	—	1.53
									2.69
4N.	7W.								
		8	0.30	—	—	—	—	—	0.30
		15	0.46	—	—	—	—	—	0.46
		18	—	0.18	—	—	—	—	0.18
		19	0.35	0.17	0.33	1.96	0.69	1.86	5.36
		20	0.13	—	0.15	.84	—	0.96	2.08
		29	0.35	0.36	0.40	.83	—	0.95	2.89
		30	1.10	0.47	0.62	2.09	1.25	1.64	7.17
									18.44
4N.	8W.								
		13	0.26	—	—	—	—	—	0.26
		24	0.84	1.44	—	0.31	0.62	—	3.21
		25	0.09	0.19	—	0.30	0.62	—	1.20
									4.67
Totals			4.50	2.81	1.50	8.40	3.18	5.41	25.80

GEOLOGIC SYMBOLS

Contact
Dashed where approximately located; short dashed where inferred; dotted where concealed

Fault
Dashed where approximately located; short dashed where inferred; dotted where concealed

Fault, showing dip
Ball and bar on downthrown side

Normal fault
Hachured on downthrown side

Thrust fault
Sawteeth on upper plate

Anticline
Showing direction of plunge; dashed where approximately located

Overturned anticline
Showing direction of dip of limbs

Syncline
Showing direction of plunge; dashed where approximately located; dotted where concealed

Overturned syncline
Showing direction of dip of limbs

Monocline
Showing direction of plunge of axis

Strike and dip of beds

Inclined *Horizontal*

Vertical *Overturned*

Strike and dip of foliation

Inclined *Vertical* *Horizontal*

Additional symbols used on this map

030705-1 Drill-hole number (see Table 1)

32" Coal outcrop, thickness in inches

Volcanic vent