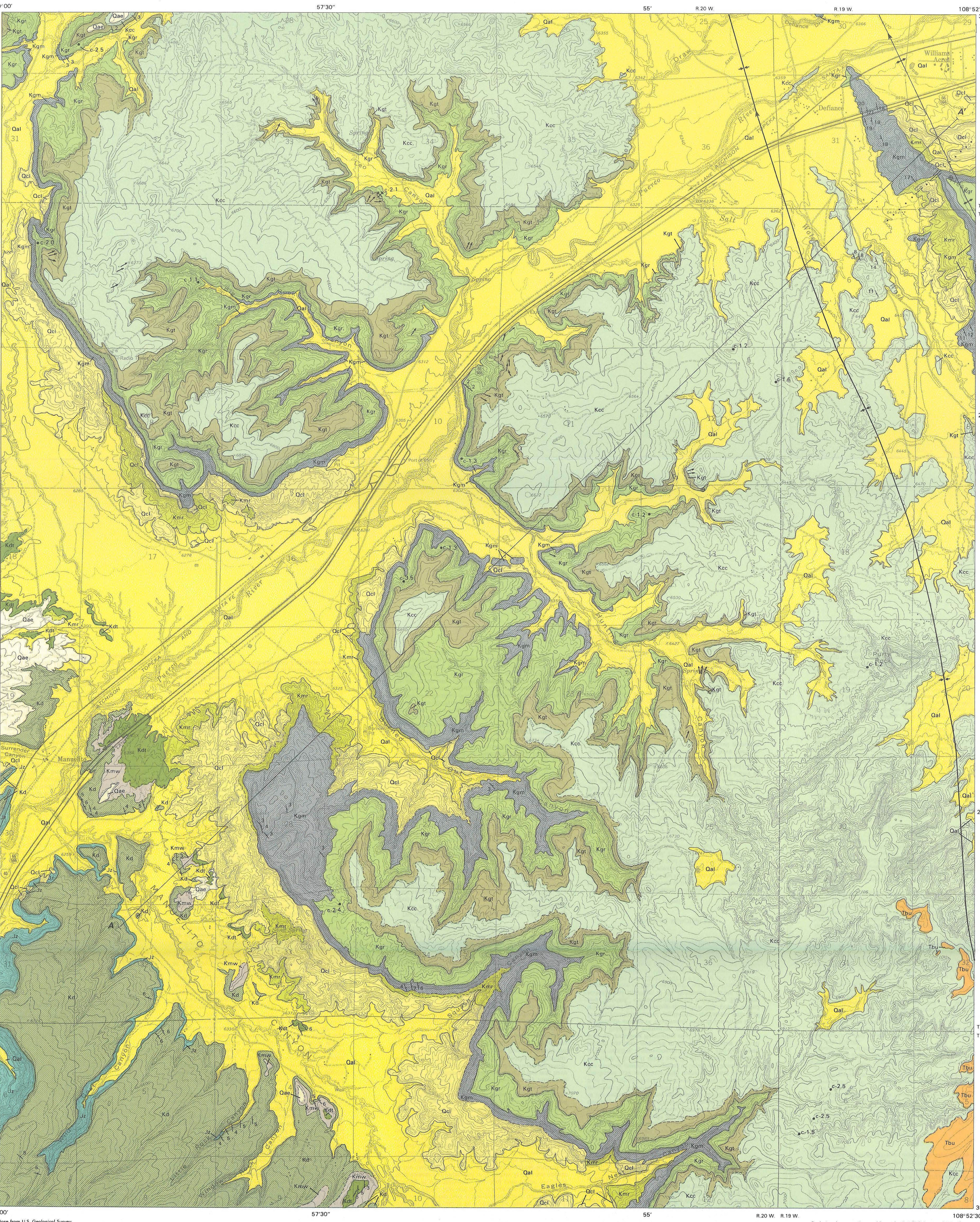


Base from U.S. Geological Survey
Geology by O. J. Anderson, 1985

Geologic color separations and layout by C. A. Salisbury and J. D. Cheney
Edited by J. C. Love

Scale 1:24,000

1 MILE — 1 KILOMETER

CORRELATION OF UNITS

Qal Qae Qcl	QUATERNARY
Tbu	PLIOCENE
unconformity	
Kcc, Kgt (minor unconformity), Kgr, Kgm, Kmr, Kdt, Kmw, Kd	UPPER CRETACEOUS
unconformity	
Jz	MIDDLE JURASSIC
unconformity	

DESCRIPTION OF UNITS

Qal **Alluvial deposits (Quaternary)**—sand, silt, clay, and minor gravel and sandstone boulders in the major drainages, their tributaries, and floodplains; from several feet to more than 50 ft thick

Qae **Mostly eolian deposits (Quaternary)**—very fine grained windblown sand as sheet deposits; veneers alluvial or colluvial deposits; no recognizable dune forms

Qcl **Colluvium and landslide debris (Quaternary)**—common on slopes developed on Mancos Shale; includes toreva blocks

Tbu **Upper member of Bidahochi Formation (Pliocene?)**—moderately reddish brown to light-brown, poorly indurated, argillaceous sandstone with lesser amounts of poorly sorted, carbonate-cemented sandstone

Kcc **Crevasse Canyon Formation (Coniacian)**—an interbedded sequence of shale, mudstone, lenticular sandstones, carbonaceous mudstone or shale, and minor coal; shale and mudstone dominate the section and vary in color from medium gray, through brownish gray, to dark gray; sandstones are fine to upper medium grained, are trough crossbedded, and vary from yellowish gray to pale yellowish brown, with pale red found approximately 300 ft above the base in the N1/2 sec. 32 T14N R19W at quadrangle boundary; thickness varies from 0 to approximately 500 ft in subsurface; good outcrops at Purty Rock (sec. 19), where 325 ft are exposed; essentially all outcrops are Dilco Coal Member except sandstone capping Purty Rock, which is Bartlett Barren Member

Kgt **Torrivio Member of Gallup Sandstone (Coniacian?)**—distinctive, medium to very coarse grained feldspathic sandstone, commonly reddish brown with pronounced crossbedding; crossbed sets indicate paleoflow directions to north, northeast, and east; considered to be a braided-stream deposit; base of unit is generally sharp and exhibits low-relief scouring; 10–50 ft thick

Kgr **Ramah unit of Gallup Sandstone (Turonian)**—variable sequence of mudstone, lenticular fluvial-channel sandstone, carbonaceous mudstone, and minor coal; one coal bed reaches 3.5 ft in thickness but is not persistent; unit is a coastal plain and lower alluvial-plain sequence that overlies regressive marine Gallup; 94–150 ft thick; thins eastward on Torrivio anticline; unit is lithogenetically a tongue of the Dilco Coal Member but has been included in the Gallup since originally defined in 1925

Kgm **Gallup Sandstone, main part, undivided (Turonian)**—very pale orange, yellowish-gray, and grayish-orange, very fine to fine-grained quartzose sandstone in coarsening-upward sequences up to 25 ft thick; shoreface, tidal and/or distributary channel, lagoonal, and restricted bay in origin; total thickness 205 ft

Kmr **Rio Salado Tongue of Mancos Shale (Cenomanian and Turonian)**—light- to dark-gray shale and arenaceous shale; base of unit sharp on top of Twowells Tongue; platy limestone debris from Bridge Creek Limestone Member of Greenhorn Formation found in float, but not in outcrop, in SE1/4 sec. 20 T14N R20W; top of unit gradational through 20 ft into overlying Gallup Sandstone; 350–400 ft thick

Kdt **Twowells Tongue of Dakota Sandstone (Cenomanian)**—tan and very pale orange, lower-very fine grained to lower-medium-grained quartzose sandstone; bioturbated and burrowed, including *Ophiomorpha* and *Thalassinoides*; ripple laminations preserved locally in middle part; base of unit is lower very fine grained and flat bedded; upper part of unit is fine to lower medium grained with trough and planar-type crossbeds; generally 30–35 ft thick but thins to <25 ft in SE1/4 sec. 20 T14N R20W

Kmw **Whitewater Arroyo Tongue of Mancos Shale (Cenomanian)**—gray to dark-gray, silty marine shale; base of unit is sharp; contains very thin, orange-weathering bentonite beds; 20–40 ft thick with the thinner outcrops along frontage road in SW1/4 sec. 20 T14N R20W

Kd **Main body of Dakota Sandstone (Cenomanian)**—grayish-orange and very pale orange, fine- to coarse-grained sandstone, conglomeratic sandstone, mudstone, carbonaceous mudstone, and coaly carbonaceous shale; basal part is of fluvial origin and is commonly a quartzite-pebble conglomeratic sandstone up to 45 ft thick that rests unconformably on Jurassic rocks; relief on unconformity as much as 20 ft; locally base may be a mudstone or carbonaceous mudstone; middle part is predominantly mudstone and carbonaceous shale up to 55 ft thick; upper part is a thin to flaggy-bedded, fine-grained sandstone interbedded with sandy mudstone or shale; upper part ranges up to 30 ft thick; upper part contains oscillation ripples trending north and northwest and a variety of burrows, including *Ophiomorpha*; *Exogyra levis* is found only at the very top of the upper part; overall thickness of Dakota varies between 110 and 130 ft

Jz **Zuni Sandstone (Middle Jurassic)**—very fine to medium-grained, white to pinkish-gray quartzose sandstone characterized by medium to thick sets of planar and planar–tangential, high-angle crossbeds; crossbed-dip direction variable, but south, southeast, and southwest are common; eolian in origin for most part; may range up to 700 ft thick locally; Zuni is the undivided equivalent of the Entrada and Cow Springs Sandstones, which generally are not mappable as separate units in this area

MAP SYMBOLS

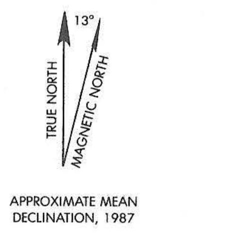
c-1.6 Measured coal locality with thickness in feet

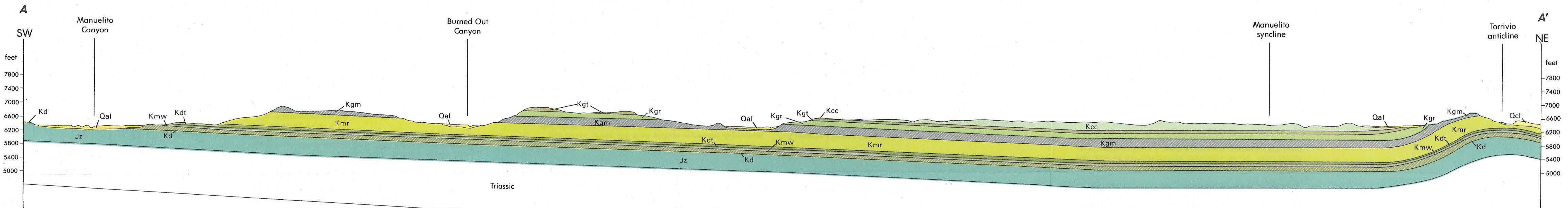
Paleoflow directions based on crossbed sets

Fault showing strike-slip movement

(additional symbols on envelope)


INDEX MAP OF NEW MEXICO

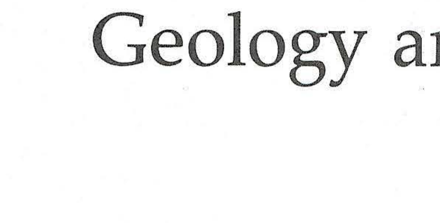

APPROXIMATE MEAN DECLINATION, 1987



Geology and mineral resources of Manuelito quadrangle, McKinley County, New Mexico

by Orin J. Anderson, 1991

New Mexico Bureau of Mines & Mineral Resources, Socorro, NM 87801



From Darton, 1928.

Abstract

The Manuelito 7½-min quadrangle lies in the northwestern part of the Zuni Basin in west-central New Mexico. The area is characterized by mesas, canyons, and cuestas cut in the gently northeastward-dipping Jurassic and Cretaceous rocks. This structural pattern is interrupted in the northeastern corner of the quadrangle by the Torrivio anticline, a north–northwest-trending, doubly plunging feature with 1000 ft of structural relief. The anticline and an associated syncline on the west flank constitute the only apparent structure in the quadrangle.

Middle Jurassic, Upper Cretaceous, and Tertiary rocks are exposed. The Middle Jurassic is represented by the Zuni Sandstone and, according to some authors (Condon and Huffman, 1984), locally by a tongue of eolian Recapture Member of Morrison Formation at the top of the Zuni. The Upper Cretaceous rocks consist of the Dakota Sandstone (Cenomanian) at the base, Mancos Shale, Gallup Sandstone, and Crevasse Canyon Formation, the last two being coal bearing. A late Tertiary basin-fill unit, the Bidahochi Formation (Pliocene?), is present over a very limited area in the southeast corner of the quadrangle. These erosional remnants of the Bidahochi are less than 45 ft thick but are of interest because they represent the northernmost outcrops of the modern distribution of the unit in New Mexico.

Mineral resources in the quadrangle are limited. Coal has been produced in very small quantities, and a small coal resource exists in the Ramah unit of the Gallup Sandstone. Several test wells have been drilled in the area, some of which bottomed in Precambrian basement. No oil or gas shows were reported. No aggregate pits or aggregate deposits exist in the quadrangle; however, a large borrow pit supplied fill material for construction of I–40, which runs diagonally northeast across the quadrangle.

INTRODUCTION

Manuelito quadrangle is located 6 mi west–southwest of Gallup, New Mexico, in the northwestern part of the Zuni Basin (Fig. 1). Access is provided by I–40, which crosses the quadrangle from northeast to southwest. A frontage road parallels the interstate highway on the south for the most part, and the Santa Fe Railroad tracks parallel it on the north. The routes follow the valley of the Puerco River. Numerous dirt roads lead off this main route and extend up the tributaries to scattered dwellings and small ranches. No incorporated cities exist in the quadrangle, but the abandoned villages of Manuelito and Defiance lie along the railroad tracks, and the western edge of the community of Williams Acres extends into the northeast corner.

Fenneman (1931) included this area in the Navajo Section of the Colorado Plateau physiographic province. Topographically, the quadrangle consists of mesas, cuestas, canyons, and alluvial-valley floors developed on Jurassic and Cretaceous rocks. Local relief is approximately 600 ft; maximum relief of 920 ft exists between the low of 6,220 ft on the channel floor of the Puerco River to the high of 7,140 ft on small buttes capped by Tertiary sediments in the southeast corner of the quadrangle. Large landslide blocks and colluvium are prevalent at the bases of the more prominent cliffs and mask outcrops of the slope-forming Mancos Shale and the Twowells Tongue of the Dakota Sandstone.

The Puerco River is the major drainage for the northern Zuni Basin and the Gallup–Church Rock vicinity. It is a perennial stream, a tributary of the Little Colorado River, and flows southwestward through the Manuelito area, against structural dip, with a gradient of 17.5 ft per mile. The water gap it has cut through the Torrivio anticline provides excellent exposures of the Gallup Sandstone. The alluvial-valley floor along the Puerco River exceeds a mile in width at many junctures. The major tributaries are Defiance Draw, which enters the trunk stream in the northeast part of the quadrangle and Manuelito Canyon, which enters in the southwestern part. In this southwestern area, the Puerco has cut through a homocline developed on a Dakota Sandstone dip slope, and the resulting water gap provides good exposures of the Jurassic Zuni Sandstone and overlying Dakota Sandstone. The Puerco and Manuelito Canyon streams are crucial water sources for the ranching and livestock industry in the area.

No dry-land farming has been attempted in this area because of the rugged topography and also because annual precipitation is generally less than 13 inches. The mesas and upland surfaces above 6,500 ft have a moderate cover of piñon and juniper (*Pinus edulis* and *Juniperus monosperma*), and the alluvial-valley floors have a cover of bunch grasses, shrubs, and scattered cactus.

Previous work in the area includes that of Darton (1910, 1915), who described the Zuni Basin in the course of a regional study, as well as the geology and landscape along the route of the Santa Fe Railroad; Sears (1925), who studied and reported on the Cretaceous stratigraphy and coal resources of the Gallup–Zuni Basin; Shomaker et al. (1971), who included the Gallup–Zuni Basin in a regional evaluation of strippable coal resources; and Molenaar (1983), who established a reference section and described in detail the Gallup Sandstone in northwestern New Mexico. The geology of the Hunters Point quadrangle, immediately northwest of Manuelito quadrangle, was detailed by Condon (1986). Most recently, Anderson (1989, 1990) has completed mapping and mineral-resource investigations in the quadrangles immediately to the southeast and south.

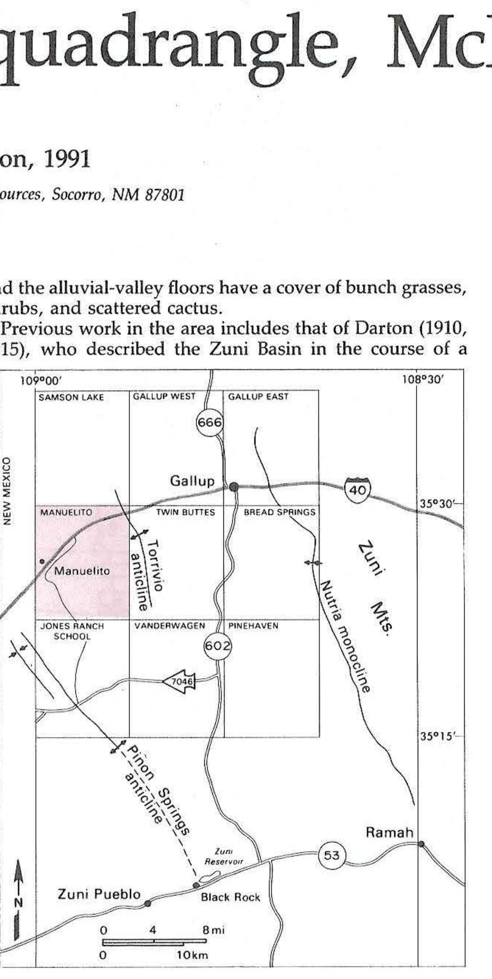


FIGURE 1—Index map of north half of Zuni Basin showing location of Manuelito quadrangle, surrounding quadrangles, and major geologic and geographic features.

ACKNOWLEDGMENTS—This geologic mapping project is the result of encouragement from Frank Kottlowski, Director of the New Mexico Bureau of Mines and Mineral Resources, to extend investigations of Cretaceous rocks and associated coal resources northwestward from the Pinehaven area to the Manuelito area. The New Mexico Bureau of Mines and Mineral Resources provided the support for the field work. Special thanks go to Stephen C. Hook and C. M. Molenaar for their help in faunal identification; to Richard M. Chamberlin, Charles E. Chapin, Spencer G. Lucas, Marvin L. Millgate, and Donald L. Wolberg for reviewing and improving the map and text; and to Lynne McNeil, who typed the manuscript. A note of appreciation also goes to Chester Nez, president of the Manuelito chapter house, and to Lenny Parker, Ellen Parker, Jim Spencer, Jaquelin Chee, and other residents of the area, who kindly permitted me access to their property or grazing leases for the purpose of mapping and sample collecting.

STRUCTURE

Uniform northeastward dips in the range of 2°–6° describe the structure of all but the northeast corner of the Manuelito quadrangle. The Torrivio anticline trends N20°W across the northeast corner (Fig. 1), reverses structural dip to form an associated syncline on the west, and brings Mancos Shale to the surface in an area surrounded by the Crevasse Canyon Formation. The west limb is the steeper with dips as much as 21°; dips on the east limb, which is off the quadrangle, do not exceed 7°. The anticline plunges both to the north and the south; however, the northward plunge is more abrupt, and the structure disappears 4 mi to the north.

Structural relief on the anticline is estimated at 1,000 ft on cross section A–A′. Drill-hole information from the SE 1/4 sec. 19 T15N R19W indicates that the depth to Precambrian basement from the floor of the water gap through the anticline is 4,890 ft. Three miles downdip to the northeast, a drill hole in sec. 3 T15N R19W encountered basement rock at 6,828 ft (ground level same for both holes). With a regional dip of approximately 300 ft per mile, 900–1,000 ft of this nearly 2,000-ft difference in depth to basement can be accounted for; thus the 1,000-ft estimate for structural relief on the anticline is substantiated. Basement involvement in this structure is also demonstrated.

The nature of the controlling basement faults is not well constrained, and thus they are not shown on the cross section. The structure is different from that of the Nutria monocline and Galestina–Atarque monoclines described by Anderson (1987) farther south in the basin. These latter structures are narrow, sharp flexures produced by reverse or thrust faulting. The Torrivio is a broad intrabasinal fold that may reflect a different style of basement faulting.

STRATIGRAPHY

The composite stratigraphic column (Fig. 2) illustrates the relationships of Jurassic through Tertiary rocks exposed in the Manuelito quadrangle. The figure is based on measured sections at eight localities. The thicknesses of subsurface units shown on cross section A–A′ were obtained from two drill holes located immediately north and northeast of the

text continued on back

quadrangle—one in sec. 3 and one in sec. 19 of T15N R19W. The drill-hole data revealed significant thickening of the Chinle Formation in the subcrop, from 800 ft in the Jones Ranch School quadrangle (Anderson, 1989) to 1,650–1,900 ft in this area, within a distance of 15 mi. Condon (1986) reported a thickness of 1,695 ft in the Hunters Point quadrangle adjacent to the northwest. This rate of southward thinning, approximately 60 ft per mile, is local and is due to both pre-Chinle topography and perhaps some post-Triassic northward tilting coupled with pre-Zuni beveling. The former is thought to be the major factor in the progressive southward onlap of younger members of the Chinle onto the flanks of the ancestral Mogollon highland. The Owl Rock Member of the Chinle pinches out southward at approximately the latitude of Manuelito–Fort Wingate (35°25′). The youngest member, the Rock Point, pinches out in the subsurface just south of Atarque; it is not present in Carrizo Wash at latitude 34°30′. These units appear to be conformable but probably are unconformable on a regional scale.

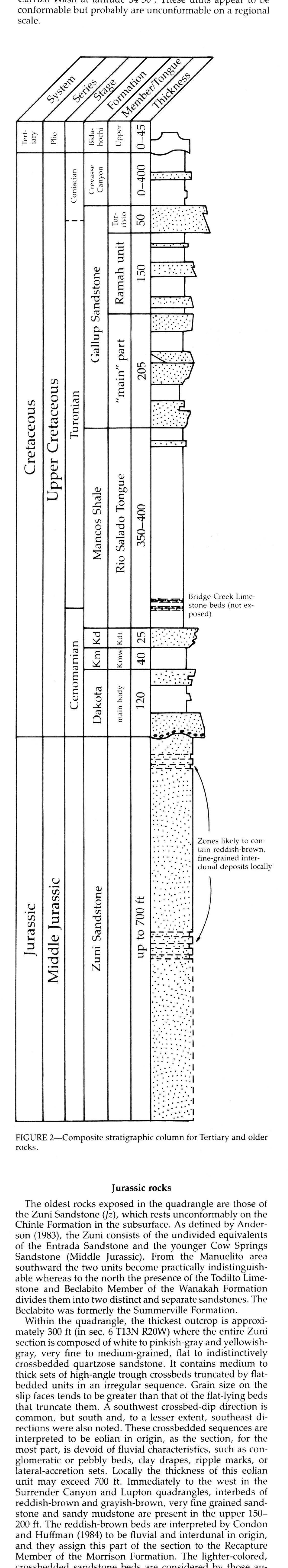


FIGURE 2—Composite stratigraphic column for Tertiary and older rocks.

Jurassic rocks

The oldest rocks exposed in the quadrangle are those of the Zuni Sandstone (*Jz*), which rests unconformably on the Chinle Formation in the subsurface. As defined by Anderson (1983), the Zuni consists of the undivided equivalents of the Entrada Sandstone and the younger Cow Springs Sandstone (Middle Jurassic). From the Manuelito area southward the two units become practically indistinguishable whereas to the north the presence of the Todilto Limestone and Beclabito Member of the Wanakah Formation divides them into two distinct and separate sandstones. The Beclabito was formerly the Summerville Formation.

Within the quadrangle, the thickest outcrop is approximately 300 ft (in sec. 6 T13N R20W) where the entire Zuni section is composed of white to pinkish-gray and yellowish-gray, very fine to medium-grained, flat to indistinctively crossbedded quartzose sandstone. It contains medium to thick sets of high-angle trough crossbeds truncated by flat-bedded units in an irregular sequence. Grain size on the slip faces tends to be greater than that of the flat-lying beds that truncate them. A southwest crossbed-dip direction is common, but south and, to a lesser extent, southeast directions were also noted. These crossbedded sequences are interpreted to be eolian in origin, as the section, for the most part, is devoid of fluvial characteristics, such as conglomeratic or pebbly beds, clay drapes, ripple marks, or lateral-accretion sets. Locally the thickness of this eolian unit may exceed 700 ft. Immediately to the west in the Surrender Canyon and Lupton quadrangles, interbeds of reddish-brown and grayish-brown, very fine grained sandstone and sandy mudstone are present in the upper 150–200 ft. The reddish-brown beds are interpreted by Condon and Huffman (1984) to be fluvial and interdunal in origin, and they assign this part of the section to the Recapture Member of the Morrison Formation. The lighter-colored, crossbedded sandstone beds are considered by those authors to be eolian facies of the Recapture. No significant red-brown sandstone or mudstone interbeds were found in the Manuelito quadrangle, and thus no attempt was made to trace out or differentiate a Recapture Member. An additional factor is that the widespread unconformity (the J-5) at the base of the Morrison Formation as described by Pipiringos and O'Sullivan (1978) is not in evidence in the upper part of the unit mapped as the Zuni Sandstone in this area.

Upper Cretaceous rocks

Dakota–Mancos sequence

The Upper Cretaceous section is composed of shoreface and nearshore sandstone, coastal-plain mudstone and fluvial-channel sandstones, and offshore mudstone and shale deposited along the western margin of the interior seaway. The shoreline for the most part trended northwest but was highly embayed. The Dakota Sandstone (*Kd*) forms the base of the Upper Cretaceous section in western New Mexico. Excellent exposures of the Dakota may be found in secs. 29, 30, 31, and 32 T14N R20W in the southwest corner of the Manuelito quadrangle. A chert- and quartzite-pebble conglomeratic sandstone 4 ft thick forms the basal part and rests unconformably on the finer-grained Zuni Sandstone. Relief on the unconformity approaches 20 ft, but locally a paludal shale with carbonaceous zones is present at the base of the Dakota and grades upward into sandstone. This basal fluvial and paludal unit is as much as 45 ft thick, and it commonly forms a darker-colored bold cliff at the top of the massive, highly sculptured Zuni Sandstone.

Overlying this cliff-forming basal sandstone is a predominantly shale and mudstone unit that locally is as much as 55 ft thick. Generally a fluvial-channel sandstone bed 5–20 ft thick can be found near the middle of the unit. Several carbonaceous zones are present in the mudstone, which constitutes the upper half.

Forming the top of the typical "tripartite" Dakota is a thinly bedded, fine-grained sandstone sequence interbedded with sandy mudstone and/or lower-very fine grained sandstone. The lower 10 ft consist of fine-grained, very pale orange, quartzose sandstone. Wave-oscillation ripple marks are abundant and commonly trend N40°–55°W (as in NW¼ sec. 29 T14N R20W). However, N80°E trends also are found in the area. Small-diameter burrow casts also identify this interval. An 8-ft-thick sandy shale and silty sandstone bed overlies the quartzose sandstone and probably represents a minor transgression of the seaway. It is in turn overlain by a 10- to 12-ft-thick, upward-coarsening sandstone that represents a regression of the seaway. It contains scattered burrow casts, including *Ophiomorpha*, locally has well-developed hummocky crossbeds, and is fossiliferous in the upper few feet. The fossils are dominated by the oyster *Exogyra levis*, and this sandstone may be the age equivalent of the Paguate Tongue of the Dakota. Megaripples in a massively bedded part of this sandstone were identified in the SW¼NE¼ sec. 29 and in the central part of the SE¼ sec. 29 T14N R20W. Widely scattered specimens of *E. levis* are present also at the megaripple locality.

The tripartite Dakota Sandstone appears to be the homotaxial equivalent of the Dakota Group in eastern and northeastern New Mexico. In those areas the Dakota consists of three formations. They are, in ascending order, the Mesa Rica Sandstone, the Pajarito Shale, and the Romeroville Sandstone. In eastern and northeastern New Mexico the Mesa Rica contains a marine fauna (Kues et al., 1985), whereas in the Manuelito area the basal Dakota is nonmarine.

Overlying the marine Dakota with a sharp basal contact is the Whitewater Arroyo Tongue of the Mancos Shale (*Kmw*). Owen (1966) described it as a well defined, persistent tongue of marine shale separating the Twowells Tongue from the rest of the Dakota Sandstone in the southwestern part of the San Juan Basin. In the Manuelito quadrangle it consists of 20–40 ft of gray to dark-gray marine shale with thin, orange-weathering bentonite beds. Selenite sheets commonly mark the bentonite beds. This shale is restricted to isolated outcrops in secs. 20, 29, and 33 T14N R20W and secs. 4 and 10 T13N R20W.

The Whitewater Arroyo Tongue represents deposition in a deeper-water, open-marine environment beyond the transition zone. Shale deposition was interrupted near the end of Cenomanian time by the progradation of a shelf sandstone—the Twowells Tongue of the Dakota Sandstone (*Kdt*). The Twowells overlies the Whitewater Arroyo Tongue with a base gradational from silty shale to silty, fine-grained sandstone through an interval of 10 ft. Above this are 25 ft of generally flat-bedded, upward-coarsening quartzose sandstone; primary bedding features have been destroyed by bioturbation in the lower third or lower half; however, some planar and trough crossbedding with south and southeast dip directions are preserved in the upper beds of lower-medium-grained sandstone. Also, in the upper beds are numerous burrows, including *Ophiomorpha*. Ripple-laminated beds may be found locally in the upper half of the unit. These beds, in addition to the relatively coarse grain size and burrows, indicate a shallow-water shelf environment. During this depositional event sand was distributed from this locality as far as 90 mi seaward to the Mesa Gigante–Suwanee area with no apparent significant migration of the shoreline.

Along the frontage road in the SE¼ sec. 20 T14N R20W the Twowells is somewhat thinner, but the upper contact is well exposed here. Lying just inches above the Twowells at the base of the overlying tongue of the Mancos Shale is a light-colored fossiliferous bed containing the oyster *Pycnodonte kellumi* and forms transitional between *P. kellumi* and the younger *P. newberryi*. *P. newberryi* commonly is present in or just below beds of the Bridge Creek Limestone in west-central New Mexico (Hook and Cobban, 1977). Beds of the Bridge Creek Limestone were identified approximately 40 ft above the top of the Twowells Tongue in the Jones Ranch School quadrangle immediately to the south (Anderson, 1989), but they cannot be identified in outcrop in this quadrangle. Pieces of tabular limestone containing inoceramid debris may be found as float above the fossiliferous bed at the sec. 20 locality just described, and these are assumed to be weathering out of a Bridge Creek interval, which here is covered by colluvium. The significance of the limestone is that it marks the time of maximum transgression of the western interior seaway during the Greenhorn cycle of sedimentation, an early Turonian event (Hook and Cobban, 1977).

Overlying the fossiliferous bed at the top of the Twowells Tongue is a 350–400-ft-thick, gray marine shale that is slightly calcareous throughout the lower half. The sharp basal contact suggests a rapid return to deep-water, open-marine conditions following deposition of the Twowells Tongue of the Dakota Sandstone. The sudden transgression apparently was triggered by a eustatic rise in sea level and represents a major and final pulse during the Greenhorn cycle of sedimentation. The name Rio Salado Tongue of the Mancos Shale (*Kmr*; Hook et al., 1983) is used for this shale tongue even though here the upper boundary is formed by the Gallup Sandstone, not the Tres Hermanos Formation as is the case in the type area. The basal Gallup Sandstone in this part of the Zuni Basin is stratigraphically contiguous with but slightly younger than basal Tres Hermanos, thus the name Rio Salado can be applied to the underlying tongue of the Mancos Shale. In this usage Rio Salado is locally equivalent to the lower Mancos Shale.

Exposures of the Rio Salado Tongue are limited because it is a slope-forming unit and generally covered. However, the calcareous aspect of the shale is lost somewhere near the middle, and the upper part becomes a darker-gray, noncalcareous sequence. The thin, fossiliferous sandstone beds within the upper 100 ft of this noncalcareous shale, which were referred to informally as the Tres Hermanos beds (Anderson, 1990) immediately to the southeast in the Vanderwagen quadrangle, are not well developed here. Those sandstone beds have yielded specimens of *Collignoniceras woollgari*. The ammonite *C. woollgari* is indicative of a middle Turonian age (Hook et al., 1983). Age-equivalent strata in the Manuelito quadrangle would appear to be offshore-marine mudstone, shale, and sandy shale; thus the Tres Hermanos regression, which so alters the stratigraphic section farther southeast in the Zuni Basin, was not felt in this area until slightly later. Condon (1986) recognized the Tres Hermanos Formation to the northwest in the Hunters Point quadrangle, and therefore the Manuelito area appears to have been within an embayment during part of middle Turonian time.

Gallup Sandstone

Overlying the Rio Salado Tongue of the Mancos Shale is a complex regressive sequence called the Gallup Sandstone. The main part of the Gallup (*Kgm*) consists of as much as 205 ft of marine and marginal-marine sandstones, siltstones, mudstones, and shales; this is overlain by a nonmarine section as thick as 200 ft, which includes the reddish-brown, coarse-grained, feldspathic Torrivio Member at the top. The lower, mostly marine 205 ft of section (*Kgm*) is an alternating sequence of shoreface, tidal-channel, and/or distributary-channel sandstones interbedded with mudstone, siltstone, and shale. These fine-grained facies represent deposition in lagoonal, restricted-bay, and lower coastal-plain environments. Some of the finer-grained (lagoonal, paludal) intervals have thin carbonaceous or coaly zones, but no coal resource exists (beds >14 inches thick) in this part of the Gallup. Lateral variability is great as is indicated by the two measured sections less than 2 mi apart (Fig. 3).

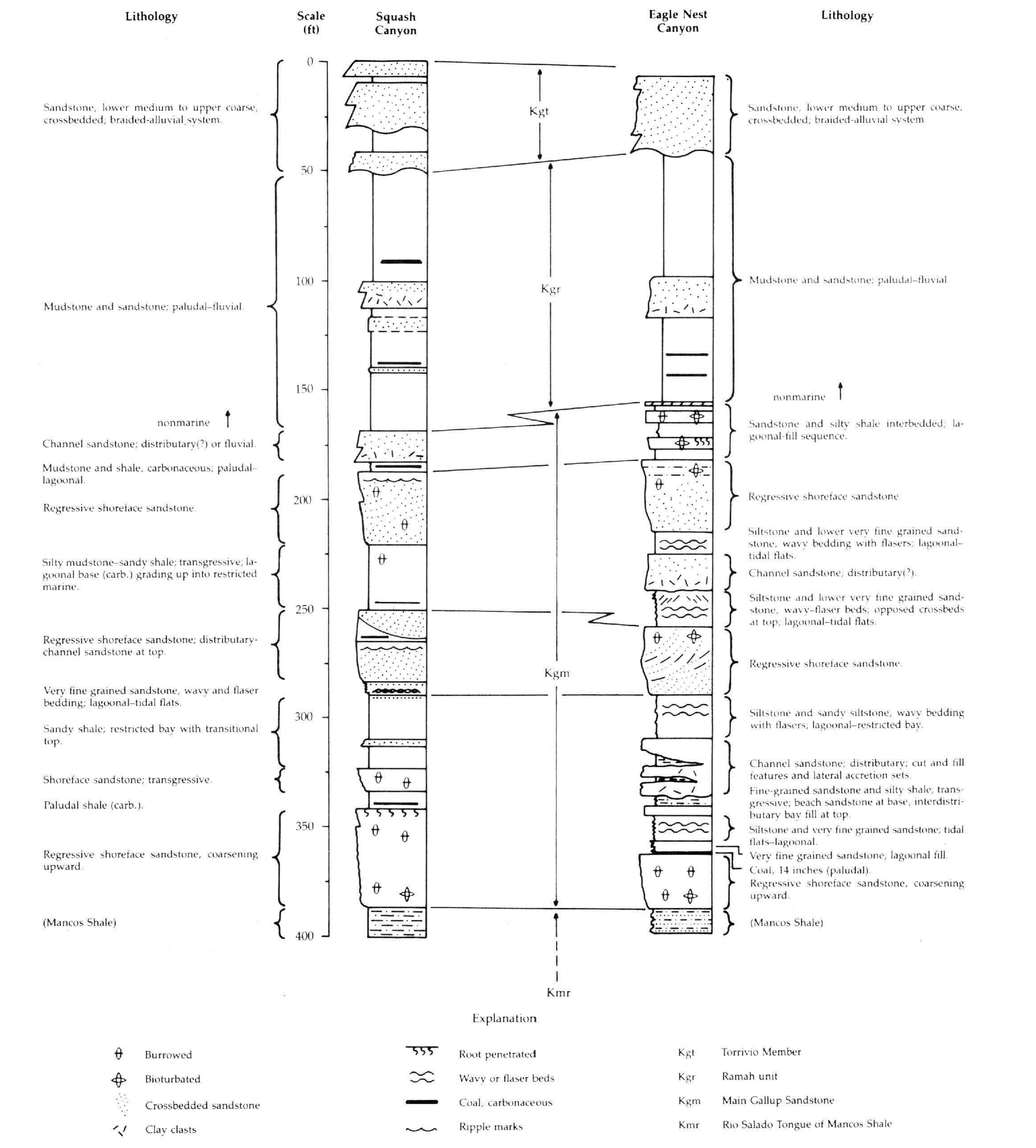


FIGURE 3—Measured sections of Gallup Sandstone at Squash Canyon (NE¼SE¼ sec. 34 T14N R20W) and at Eagle Nest Canyon (SW¼SE¼ sec. 2 T13N R20W), approximately 2 mi apart along a line parallel to depositional strike.

The entire lower 205 ft of section represent deposition and accumulation along a segment of the coast that was subject to repeated minor oscillations of the shoreline. Some of the sandstones in the section are "doublets" and may have transgressive and regressive components. The sandstones are generally burrowed, including *Ophiomorpha*, and bioturbated (Fig. 3). Ripple marks are common, and within the flaser-bedded, ripple-bedded, lagoonal–tidal-flat sequences, considerable variation in trend can be found. This diversity in ripple-mark trend perhaps reflects the oval-elongate configuration of the lagoon and contrasts with the more uniform trends found in the shoreface–barrier-beach environment, which are generally northwest and west. The sequences accumulated near a pivotal point along the regressing shoreline, which swung sharply eastward to the south of Manuelito quadrangle; southward the Tres Hermanos regressive–transgressive wedge was deposited. At the pivot point and northward the marine portion of the Gallup accumulated as the age equivalent of much of the Tres Hermanos and the Pescado Tongue of the Mancos Shale (Anderson, 1990).

Overlying the cliff-forming, marine Gallup is a nonmarine, slope-forming unit that is as much as 150 ft thick and has been referred to informally as the Ramah unit (*Kgr*) by Anderson and Stricker (1984); the name is used here informally also. This is the coal-bearing part of the Gallup, and it represents deposition in the lower alluvial-plain environment that developed following withdrawal of the Gallup seaway. The coal, however, is highly lenticular. The thickest coal bed in the unit is 46 ft above the base of the Ramah unit in the central part of the quadrangle in the SW¼ sec. 15 T15N R20W. This bed is 3.5 ft thick but cannot be traced laterally at that thickness. One half mile to the northeast its thickness has decreased to 15 inches. It does not appear in the carbonaceous zone at this stratigraphic interval to the northwest in secs. 8 and 9, but coaly beds and a thin coal are present in this interval 3 mi to the south at the Squash Canyon measured section (Fig. 3). Locally, fluvial-channel sandstones dominate the Ramah unit lithologies, each of which may be as much as 30 ft thick. In the upper part of the unit the fluvial-channel sandstones commonly contain coarse-grained lenses. These upper Ramah sandstones resemble the sandstone of the overlying Torrivio Member; however, they do not become as coarse grained or as thick, nor have they developed the deep reddish-brown oxidized colors of the Torrivio. A persistent 10- to 20-ft-thick, slightly carbonaceous, locally coaly mudstone forms the uppermost part of the Ramah unit; this may have served as an aquatard or aquafuge and restricted the downward movement of the oxidizing water within the Torrivio.

At the top of the Torrivio anticline (topographically the feature is known as Torrivio Mesa) in the northeast corner of the quadrangle only one fluvial-channel sandstone is present in the Ramah unit. It is approximately 45 ft above the marine Gallup and replaces the carbonaceous zone containing the thickest coal. This sandstone, which is from 15 to 35 ft thick, is somewhat unusual in that it contains coarse-grained facies and large-diameter burrows; evidence of burrowing is not commonly seen in fluvial sandstones of this area. The coarse-grained facies apparently represent early pulses of the type of sediments that characterize the overlying Torrivio Member. A carbonaceous zone appears above the sandstone and contains a 10-inch-thick coal bed, but this outcrop, as well as those of the overlying Torrivio Member, is just off the eastern edge of the quadrangle in sec. 5 T14N R19W. The entire Ramah unit here has thinned to 94 ft. This is consistent with general eastward thinning observed in the unit and apparently is not due to any pre-Laramide growth of the anticline.

The base of the overlying Torrivio Member (*Kgt*) is sharp and, at most localities, is a slightly scoured surface developed on carbonaceous mudstone (Fig. 3). The Torrivio, named from exposures at Torrivio Mesa by Molenaar (1973), is a highly crossbedded, medium to very coarse grained, locally feldspathic sandstone, with scattered grains exceeding 4 mm. The crossbedding is of both the trough type and planar type; thinner sets generally are planar. Dip directions are to the north, northeast, and east. A well-developed and exceptionally well exposed set of planar crossbeds, as much as 6 ft thick and dipping N25°E, may be seen at the spring in the center of sec. 24 T14N R20W. Anomalous northwest-dipping planar sets were noted in the NE¼ sec. 33 T15N R20W. Clay galls and casts of woody trash are common at the base of upward-fining depositional sequences in the Torrivio.

The total thickness of the Torrivio Member is as much as 50 ft. Excellent outcrops are present is secs. 8, 9, 10, 14, 15, 34, and 35 T14N R20W. For a discussion of the tectonic implications of the Torrivio, see Hayes (1970) or Anderson (1990). Stratigraphically and lithogenetically, the Torrivio Member and the Ramah unit are unrelated to the main (marine) Gallup Sandstone. Stratigraphically, the Torrivio is merely a distinctive fluvial unit within the overlying nonmarine Crevasse Canyon Formation, although it may have been a feeder system for some of the younger marine sand units. Lithogenetically, the informal Ramah unit is the basal tongue of the Dilco Coal Member of the Crevasse Canyon Formation. At the hogback just east of Gallup, New Mexico, where Sears (1925) originally named the Gallup Sandstone, the Torrivio Member rests stratigraphically much closer to the main (marine) Gallup, and thus a formation name for the entire sandstone sequence appeared quite logical. Also, at that time there was no emphasis on specifying or recognizing genetic units. However, out in the basin to the southwest, it is not logical to treat this sequence as a formation-rank unit.

Crevasse Canyon Formation

Named by Allen and Balk (1954) for exposures in the Tohatchi quadrangle 20 mi to the north, the Crevasse Canyon Formation (*Kcc*) overlies the Torrivio Member of the Gallup Sandstone. It is a mostly nonmarine unit (entirely nonmarine in the Zuni Basin) composed of shale, mudstone, lenticular fluvial-channel sandstones, and minor coal and carbonaceous mudstone. The distribution, morphology, and grain size of the sandstone bodies, as well as the fact that they are encased in the fine-grained sediments of the flood basin or backswamp, suggest that there was an abrupt return to a meandering fluvial system following deposition of the Torrivio braid plain. The mudstones and sandstones forming this sequence are equivalent to the Dilco Coal Member and Bartlett Barren Member, which are the subdivisions used farther east where the formation is thicker.

Dips are gently northeastward 2°–4°, and the Crevasse Canyon Formation is present extensively in the east half and in the northwest quadrant of the quadrangle. It thickens from a feather edge in sec. 34 T14N R20W to perhaps as much as 500 ft at Purty Rock in sec. 19 T14N R19W; at this locality 325 ft are exposed. The cross section accompanying the geologic map shows these structural and stratigraphic details.

At Purty Rock a 14-inch coal bed is present in the lowermost 30 ft of the exposed section (basal 120 ft of the formation) just above stream level on the west side of the mesa (SW¼NE¼ sec. 19 T14N R19W). No coal beds thicker than 3 inches were found in the overlying 300 ft of section. Coal also was noted in outcrop in the W½ sec. 6 T13N R19W in the southeast corner of the quadrangle. A maximum thickness of 2.5 ft was recorded for the lower of two coal beds in the basal 120 ft of the Crevasse Canyon Formation in sec. 6. Coal resources in this unit and in the Gallup Sandstone are discussed in a following section.

Tertiary

An upper Tertiary (Pliocene?) sedimentary unit unconformably overlies the Crevasse Canyon Formation. It is preserved only on the higher surfaces in the extreme southeast corner of the quadrangle but becomes much more widespread westward into Arizona. Named the Bidahochi Formation (*Tbu*) by Reagan (1924) for exposures near the village of the same name, it was subsequently divided into three members by Repenning and Irwin (1954). The three members were designated: (1) the lower member, dominated by mudstone and sandstone with some lacustrine facies; (2) the volcanic member composed of basalt and basaltic lapilli tuff from 2 to 50 ft thick; and (3) the fluvially dominated upper member, approximately 270 ft thick. The Zuni Basin section has been assigned to the upper member by most authors, including Repenning et al. (1958).

The Bidahochi Formation remnants in the Manuelito quadrangle consist of moderately reddish brown to light-brown, poorly indurated, argillaceous sandstone, with local interbeds of grayish-orange–pink (5YR 7/2), poorly sorted and "banded," carbonate-cemented sandstone. The color, texture, and lithology of the Bidahochi indicate that the major sources of these sediments were the Permian and Triassic rocks of the Zuni uplift 14 mi to the east with lesser amounts provided by the Jurassic and Cretaceous section. Reworked Cretaceous molluscs can be found locally in the Bidahochi (Anderson, 1990). Good exposures of the Bidahochi are present in the NW¼ sec. 32 T14N R19W, where erosional remnants attain a maximum thickness of just over 40 ft.

MINERAL RESOURCES

Coal

Coal resources (coal in beds >14 inches thick) are present in two stratigraphic intervals in the quadrangle, the middle part of the Ramah unit of the Gallup Sandstone and within the basal 120 ft of the Crevasse Canyon Formation. Table 1 is a list of localities where coal beds 1.2 ft thick (14 inches) or greater were measured. These are indicated on the map as well by a "c" and with thickness in feet.

The thickest coal is a 3.5-ft bed in the middle part of the Ramah unit of the Gallup Sandstone. Proximate analyses indicate that this is a high-ash coal; one sample yielded an ash value of more than 30% (courtesy of Frank Campbell, NMBMMR). Because the bed is present in less than half of sec. 15 T14N R20W and because there is only one control point, no coal resources were calculated. All indications are that the coal thins away from the control point; 0.5 mi to the northeast it has thinned to 1.3 ft. Two and one-half miles to the southwest in the NE¼ sec. 33 T14N R20W an outcrop of the same horizon exposes a 2.4-ft coal bed (Table 1). This also is an isolated observation point on a mesa top where large areas of the coal-bearing unit have been removed by headward erosion of canyons. Coal resources would be minimal in sec. 33 and adjacent sections.

The coal beds of the Ramah unit are of interest even though insufficient data is available from outcrop to warrant resource calculations. Coal has been produced from a 2.1-ft-thick bed in the SW¼SW¼ sec. 34 T15N R20W, and a small waste dump remains at the site. This bed may be slightly higher stratigraphically than the 3.5-ft bed in sec. 15. Production has also been realized from an interval approximately 40–50 ft above the base of the Ramah 0.75 mi to the northeast of the quadrangle boundary in sec. 20 T15N R19W of the Gallup West quadrangle. This was reported as the Myers mine by Sears (1925), who stated that it produced from two beds, each 2.5–3.0 ft thick, separated by a shale interbed that thickened westward. Production was before 1924 and was essentially the only local production from the Gallup Sandstone.

TABLE 1—Measured coal sections in Ramah unit of Gallup Sandstone (Kgr) and in Crevasse Canyon Formation (Kcc); measured August 1985.

Location		Stratigraphic position	Coal bed thickness (ft)
		Ramah unit of Gallup Sandstone	
1. T14N R20W	NE¼NE¼ sec. 33	Kgr; 40 ft above base	2.4
2.	C of SW¼ sec. 15	Kgr; 44 ft above base	3.5 with 1.5-ft rider 19 ft above
3.	SW¼NE¼ sec. 15	Kgr; 50 ft above base	1.3
4.	NW¼NW¼ sec. 13	Kgr; 40 ft above base	1.2
5.	SE¼SE¼ sec. 10	Kgr; 60 ft above base	1.3
6.	NE¼SE¼ sec. 5	Kgr; 40 ft above base	1.1
7. T15N R20W	SW¼SW¼ sec. 34	Kgr; 40 ft below top	2.1
8.	SE¼SE¼ sec. 30	Kgr; 40 ft below top	2.5
		Crevasse Canyon Formation	
1. T13N R19W	SW¼SW¼ sec. 6	Kcc; 100–120 ft above base	1.5
2.	NE¼SW¼ sec. 6	Kcc; 100–120 ft above base	2.5
3.	SE¼NW¼ sec. 6	Kcc; 120 ft above base	2.5
4. T14N R19W	SW¼NE¼ sec. 19	Kcc; 110 ft above base	1.2
5. T14N R20W	NE¼NE¼ sec. 12	Kcc; 120–140 ft above base	1.6
6.	NW¼NE¼ sec. 12	Kcc; 120–140 ft above base	1.2

A subsurface exploration program to determine or delineate additional coal resources might concentrate on the synclinal axis along the eastern margin of the map, following the concept that initial movement on some of these structures may have been pre-Laramide (Stricker and Anderson, 1985). Hence, the syncline may have been a mildly negative area.

Six measured coal sections from outcrop localities of the Crevasse Canyon Formation are given in Table 1. Using only those coal-outcrop thicknesses of 2.5 ft or greater for coal-resource calculations restricts the resources to sec. 6 T13N R19W where two control points exist 0.5 mi apart. The calculations result in a measured resource (coal within 0.25-mi radius of the control point; Wood et al., 1983) in sec. 6 of 547,000 tons and an indicated resource (coal within the 0.25-mi–0.75-mi band around the control point) of 3.1 million tons. In the absence of extensive coal-quality data, a factor of 1750 tons per acre feet was used in the calculations. An exploration program to further establish coal resources in this stratigraphic interval would best be carried out in the adjacent Twin Buttes quadrangle (Millgate, in press), where the coal lies a little deeper in the subcrop and straddles the extension of the synclinal axis shown on the Manuelito map.

Limited coal-quality work was undertaken for the Manuelito quadrangle. At the New Mexico Bureau of Mines and Mineral Resources analyses (courtesy of Frank W. Campbell) of sample nos. 1 and 5 of the locations in the Crevasse Canyon Formation (Table 1) indicated coal of relatively good quality. Sample 5 was slightly higher in overall quality; however, both were low ash (5–7%), low sulfur (0.38–0.43%) coals with BTU values of 9700–9800 on a moist, mineral-matter-free basis. Most of the sulfur (70%) is in organic form as opposed to FeS or SO_4; moisture content is in the range of 6–7%.

An additional coal sample collected in sec. 29 T14N R19W just east of the quadrangle boundary in the Twin Buttes quadrangle indicated much higher ash contents (28%) and lower BTU values (7360).

Petroleum and natural gas

No oil or gas shows were reported from a test drilled in the SW¼ sec. 5 T14N R19W in the northeast corner of the map. The hole was drilled in 1926 by Marlan Oil Company of Colorado to a T.D. of 1,390 ft. Two other tests in the vicinity reached Precambrian basement rock after penetrating more than 6,000 ft of sedimentary rock. One was drilled in 1954 in the SE¼ sec. 3 T15N R19W, and the other was drilled in 1967 in the SE¼ sec. 19 T15N R19W, 0.7 mi north of the quadrangle boundary. A drill-stem test was run in the sec. 19 hole but not in the sec. 3 test. Neither reported an oil show.

Clay

Although no clay production has been reported for the quadrangle, the potential for production probably exists. Clay pits have been operated in the Gallup area at various times during the past 80 yrs. These have produced refractory clays from thin claystone beds within the lower part of the Crevasse Canyon Formation that are from 2 ft to more than 6 ft thick (Van Sant, 1964). The largest of these clay pits was operated by the Gallup Clay Products Company. They produced a refractory clay with a Pyrometric Cone Equivalent (PCE) of >20, which was suitable for use in the manufacture of common brick, low-duty refractories, and mortar.

The stratigraphic interval that yields refractory clays in the Gallup vicinity, the lower part of the Crevasse Canyon Formation, is present in the Manuelito quadrangle. Nonmarine coal-bearing sections, such as the Crevasse Canyon, are a natural environment for refractory (high kaolin) clays because the low-pH environment associated with the formation of the peat swamps also promoted leaching of the fine-grained, mineral detritus, leading to kaolinite as the end product.

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