U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

GEOLOGIC MAP OF THE PINEDALE QUADRANGLE, McKINLEY COUNTY, NEW MEXICO

By

Jacques F. Robertson

2005

Miscellaneous Field Studies Map MF-2417

ABSTRACT

The 1:24,000 scale geologic map of the Pinedale 7.5' quadrangle lies in the western part of the Grants uranium mineral belt, which was mapped and studied under a cooperative agreement between the USGS and the U.S. Department of Energy. A spectacular panoramic view of the southern half of the Pinedale quadrangle is obtained looking northward from Interstate Highway 40, particularly from the New Mexico State travelers' rest stop near the Shell Oil Company's Ciniza Refinery, 28.5 kilometers (17.8 miles) east of Gallup. A west-trending escarpment, 200 meters high, of massive red sandstone, rises above a broad valley, its continuity broken only by a few deep and picturesque canyons in the western half of the quadrangle. The escarpment is formed by the eolian Entrada Sandstone of Late Jurassic age. The Entrada unconformably overlies the Chinle Formation of Late Triassic age, which occupies the valley below. The Chinle Formation consists of cherty mottled limestone and mudstone of the Owl Rock Member and underlying, poorly consolidated, red to purple fluvial siltstone, mudstone, and sandstone beds of the Petrified Forest Member. The pinyon- and juniper-covered bench that tops the escarpment is underlain by the Todilto Limestone. A quarry operation, located just north of the Indian community of Iyanbito in the southwestern part of the quadrangle, produces crushed limestone aggregate for highway construction and railroad ballast.

Beyond the escarpment to the north and rising prominently above it, is the northwest-trending Fallen Timber Ridge. Near the west side of the quadrangle lie the peaks of Midget Mesa, and Mesa Butte, the latter of which has the highest altitude in the area at 2,635 meters (8,030 feet) above sea level. The prominences are capped by buff-colored resistant beds of the Dakota Sandstone of Late Cretaceous age, containing some interbedded coal. These beds unconformably overlie the uranium-bearing Morrison Formation, which consists of red, green, and gray shale, orange feldspathic sandstone, and green tuffaceous mudstone, deposited in ancient lakes, alluvial fans, and rivers during the Upper Jurassic Period. Thick, crossbedded, white beds of the Cow Springs Sandstone, derived from ancient windblown desert sands, underlie the Morrison. In the northern part of the quadrangle, the Dakota Sandstone is overlain by gray Mancos Shale and yellowish-gray Two Wells and Gallup Sandstones that were deposited in Late Cretaceous seas. Unconsolidated deposits of Quaternary age are found throughout the quadrangle in talus, slope wash, fans, valley alluviums, pediments, and as windblown sands in dunes and blanket deposits.

The strata conform to the regional dip of about three degrees to north, except where they are down-folded some 200 meters along the Pinedale monocline, whose limbs follow a sinuous west-northwest trend across the northern half of the quadrangle. The monocline is beautifully exposed at Pinedale, where it shows as much as 20 degrees dip on the pine-studded bare rock slope of the Two Wells Sandstone. A north-plunging broad anticline and accompanying syncline is developed in the east-central part of the quadrangle but dies out against the monocline. A minor fault, with barely 3 meters of vertical displacement, extends several kilometers westward across the Todilto Limestone bench. A large landslide mass, 1.5 kilometers long by 0.7 kilometers wide occurs in the Mancos Shale west of Pinedale. Exploration drilling for uranium in the Morrison Formation has been extensive in the quadrangle, particularly north of the monocline, which adjoins the Old Church Rock mine area, west northwest of the quadrangle.

ILLUSTRATIONS

CORRELATION DIAGRAM OF THE MORRISON FORMATION AND UPPER PART OF THE SAN RAFAEL GROUP SHOWING VARIOUS STRATIGRAPHIC NAMES ASSIGNED TO UNITS IN GALLUP-GRANTS AREA

NDEX SHOWING LOCATION OF THE PINEDALE QUADRANGLE (SHADED) AND PUBLISHED U.S. GEOLOGICAL SURVEY GEOLOGIC QUADRANGLES (GQ) AND OPEN-FILE REPORT (OF) MAPS.

DESCRIPTION OF MAP UNITS

[Coded color designations, where used, are from Goddard and others (1948)]

Artificial fill (Holocene)—Levee-type motor roadway and railroad beds in southern part of quadrangle, built upon floodplains of ephemeral streams and alluvial fans that are susceptible to damaging flash floods. Thickness 2–4 m

Alluvial deposits

Unit Qa1 Alluvial deposits, unit 1 (upper Holocene)—Mostly light-yellowish-gray (5Y8/2) sand and gravel deposited as alluvium in arroyos and on valley floors since the latest cycle of arroyo cutting, which began about 1850 (Bryan, 1954, p. 15). Scale of map prohibits showing deposits in many small arroyos, which are cut in valley floors and fans and contain alluvium of unit 1. Unit 1 generally mantles broad valley flood plains and locally covers deposits of alluvium of unit 2 (unit Qa2). Includes some eolian sand reworked by floodwaters, and minor clay and silt deposited in ephemeral ponds and reservoirs. Generally thin, probably not more than 3 m thick

Unit Qa2 Alluvial deposits, unit 2 (Holocene)—Light-gray (N7) to yellowish-gray (5Y7/2), unconsolidated silt, sand, and gravel in aggraded valley bottoms and flood plains. Locally contains thin clay lenses and eolian deposits. Generally stabilized by vegetation and incipient soil formation. Deposited prior to latest cycle of arroyo cutting. Grades upslope into colluvium (unit Qc). Observed thickness 0–5 m, but probably exceeds 8 m thick in some alluviated valleys

Unit Qa3 Alluvial deposits, unit 3 (lower Holocene and Pleistocene?)—Grayish-orange (10YR7/4) to light-brown (5YR6/4), compact, semiconsolidated silt, sand, and gravel, including some boulders, in terraces 1.5–6.5 m above flood plains, which are underlain by alluvium of unit 2. Terraces and remnants of terraces composed of unit 3 are generally preserved in headward parts of valleys. Includes dissected older flood-plain and fan deposits of the bajada that spread southward from the pediments and escarpment in the southern quarter of the quadrangle. Unit 3 is commonly exposed in arroyo walls beneath unit Qa2 and, in some places, below colluvium (unit Qc) and some alluvial-fan deposits (unit Qf). Generally underlain by older alluvium (unit Qoa). Unit 3 has developed a medium-dark-brown soil as much as 120 cm thick, where not reduced by erosion, and commonly includes a moderately well developed caliche zone as much as 30 cm thick. Thickness 0–6 m

Unit Qoa Older alluvium (Pleistocene?)—Mostly grayish-orange (10YR7/4) to moderate-yellowish brown (10YR5/4) and light-brown (5YR6/4) to moderate-brown (5YR4/4), poorly to partly consolidated silt, sand, and gravel, generally of fluvial origin. The gravel, which is composed of subangular to subrounded pebbles, cobbles, and boulders of sandstone, chert, and quartzite, is poorly sorted to moderately well sorted, is considerably altered except for chert component, and is commonly permeated by caliche. Gravel appears to have been derived from local formations. The older alluvium (unit Qoa), whether buried or on the surface, exhibits mature relic soils in some places.

These soils attain 1–2 m in thickness where preserved and consist of the following layers, from top to bottom: dark-gray, organic A horizon at top, 10–30 cm thick; a reddish-gray, clayey B horizon, 30–105 cm thick, which includes, in the lower part, a Bca zone of filigree to massive, off-white, calcium carbonate caliche, 30–45 cm thick; and the C horizon of alteration, which fades into the underlying parent alluvium. Deposits of older alluvium occur as valley fill and underlie remnants of ancient pediments and piedmont alluvial terraces, plains, and fans. It also underlies younger alluvium in stream valleys and is exposed in many arroyo walls; it is well exposed in partially exhumed upland valleys and ridges in central part of quadrangle. Such exposures indicate four or more alluvial cycles, commonly separated by soil zones or scour surfaces; these cycles are not differentiated on map. Unit also includes some older eolian sand (unit Qoe). Thickness 0–10 m

Unit Qe Younger eolian deposits (Holocene)—Very pale orange (10YR8/2) and yellowish-gray (5Y7/2) to white, fine-grained to very fine grained, moderately well sorted, unconsolidated, and generally unoxidized sand and silt. Eolian deposits accumulated in barchan and seif dunes and in large sand sheets, mostly on broad flood plains where deposits are underlain by alluvial units 1 and 2 (units Qa1 and Qa2). Unit Qe, 0–3 m thick, extensively blankets the alluvial plain and hills in the vicinity of Iyanbito in the southwestern part of the quadrangle. There, numerous troughlike “blowouts” uncover underlying accumulations of oxidized older eolian deposits (unit Qoe), as well as older alluvial deposits (unit Qoa) and pediment gravel (unit Qp). Thickness 0–4 m

Unit Qoe Older eolian deposits (Holocene and Pleistocene)—Grayish-orange-pink (5YR6/2) to grayish-orange (10YR7/4–6/4) and light-brown (5YR6/6–5/4), fine-grained to very fine grained, semiconsolidated sand and silt; somewhat clayey and oxidized. Unit is stabilized by vegetation and soil, which exhibits moderately to well developed caliche. Extensive accumulations of unit Qoe underlie blanketlike younger eolian deposits (unit Qe) and occur on flanks and tops of ridges and escarpments in the southern part of the quadrangle; lightly masks many areas mapped as bedrock. Deposits of unit Qoe are mixed with, and mapped as, colluvium (unit Qc), older alluvium (unit Qoa), and pediment gravel (unit Qp). Thickness 0–4 m

Unit Qp Pediment gravel (Holocene and Pleistocene?)—Thin deposits of yellowish-gray (5Y7/4) to pale-yellowish-brown (10YR6/2) and light-brown (5YR6/4), poorly sorted, unconsolidated, subangular pebbles, cobbles, and sand that lie on dissected pediment surfaces. Tightly packed lag gravel forms thin continuous pavement in headward parts of pediments; downslope, gravel occurs as residual patches and in reworked deposits mixed with the older eolian silt and sand (unit Qoe). Pediment surfaces decline gradually from 6° at the base of cliffs to 1.5° downslope. Pediments occur at several erosional levels but are developed most generally on old alluvium (unit Qoa). The toe of the pediment along the north flank of Fallen Timber Ridge in the northern part of the quadrangle has been cut back by more recent cycles of erosion, making it relatively narrow and steep. Remnants of high-level graveled pediments below the steep escarpment in the southern part of the quadrangle have their headward parts truncated by erosion, exposing thick accumulations of underlying old alluvium. Some younger pediments at a lower level of erosion are coextensive with the downslope bajada surfaces and are mantled by gravel deposits equivalent to, and mapped as, alluvium of unit 3 (unit Qa3). Remnants of pediment gravel, not mapped, are scattered over hilltops and upland surfaces, and are commonly underlain by old alluvium (unit Qoa). Thickness 0–3 m

Unit Qf Alluvial-fan deposits (Holocene and Pleistocene?)—Poorly sorted, unconsolidated sand, silt, and gravel in fan-shaped deposits on valley sides, in tributary valleys, and in upper reaches of some main stream valleys. Fans formed by aggradation where detrital bedload exceeded transport capacity of streams; they are characterized by numerous distributary channels in their upper reaches. Grade laterally into colluvium (unit Qc). Probably as much as 5 m thick locally

Unit Qc Colluvium (Holocene and Pleistocene?)—Unsorted to poorly sorted silt, sand, and gravel deposited between steep valley sides and flatter valley floors. Material has moved downslope by sheetwash and locally by mudflow. Includes some talus (unit Qt), as well as some valley alluvium (units Qa1, Qa2), and eolian sand (unit Qe); grades laterally into fan deposits (unit Qf)

Unit Qt Talus deposits (Holocene and Pleistocene?)—Fallen rock fragments and blocks that form steep, unstable slopes below cliffs. Include disaggregated blocks and debris-flow material. Form mainly as debris aprons below high cliffs in southern part of quadrangle and in deeply incised valleys

Unit Ql Landslide deposits and slump blocks (Holocene and Pleistocene?)— Large blocks of rock that have become detached from cliffs and slid, fallen, or slumped as more or less integral units, as well as incoherent masses of material that have flowed over the surface. A large landslide mass west of the community of Pinedale, outlined by crosshatch pattern on the map, is 1.6 km long by 0.8 km wide and contains numerous displaced and tilted blocks of Gallup Sandstone (bed A), as well as of the main body of the Mancos Shale (unit Km), and of the Juana Lopez Member (unit Kmj)

Gallup Sandstone (Upper Cretaceous, Coniacian to Turonian)—The main body of the Gallup Sandstone, as well as Gallup bed B, which lies stratigraphically 23 m below the main body within the underlying Mancos Shale, have been eroded from the area of the quadrangle, but they crop out immediately to the north in the Oak Spring quadrangle (Kirk and Zech, 1984). Outliers of the stratigraphically lower bed A of the Gallup Sandstone, which is interbedded also within the Mancos Shale (unit Km), are found in the northern part of the quadrangle. The Gallup Sandstone beds represent well-developed regressive shoreline deposits. For further discussions of the Gallup Sandstone, see Sears (1925), Sears and others (1941), O'Sullivan and others (1972), Molenaar (1973), and Kirk and others (1978)

Unit Kga Gallup Sandstone, bed A—Very light gray to yellowish-gray, very fine grained to fine-grained, well-sorted sandstone. Sandstone beds coarsen, thicken, and become the predominant lithology upward in a typical marine regressive sequence; some beds are bioturbated and contain Ophiomorpha trace-fossil burrows; some are massive and contain lumpy, ellipsoidal, ball-and-pillow structures and sparse brown-weathering limestone concretions. A few beds, thin to medium in thickness, have shallow trough and wedge-planar crossbedding, and some contain finely divided plant detritus. Uppermost bed consists of brown-weathering, gray, sandy, iron-stained, thinly bedded calcarenite, 50–100 cm thick, that contains medium- to coarse-grained crystalline calcite, and rose, white, gray, and black quartz, quartzite, and chert, as well as scattered fossil shell debris. Top surface is planar, slightly eroded. Lower 1.5–3 m consists of very fine grained, thin, horizontally bedded and ripple-laminated silty sandstone, and interbedded medium- to dark-gray and olive-gray mudstone and shale, which grades downward into underlying Mancos Shale (unit Km). Regionally, bed A is interbedded in the marine Mancos Shale and is lenticular and discontinuous. Its extent is uncertain northward in the subsurface, but in outcrops north of this quadrangle its top is roughly 30 m stratigraphically below the base of the main body of the Gallup Sandstone. Probably deposited as an offshore marine sandbar. Thickness 12–17 m

Unit Km Mancos Shale, main body (Upper Cretaceous)—Mainly medium-dark-gray to medium-light-gray (N4–N6), but in some places grayish-black (N2), fissile shale, which commonly contains very finely divided coaly plant detritus. Shale is interbedded with sparse, thin-bedded, gray to brown sandy limestone and very fine grained limy sandstone and siltstone. Weathers dark yellowish brown to light grayish buff. Contact with underlying Twowells Tongue of Dakota Sandstone (unit Kdt) is sharp. The upper part of the Mancos Shale main body (unit Km), above the interbedded sandstone bed A of the Gallup Sandstone (unit Kga), is missing in this quadrangle. The Juana Lopez Member (unit Kmj), described below, is interbedded stratigraphically in the middle part of the Mancos main body (unit Km), but below bed A of the Gallup Sandstone (unit Kga). Calcarenite beds, 0–1 m thick, which commonly occur at the base, contain abundant and distinctive fossil mollusks Pycnodont "Gryphaea" newberryi Stanton and Exogyra levis Stephenson (Landis and others, 1973, p. J9 and J27). Deposited in off-shore marine environment. Total thickness of unit in nearby measured sections outside the quadrangle between main body of the Gallup Sandstone and the Twowells Member of the Dakota Sandstone (unit Kdt) is about 230 m, but the unit is only 155 m thick in this quadrangle.

This unit also includes the Bridge Creek Limestone Member (Cenomanian), which was not mapped separately because of sparse outcrops in the map area. Called Greenhorn Limestone Member by some workers. Consists of as many as three very thin, white porcelaneous limestone beds, interbedded with black shale. They occupy a zone 4 m thick, 10–12 m above base of the main body of the Mancos Shale (unit Km); they form a readily distinguishable marker zone on geophysical well logs, but outcrops are poor to nonexistent. Limestone beds contain late Cenomanian index fossil Sciponoceras gracile and are correlated with basal part of the Bridge Creek Member of the Greenhorn Formation of southeastern Colorado (Hook and Cobban, 1981, p. 6)

Unit Kmj Mancos Shale, Juana Lopez Member (Turonian)—Pale-yellowish-brown (10YR7/2) to light-olive-gray (5Y6/2), thin (15–45 cm), platy, silty calcarenite interbedded with thin to thick intervals of dark-gray, noncalcareous, fissile shale; calcarenite typically weathers moderate yellowish brown to orange brown. Calcarenite beds number four or more, are very fine grained to coarse-grained, consist predominantly of bioclastic detritus and quartz grains cemented with calcium carbonate, and contain abundant marine fossils, shark teeth, and phosphatic fish-bone debris. Calcarenite beds are persistent and are marked by sharp attenuations on resistivity and spontaneous-potential geophysical logs. On outcrop, calcarenite beds are more resistant than enclosing shale, forming subdued cuestas and ledgy slopes. Basal beds typically overlie very dark gray carbonaceous shale having thin platy interbeds of limy siltstone. Faunal zonation and correlation of Juana Lopez is based on widely distributed ammonites Prionocyclus, Scaphites, Baculites, and Coilopoceras and pelecypods Inoceramus, Lopha, and Lucina (Dane and others, 1966, p. H7). Top of the Juana Lopez is about 130 m stratigraphically above base of the main body of the Mancos Shale (unit Km). Beds are thought to have accumulated slowly in deep marine waters at the maximum regional transgression of the sea during Cenomanian-Turonian time. Thickness 15–20 m, depending on number and arrangement of calcarenite beds

Unit Kmw Mancos Shale, Whitewater Arroyo Tongue (Cenomanian)—Medium- to dark-grayish-green, fossiliferous, silty shale. Weathers very pale yellowish gray. Includes thin lenses of laminated, yellowish-gray, very fine grained sandstone and clayey siltstone, and white bentonitic clay; also contains scattered pale-yellowish-orange (10YR8/6) limestone concretions as much as 1 m in diameter having cone-in-cone structure. Tongue contains Exogyra sp., Pycnodont sp., and other fossil mollusks. Contact with overlying Twowells Tongue of the Dakota Sandstone (unit Kdt) is gradational; basal contact with sandstone or shale of the main body of the Dakota (unit Kd) is sharp. Deposited in shallow-water marine shelf environment. Thickness is generally 20–26 m; thickness of combined Whitewater Arroyo Tongue and Twowells Tongue (unit Kdt) is nearly constant at 37 m

Unit Kdt Dakota Sandstone, Twowells Tongue (Upper Cretaceous, Cenomanian)—Yellowish-gray (5Y7/2–5Y7/4), very fine grained to fine-grained, silty sandstone, coarsening upward to fine to medium grained at top. Thin argillaceous sandstone beds in lower part are parallel bedded and ripple laminated, and interbedded with clayey shale and siltstone. Upwards, sandstone becomes better sorted, slightly coarser grained, and cleaner, and contains more siliceous and calcareous cement. Beds, 0.5–1.5 m thick, are mainly flat bedded, laminated, and amalgamated, but are massive in places; low-angle trough or tabular-planar crossbeds are rare. Many beds are bioturbated; vertical Ophiomorpha or horizontal Thalassinoides burrows 10 mm in diameter are abundant throughout, particularly in uppermost beds; some U-shaped burrows 4 mm in diameter are also present. At top, locally, are thin calcareous oyster banks and fossiliferous limestone lenses and pods. Molluscan fossils Exogyra and Pycnodonte are common. Upper contact with Mancos Shale (unit Km) is sharp; lower contact with White- watfer Arroyo Tongue of the Mancos Shale (unit Kmw) is gradational. Crops out prominently along north flank of Fallen Timber Ridge, where its top sandstone bed forms steep dip slope of monoclinal flexure and displays conspicuous joint patterns. Deposited as a shallow marine offshore bar. Thickness 12–15 m, rarely as much as 20 m

Unit Kd Dakota Sandstone, main body (Upper Cretaceous, Cenomanian)—Mostly light-grayish-yellow and very pale orange (10YR8/2) siliceous sandstone in cliff-forming beds as thick as 10 m and commonly at or near the top of the unit. Sandstone beds are variously massive, thin bedded, tabular-planar and trough crossbedded, burrow mottled, and ripple marked; some contain plant remains, and a few are slightly calcareous. In some places (as in the SW1/4 sec. 20, T. 16 N., R. 15 W., southwest of Pinedale), the Dakota consists mostly of thin-bedded, light-gray to black carbonaceous claystone, shale, siltstone, and very fine grained, ripple-laminated sandstone, which contain carbonized plant debris. All range from partings to beds 2 m thick. Includes lignitic and bituminous coal beds, 2 cm to 0.8 m thick, and lenses of coarse- to fine-grained fluvial-channel sandstone, as much as 2 m thick. Some beds are interpreted as lagoonal, deltaic, and beach deposits; others were probably deposited in the flood plains of rivers, in abandoned channels and meander loops, and in associated freshwater and coastal swamps. Unit is correlative with Oak Canyon Member of the Dakota of Landis and others (1973) in the Laguna, N. Mex., area, 100 km east-southeast of quadrangle. Tricolporate pollen, Nyssapollenites albertensis, near base establish age as early Cenomanian (early Late Cretaceous) (R.H. Tschudy, written commun., 1981). Base of Dakota lies on a widespread erosional unconformity. Top of unit contains thin and sparsely scattered conglomerate beds, as much as 30 cm thick, containing fairly well rounded chert pebbles. Conglomerate probably represents beach lag gravel from marine encroachment. Contact with overlying Whitewater Arroyo Tongue of the Mancos Shale (unit Kmw) is disconformable. Thickness of main body ranges from 20 to 40 m

Morrison Formation (Upper Jurassic)—The Morrison Formation, from top to bottom, consists of Brushy Basin, Westwater Canyon, and Recapture Members in the region between Grants and Gallup, N. Mex. Fluvial feldspathic sandstone of the Westwater Canyon Member continued to be deposited throughout the accumulation of the Brushy Basin tuffaceous flood-plain and lacustrine deposits; the upper part of the Westwater Canyon Member interfingers with, and in some places has scoured out and displaced, appreciable amounts of the Brushy Basin Member, so that the two members vary greatly and reciprocally in thickness. Sandstone, similar to that of the Westwater Canyon Member, forms discrete channel deposits interbedded within, and to the top of, the Brushy Basin. Some of these deposits in the lower part of the member have been loosely correlated with the uranium-bearing Poison Canyon Sandstone in the Grants and Laguna mining districts. Lithology of these units is described below

Unit Jmb Morrison Formation, Brushy Basin Member (Upper Jurassic)—Mostly pale-olive (10Y6/2) and light-olive-gray (5Y5/2), massive sandy mudstone; greenish- and reddish- to purplish-gray, thinly bedded and laminated clayey siltstone, claystone, and shale. Bedding is poorly defined. Clay mostly bentonitic from incorporated altered air-fall and water-laid tuff. Mudstone is generally composed of angular to rounded, very fine grained to silt-size quartz, feldspar, and rock fragments, and sparse chlorite, biotite, and muscovite, enclosed in a dense, structureless montmorillonitic clay matrix. Contains lenses of interbedded feldspathic sandstone. Intertongues with underlying Westwater Canyon Member (unit Jmw). Mainly of fluvial flood plain and lacustrine origin. Thickness 5–50 m

Unit Jmbs Sandstone lenses within Brushy Basin Member—Light-yellowish-brown, pale-red (5R7/6), and white, fine- to coarse-grained, poorly sorted, friable, trough-crossbedded feldspathic sandstone, similar to underlying sandstone of Westwater Canyon Member (unit Jmw). Locally, sandstone is conglomeratic and contains abundant chert pebbles and clay balls, and a scattering of igneous rocks of different types. Sandstone has a detrital and authigenic clay matrix. Authigenic clay consists of clots (or nests) of white kaolin. Those lenses in contact with the overlying Dakota Sandstone (unit Kd) are commonly rich in kaolin, altered and bleached from acid-bearing ground water that descended from overlying organic-rich and coaly beds. Only lenses large enough to map are shown. Geometry of sandstone bodies, primary sedimentary structures, and textural characteristics indicate a fluvial-channel origin. Thickness 0–15 m

Unit Jmw Morrison Formation, Westwater Canyon Member (Upper Jurassic)—Moderate-red (5R6/4) to pale-red (10R6/2) and orange-pink (10R6/4), fine- to coarse-grained, fairly well to poorly sorted, trough-crossbedded feldpathic sandstone; forms imposing cliffs of stacked channels, generally in two tiers. Contains a few thin lenses of grayish-red (5R4/2) claystone that represent abandoned channel-fill and overbank deposits. Locally includes very coarse sandstone and chert-pebble conglomerate, and rarely a few cobbles; commonly contains rip-up clay clasts in basal part of scour channels. Composed mainly of quartz (more than 55 percent) and feldspar (15–30 percent), fragments of quartzite, chert, sparse igneous and metamorphic rocks, varying amounts of clay galls and clay matrix, and minor accessory and heavy minerals. Pink microcline is most abundant feldspar, followed by sodic plagioclase, orthoclase, sanidine, and perthite. The sandstone has been completely altered, first diagenetically, and then, in some places, by early cycles of reduction and oxidation associated with widespread uranium mineralization; at and near the surface it has been altered thoroughly by oxidation processes and weathering. Mottling, caused by clots of white authigenic kaolin in the matrix, is common. Contains limestone concretions as much as 3 m in diameter that produce hoodoo forms upon weathering. Includes a few lenses of eolian sandstone; one such bed, 11 m thick with prominent sweeping crossbeds, is exposed at the foot of Midget Mesa. Intertongues with overlying Brushy Basin Member (unit Jmb); scours underlying Recapture Member (unit Jmr). Derived from volcanic and granitic debris deposited by extensive braided stream-fan systems. Thickness 50–60 m

Unit Jmr Morrison Formation, Recapture Member (Upper Jurassic)—Deposits record transition from eolian to mixed lacustrine and fluvial environments. They include mostly thick units of interlayered, thinly bedded claystone, calcareous, clayey sandy siltstone, silty sandstone, and white, platy limestone, deposited in playa lakes; some are derived from reworked eolian sand and loess. The beds are mostly dark reddish gray (10R3/4), but many are light greenish gray (5GY7/1), reflecting deposition under, respectively, oxidizing or reducing conditions. In the lower part, they include relatively few thin beds of very fine-grained eolian sandstone and small fluvial channels of fine- to coarse-grained sandstone. Some interlayered flat and ripple-laminated, fine-grained sandstone represents either overbank or low-energy stream deposits. Common are burrow casts, 3–12 mm thick and as much as 30 cm long, many of them vertical; also present are bioturbated layers and calcium carbonate concretions. The upper part includes some thick (<10 m) beds of trough and planar crossbedded, poorly sorted, fine-grained to very coarse grained, feldspathic fluvial sandstone and conglomerate. Content of pink potassium feldspar in sandstone near the base is negligible but increases upward in section, so that stratigraphically higher sandstone beds approach the feldspathic composition of arkose and the character of the overlying Westwater Canyon Member. Upper sandstone beds typically contain scattered concentrations of white authigenic kaolin in their matrices from the alteration of feldspar. Thickness 25–37 m

Unit Jmrs Sandstone lenses within Recapture Member—Discontinuous lenses and channels of pale-reddish-gray, fine- to coarse-grained, poorly sorted fluvial feldspathic sandstone, interbedded in the upper part of the Recapture Member and of large enough extent to be shown on the map. They are similar to, and precursors of, the outpouring of sand that makes up the sandstone of the overlying Westwater Canyon Member. Thickness as much as 10 m

Cow Springs Sandstone (Upper and Middle Jurassic)—Composed of upper (unit Jcsu) and lower (unit Jcsl) eolian members, which are separated by a middle member (unit Jcsm) consisting of lacustrine beds of reworked eolian sandstone, siltstone, and claystone. The upper eolian member and middle member correlate with the Cow Springs Sandstone to the east in the Thoreau NE quadrangle (Green and Pierson, 1971), Bluewater quadrangle (Thaden and Ostling, 1967), and Goat Mountain and Dos Lomas quadrangles (Thaden and others, 1966 and 1967, respectively). The lower member correlates with the now-abandoned Bluff Sandstone as shown in those same quadrangles.

The middle member (unit Jcsm) is included at the top of the lower member of the Cow Springs Sandstone (unit Jcsl) in the Continental Divide quadrangle (Green, 1976) and at the top of the restricted Cow Springs Sandstone (unit Jcs) in the Thoreau Quadrangle (Robertson, 1990). Cooley and others (1969) described it as a lower tongue of the Recapture Member of the Morrison Formation, presumably because of its red claystone content in places. Detailed mapping by me, however, and by Green and Jackson (1975a,b) in the adjoining Church Rock and Mariano Lake quadrangles, found no connection. Erosion of both upper and lower eolian members results in badlands having characteristic dentritic drainage with many ravines and sharp spur ridges. The three members are described in detail below.

Unit Jcsu Cow Springs Sandstone, upper member (Upper and Middle Jurassic)—Pale-grayish-yellow-green (5GY7/2) to moderate-greenish-yellow (10Y7/2) and very light gray, very fine grained, silty, clean, well-sorted, friable sandstone having sweeping, high-angle, tangential to tabular crossbedding in large-scale cosets, 1–9 m thick. Generally neither clayey nor calcareous, but cosets are commonly truncated and separated by thin interbeds and partings of flat-bedded, calcareous and gypsiferous, very fine grained sandstone, siltstone, and claystone. Distributed widely are small colonies of "worm burrows" (trace fossils), 8 mm thick and 0.30 m or so long. Contact with overlying Recapture Member of the Morrison Formation (unit Jmr) ranges from sharp to gradational and intertonguing. Contact with lower beds is sharp. Represents extensive field of large eolian dunes and interdune playa deposits. Thickness 50–67 m

Unit Jcsm Cow Springs Sandstone, middle member (Middle Jurassic)—Interbedded pale-greenish-gray (5GY8/1), very fine sandstone and siltstone, reddish-gray clayey siltstone and claystone, and some nearly white to moderate brown (5YR4/2), highly calcareous sandstone and limestone. Generally thin to very thin and laminated, flat-bedded, and commonly ripple-bedded. Weathering of relatively minor red claystone interbeds coats underlying greenish-gray sandstone beds, giving false impression that claystone is the predominant rock type. Interbedded limestone and calcareous sandstone beds, 0.3–0.6 m thick, are generally platy and hard, and in many places they contain a honeycomb of worm burrows or a concentration of gypsum nodules at the top of beds. Interbedded clayey redbeds thin and disappear east of the quadrangle, but character of unit is recognizable at the top of the lower eolian unit of the Cow Springs Sandstone in the Continental Divide and Thoreau quadrangles. Although the upper contact is generally sharp and planar, it is somewhat eroded and scoured in places. The lower contact is everywhere planar and sharp. Accumulated in an extensive lake or playa that had inundated and leveled the underlying dune field during a prolonged wet cycle. Thickness 6–12 m

Unit Jcsl Cow Springs Sandstone, lower member (Middle Jurassic)—Has colors and lithology similar to the upper member (unit Jcsu). Mainly light greenish gray (5GY8/1) to very light gray (N8) and pinkish gray (5YR8/1) to white in upper part, more pale reddish brown (10R5/4) to grayish orange pink (5YR7/2) to white and mottled in the lower third. Predominantly thick-bedded, very fine grained, well sorted, friable sandstone, in some places calcareous and silty. Forms cliffs. Beds contain predominantly medium- to large-scale tangential and tabular crossbedding, as well as some asymmetric shallow crossbedding, all of eolian origin. The top part of each coset of crossbedded strata is generally truncated by an extensive planar erosion surface, upon which the succeeding coset is deposited. Commonly interbedded with the eolian crossbedded cosets is fine-grained to very fine grained, silty, generally clayey, thin, flat-bedded to laminated and massive sandstone. Sandstone beds, 0.3–2.7 m thick or more (average 0.9 m), are commonly separated by discontinuous, reddish- or greenish-gray claystone partings, which are generally much less than 0.3 m thick. Tops of beds commonly contain small colonies of trace fossil burrows. Basal 13 m has more massive and silty beds, similar to underlying Beclabito Member of the Wanakah Formation (unit Jwb), with which it is interbedded. Distinguished from the Beclabito by three or four persistent marker beds of white, fine-grained to very fine grained, well-sorted, medium-scale tabular and low-angle trough-crossbedded, highly calcareous eolian sandstone, the lowermost 1-m-thick bed of which defines the base of the Cow Springs Sandstone in the region. Represents accumulation of medium- to large-scale eolian dunes and interdune lake deposits of sand, silt, and clay. Massive silty beds in basal part suggest loess and reworked eolian sands of sebkha deposits. Thickness ranges from 50 to 60 m, increasing westward at the expense of the underlying Beclabito

Unit Jwb Wanakah Formation, Beclabito Member (Middle Jurassic)—Beds, 1–4 m thick, of light-brown (5YR6/4) to grayish-orange-pink (5YR7/2), clean, well-sorted, slightly to highly calcareous, very fine grained silty sandstone and siltstone; essentially quartz arenite, containing no feldspar and very minor heavy minerals. Mostly massive to flat bedded, faintly parallel bedded and ripple laminated. Considerable bioturbation and worm burrows occur in some beds. Slump structures, load casts, and undulatory and contorted bedding are common. Some beds have thin top rinds of lime-cemented sandstone. At the base of the member and interbedded throughout are thinly bedded, ripple-marked, dusky reddish-brown (10R2/4) clayey siltstone and mudstone and purplish-gray shaly claystone, 5–30 cm thick. Also interbedded at intervals, but more abundant toward the top, are persistent thin beds of very well sorted, clean, calcareous, white, fine-grained sandstone, 15–75 cm thick, containing well-defined eolian crossbedding. Member thins from east to west and grades laterally into the lower part of the overlying Cow Springs Sandstone. Top of member is arbitrarily placed at the base of the highest white sandstone bed, 1 m or more thick. Thin lenses of freshwater limestone are commonly interbedded in basal 6 m. Weathers to gentle slopes and is poorly exposed. Deposited in sebkha environment. Thickness 18–25 m

Unit Jwt Wanakah Formation, Todilto Limestone Member (Middle Jurassic)—Mostly light- to medium-dark-gray (N7–N4), thin-bedded lithographic limestone. Upper 0.3–1.0 m generally recrystallized to a coarse-grained texture. Slumping, flow rolls, load casts, and small-scale folding and crumpling of beds in the upper part are common. Lower part, as much as 6 m thick, includes interlaminated light-gray to brownish- and greeenish-gray (5YR5/1 and 5GY8/2), flat-bedded calcareous siltstone, very fine grained sandstone, and limestone, in layers 0.6–15 cm thick; some is ripple-laminated. Basal beds include, in many places, low-angle tangentially crossbedded, silty, fine-grained calcareous sandstone as much as several meters thick, reworked from the underlying Entrada Sandstone, with the basal 0.5 m or so marked by disturbed bedding, scour, and flame and roll structures. Maxwell (1976) suggested that the variable relief in the basal part represents an early-stage filling of topographic lows as the Todilto body of water migrated over the underlying eolian sands. Limestone forms erosion-resistant cap over Entrada cliffs and extensively stripped plains on top bedding surface. Origin uncertain, probably lacustrine or restricted marine embayment having euxinic environment. Thickness 2–10 m

Unit Jeu Entrada Sandstone, upper sandstone member (Middle Jurassic)—Reddish-orange to reddish-brown (10R5/6), very fine grained to medium-grained, well-sorted eolian-crossbedded sandstone in cosets as thick as 6 m, having generally moderate to large-scale, sweeping-tangential and trough crossbedding. Upper half locally contains interbedded lenticular beds of flat-bedded, reddish-gray, fine-grained, calcareous silty sandstone. The uppermost 0.3-3 m is commonly bleached to very pale orange or brown and is low-angle trough crossbedded and flat-bedded, in some places ripple laminated, suggesting reworking of eolian sands by encroaching lacustrine waters of the Todilto. The basal contact is sharp and planar. The lower 15 cm is bleached white and is highly calcareous; alteration probably occurred postdepositionally from circulating groundwaters. Forms bold cliffs, nearly shear in many places. Eolian dune and interdune sebkha origin. Thickness is relatively constant at 54–62 m

Unit Jer Entrada Sandstone, Rehoboth Member (Middle Jurassic)—Mostly water-deposited, dark-reddish-gray, well-sorted, very fine grained to fine-grained, argillaceous and calcareous sandstone and siltstone. Contains predominately subangular to subrounded quartz grains, coated by hematite; also, thin clay partings and bleached white mottling along some bedding planes. Beds are well consolidated, thick, and massive-appearing, with poorly defined bedding and laminations; oscillation ripples on some bedding planes. Forms bold cliffs having columnar jointing and hoodoo weathering features. Contains a few lenses of crossbedded eolian sandstone in its upper part. Upper contact is universally sharp and planar in eastern half of quadrangle and beyond quadrangle to east. In western half of quadrangle, lower part intertongues with the underlying Iyanbito Member and incorporates increasingly more interbeds and lenses of fine- to medium-grained eolian sandstone from east to west, causing progressive thickening of the Rehoboth from 15 m to as much as 25 m. Probably deposited in an inland sebkha, surrounded by widespread eolian dune fields. Formerly known as the medial siltstone member; it was renamed by Robertson and O'Sullivan (2001, p.61). The type section is in the Pinedale quadrangle, 4 km north northeast of Iyanbito

Unit Jei Entrada Sandstone, Iyanbito Member (Middle Jurassic)—Complex of thick eolian sandstone beds and interbedded, discontinuous interdune pond and playa deposits of siltstone, claystone, and reworked sandstone that weather to moderate slopes and crumbling exposures. Moderate- to pale-reddish-orange (10R6/6–10R8/6), crossbedded eolian sandstone accounts for 50–80 percent of the member. It contains mostly very fine grained to medium-grained, well-sorted, well-rounded quartz, minor clay and feldspar, and abundant, fine- to coarse-grained, subrounded to angular, white chert. Chert probably formed secondarily from silica through chemical interactions in interdune playas, then was reworked in water-laid sediments or blown into dunes; it is conspicuous along coarse-grained cross laminations, but is widespread throughout the member. Interdune deposits are more prevalent in the upper one-third, where beds are transitional to the overlying Rehoboth Member (unit Jer); they are abundant in the lower part but are thinly

Unit Trco Chinle Formation, Owl Rock Member (Upper Triassic)—White- and purplish- to greenish-gray-mottled, cherty, nodular limestone of freshwater origin. It has faint horizontal bedding, is bioturbated, locally contains trace-fossil burrows, and is extensively replaced by irregular masses of chalcedony. Consists of a single bed, 0–1.2 m thick, topped by the regional J–2 erosional unconformity (Robertson and O'Sullivan, 2001). Locally, it is broken and brecciated in the upper part or scoured out by erosion; it is entirely missing in the east half of the quadrangle. Deposited in a broad lacustrine basin

Unit Trcpu ddish- to purplish-gray, sandy to clayey siltstone and claystone, commonly calcareous. Poorly exposed generally, but well exposed below Entrada cliffs and in dissected pediments in southeastern part of quadrangle. Many beds are packed with small (5 mm to 3.4 cm), rounded, silty, clayey calcium carbonate nodules, crystallized in place in, or reworked from, calichified paleosol. Bedding, obscure or obliterated in many places, is thick, massive to undulating, flat, and laminated; some beds are ripple laminated, a few have large-scale shallow-trough and hummocky crossbedding; some false bedding. Smectite-rich clays swell and become slick when wet, forming frothy weathered surfaces, and cause extensive slump failure in overlying beds. Includes medium- to dark-greenish and reddish-gray, fine- to coarse-grained, poorly sorted to well-sorted, micaeous and lithic fluvial sandstone and conglomerate in thin, lenticular beds. Flood-plain and lacustrine origin. Overlies Sonsela Sandstone Bed of the Petrified Forest Member. Base is not exposed in quadrangle but is exposed 1.5 km south of quadrangle in Ciniza quadrangle. Thickness 280 m

Unit TRcpc Chinle Formation, Petrified Forest Member, upper part, sandstone bed at Crazy Woman Canyon (Upper Triassic)—Prominent ledge, within, and 56 m stratigraphically below the top of, the Petrified Forest Member. Westward pinchout edge is 4 km east of community of Iyanbito, and bed extends 12 km east of quadrangle. Distinctive fluviatile sandstone and conglomerate beds occur in one to three units of complex, fining-upward cycles. Includes unsorted debris mudflows, poorly sorted granule-pebble conglomerate (cobbles locally), and very coarse grained conglomeratic sandstone, commonly in channels and lenticular beds at the base. In lower third to half of upward-fining cycles, conglomerates are interbedded with, and succeeded by, mostly grayish-purple, poorly sorted, fine- to coarse-grained, locally pebbly sandstone. The associated sandstone and conglomerate form complex stacked channels, 0.3–3 m thick, having medium-scale, low-angle trough crossbeds. Upper part of cycles, as well as upper part of unit generally, contains mostly very fine grained to fine-grained, well-sorted sandstone, which grades into siltstone and claystone at the top; beds range in thickness from 0.3 to 1.2 m. Beds generally contain medium- and small-scale, low-angle trough crossbedding, but also contain much interbedded tabular-planar crossbedding and planar bedding with abundant parting lineation. Sandstone is markedly immature in composition; contains variable mixture of angular to well-rounded quartz, chert, cherty calcareous nodules, red and green clay chips, biotite and other femic minerals, abundant red and black iron oxides, and relatively high content of feldspar, rock detritus, and silty clay matrix. Classified as feldspathic lithic arenite or wacke. Deposited primarily by braided streams dominated by flash floods and high flow regimes, in a tropical climate that fluctuated between monsoon rain and hot dry seasons. Thickness 0–12 m

Unit TRcpt Chinle Formation, Petrified Forest Member, upper part, Taaiylone Sandstone Bed (Upper Triassic)—Fluvial sandstone, poorly represented in a few outcrops near its pinchout in the southwest corner of the quadrangle. Well exposed in adjoining Churchrock quadrangle (Green and Jackson, 1975a) to west, where it generally consists of three ledges of medium- to light-brownish-gray (5YR6/1) to dusky-grayish-red (5R4/2), poorly sorted, very fine to very coarse grained sandstone, interbedded conglomerate, and thin, dusky-reddish-gray claystone and siltstone. It is similar in composition and origin to the sandstone bed at Crazy Woman Canyon. Named by Cooley (1959, p. 71). Thickness 0–13 m

LIST OF SYMBOLS USED ON MAP

Contact

Fault—Showing vertical dip and amount of displacement in meters where measured. Dashed where approximately located; dotted where concealed.

U, upthrown side; D, downthrown side

Anticline—Showing bearing and plunge of axis

Syncline—Showing bearing and plunge of axis

Monoclinal flexures—Showing upper and lower fold axes. Arrows indicate direction of dip; amounts of dip shown where measured. Longer arrows indicate flatter dip

Strike and dip of inclined beds

Strike of vertical joints

Direction and amount of dip of crossbedding

Structure contour—Showing base of Dakota Sandstone (unit Kd). Dashed where projected above ground surface. Contour interval 100 ft. National Geodetic Vertical Datum of 1929

Massive landslide—Shown by diagonal lines. Top of slip surface marked by line, with hachures on failure side; dotted where concealed

Earth dam or dike

Limestone quarry

Jeep trail

Ephemeral lake bed

NOTE

The upper member of the Cow Springs Sandstone (unit Jcsu) was assigned as an eolian facies of the overlying Recapture Member of the Morrison Formation (unit Jmr) along the southern margin of the San Juan Basin by Condon and Peterson (1986, p. 18, and stratigraphic section, fig. 4b) and Condon and Huffman (l984, p. 103). To accommodate this view, Robertson (1990) included it as a basal eolian sandstone member of the Morrison Formation (unit Jms) in the Thoreau quadrangle. It is restored in the Pinedale quadrangle, however, to the upper member of the Cow Springs Formation because of its lithologic affinities and depositional continuity with the lower and middle members. It is defined as part of the Cow Springs Formation by Harshbarger, Repenning, and Jackson (1951, p. 97) and by Harshbarger, Repenning, and Irwin (1957, p. 48), and is shown as part of the Cow Springs Formation on the geologic map of the Gallup area by Cooley and others (1969, pl. I, sheet 8 of 9).

STRUCTURE

The Pinedale quadrangle is situated at the south margin of the Chaco Slope in the southern part of the San Juan Basin and a few kilometers northeast of the Zuni uplift. The sedimentary rock formations, about 1,000 m thick, form a gentle homocline, striking west-southwest and east-west and dipping 21/2°–3° N., that is interrupted by the Pinedale monocline, which traces a sinuous west-northwest trend across the north half of the quadrangle and downfolds the strata some 200 m (cross section A–A'). The lower limb of the monocline is well exposed in the vicinity of Pinedale, where the top bed of the Twowells Tongue (unit Kdt) dips as much as 20° N. The lower limb has a sharp bend along its trend in the eastern part, at the prominent canyon where the drainage has eroded through the upturned strata of the hogback ridge. The upper limb is marked by a north-plunging anticlinal flexure in its eastern end, followed by broad synclinal and anticlinal flexures adjoining it to the northwest. The bends or flexures are reflected in the broad syncline and depicted by the structure contours north of the monocline.

A fault, having only about 3 m of vertical down-to-the-north displacement, trends several kilometers westward across the Todilto Limestone Member bench in the southwest quarter of the map. Two vertical joint sets are prominently developed to the southeast of Pinedale in the Twowells Tongue (unit Kdt), which makes up the hogback ridge of the Pinedale monocline. One set essentially follows the strike of the beds; the other strikes mostly N. 40° E. to N. 55° E. A lineament, strongly defined by linear drainage and outcrop patterns, trends N. 30° E. from the southwest quarter of the map, through deeply incised canyons in the central part of the quadrangle, and passes through the prominent canyon and notch cut in the hogback ridge of the monocline. Although no displacement could be discerned, such a persistent lineament or joint fracture may be controlled by a buried fault. Other nearby valley drainages and outcrop patterns indicate a joint set having the same strike.

Deformation that produced the homoclinal structure and the Pinedale monocline, as well as the persistent northeast-trending joints and lineaments, is probably related to stresses associated with renewed uplift of the Zuni Mountains that took place in latest Cretaceous and earliest Tertiary time, during the Laramide orogeny (Kelly and Clinton, 1960, p. 22 and 47).

REFERENCES CITED

Bryan, Kirk, 1954, The geology of Chaco Canyon, New Mexico—In relation to the life and remains of the prehistoric peoples of Pueblo Bonito: Smithsonian Miscellaneous Collections, v. 122, no. 7, 65 p.

Condon, S.M., and Huffman, A.C., Jr., 1984, Stratigraphy and depositional environments of Jurassic rocks, San Juan Basin, New Mexico, with emphasis on the south and west sides, in Brew, D.C., ed., Field Trip Guidebook, 37th Annual Meeting of Rocky Mountain Section, Geological Society of America: Durango, Colo., Four Corners Geological Society, p. 93–107.

Condon, S.M., and Huffman, A.C., Jr., 1988, Revisions in nomenclature of the Middle Jurassic Wanakah Formation, northwest New Mexico and northeast Arizona: U.S.Geological Survey Bulletin 1633–A, p. A1–A12.

Condon, S.M., and Peterson, Fred, 1986, Stratigraphy of Middle and Upper Jurassic rocks of the San Juan Basin—Historical perspective, current ideas, and remaining problems, in Turner-Peterson, C.E., Santos, E.S., and Fishman, N.S., eds., A basin analysis case study—The Morrison Formation, Grants uranium region, New Mexico: American Association of Petroleum Geologists Studies in Geology 22, p. 7–26.

Cooley, M.E., 1959, Triassic stratigraphy in the state line region of west-central New Mexico and east-central Arizona: New Mexico Geological Society Guidebook of west-central New Mexico, Tenth Field Conference, p. 66–73.

Cooley, M.E., Harshbarger, J.W., Akers, J.P., and Hardt, W.F., 1969, Regional hydrogeology of the Navajo and Hopi Indian Reservations, Arizona, New Mexico, and

Utah, with a section on Vegetation by O.N. Hicks: U.S. Geological Survey Professional Paper 521–A, 108 p.

Dane, C.H., Cobban, W.A., and Kauffman, E.G., 1966, Stratigraphy and regional relationships of a reference section for the Juana Lopez Member, Mancos Shale, in the San Juan Basin, New Mexico: U.S. Geological Survey Bulletin 1224–H, 15 p.

Goddard, E.N., chm., and others, 1948, Rock-color chart: National Research Council; reprinted by Geological Society of America, 1970, 6 p.

Green, M.W., 1974, The Iyanbito Member (a new stratigraphic unit) of the Jurassic Entrada Sandstone, Gallup-Grants area, New Mexico: U.S. Geological Survey Bulletin 1395–D, 12 p.

Green, M.W., 1976, Geologic map of the Continental Divide quadrangle, McKinley County, New Mexico: U.S. Geological Survey Geologic Quadrangle Map GQ–1338, scale 1:24,000.

Green, M.W., and Jackson, T.J., 1975a, Geologic map of the Church Rock quadrangle, McKinley County, New Mexico: U.S. Geological Survey Open-File Report 75–258, scale 1:24,000.

Green, M.W., and Jackson, T.J., 1975b, Geologic map of the Mariano Lake quadrangle, McKinley County, New Mexico: U.S. Geological Survey Open-File Report 75–261, scale 1:24,000.

Green, M.W., and Pierson, C.T., 1971, Geologic map of the Thoreau NE quadrangle, McKinley County, New Mexico: U.S. Geological Survey Geologic Quadrangle Map GQ–954, scale 1:24,000.

Harshbarger, J.W., Repenning, C.A., and Irwin, J.H., 1957, Stratigraphy of the uppermost Triassic and the Jurassic rocks of the Navajo Country: U.S. Geological Survey Professional Paper 291, 74 p.

Harshbarger, J.W., Repenning, C.A., and Jackson, R.L., 1951, Jurassic stratigraphy of the Navajo Country: New Mexico Geological Society Guidebook, Second Field Conference, San Juan Basin, p. 95–99.

Hook, S.C., and Cobban, W.A., 1981, Late Greenhorn (mid-Cretaceous) discontinuity surfaces, southwest New Mexico, in Contributions to mid-Cretaceous paleontology and stratigraphy of New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 180, p.5–15.

Kelly, V.C., and Clinton, N.J., 1960, Fracture systems and tectonic elements of the Colorado Plateau: Albuquerque, University of New Mexico Publications in Geology Number 6, 104 p.

Kirk, A.R., Huffman, A.C., Jr., Zech, R.S., Robertson, J.F., and Jackson, T.J., 1978, Review of the history of usage of the Gallup Sandstone and related units, southern and western San Juan Basin, New Mexico: U.S. Geological Survey Open-File Report 78–1055, 51 p.

Kirk, A.R., and Zech, R.S., 1984, Geologic map of the Oak Spring quadrangle, McKinley County, New Mexico: U.S. Geological Survey Geologic Quadrangle Map GQ–1583, scale 1:24,000.

Landis, E.R., Dane, C.H., and Cobban, W.A., 1973, Stratigraphic terminology of the Dakota Sandstone and Mancos Shale, west-central New Mexico: U.S. Geological Survey Bulletin 1372–J, 44 p.

Maxwell, C.H., 1976, Geologic map of the Acoma Pueblo quadrangle, Valencia County, New Mexico: U.S. Geological Survey Geologic Quadrangle Map GQ–1298, scale 1:24,000.

Molenaar, C.M., 1973, Sedimentary facies and correlation of the Gallup Sandstone and associated formations, northwestern New Mexico, in Fassett, J.E., editor, Cretaceous and Tertiary rocks of the Colorado Plateau: Four Corners Geological Society Memoir, p. 86–110.

O’Sullivan, R.B., and Beaumont, E.C., 1957, Preliminary geologic map of western San Juan Basin, San Juan and McKinley Counties, New Mexico: U.S. Geological Survey Oil and Gas Investigations Map OM–190, scale 1:125,000.

O’Sullivan, R.B., Repenning, C.A., Beaumont, E.C., and Page, H.G., 1972, Stratigraphy of the Cretaceous rocks and the Tertiary Ojo Alamo Sandstone, Navajo and Hopi Indian Reservations, Arizona, New Mexico, and Utah: U.S. Geological Survey Professional Paper 521–E, p. E1–E65.

Robertson, J.F., 1973, Geologic map of the Thoreau quadrangle, McKinley County, New Mexico: U.S. Geological Survey Open-File Report, scale 1:24,000.

Robertson, J.F., 1990, Geologic map of the Thoreau quadrangle, McKinley County, New Mexico: U.S. Geological Survey Quadrangle Map GQ–1675, scale 1:24,000.

Robertson, J.F., and O’Sullivan, R.B., 2001, The Middle Jurassic Entrada Sandstone near Gallup, New Mexico: The Mountain Geologist, v. 38, no. 2 (April 2001), p. 53–69.

Sears, J.D., 1925, Geology and coal resources of the Gallup-Zuni Basin, New Mexico: U.S. Geological Survey Bulletin 767, 53 p.

Sears, J.D., Hunt, C.B., and Hendricks, T.A., 1941, Transgressive and regressive Cretaceous deposits in southern San Juan Basin, New Mexico: U.S. Geological Survey Professional Paper 193–F, p. 101–121.

Smith, C.T., and others, 1954, Geology of the Thoreau quadrangle, McKinley and Valencia Counties, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 31, 36 p.

Smith, C.T., and others, 1967, Jurassic stratigraphy of the north flank of the Zuni Mountains, in Trauger, F.D., ed., Guidebook of Defiance–Zuni–Mt. Taylor region, Arizona and New Mexico; New Mexico Geological Society, 18th Field Conference, 1967: Socorro, New Mexico Bureau of Mines and Mineral Resources, p. 132–137.

Thaden, R.E., and Ostling, E.J., 1967, Geologic map of the Bluewater quadrangle, Valencia and McKinley Counties, New Mexico: U.S. Geological Survey Geologic Quadrangle Map GQ–679, scale 1:24,000.

Thaden, R.E., Santos, E.S., and Ostling, E.J., 1966, Geologic map of the Goat Mountain quadrangle, McKinley County, New Mexico: U.S. Geological Survey Geologic Quadrangle Map GQ–518, scale 1:24,000.

Thaden, R.E., Santos, E.S., and Ostling, E.J., 1967, Geologic map of the Dos Lomas quadrangle, Valencia and McKinley Counties, New Mexico: U.S. Geological Survey Geologic Quadrangle Map GQ–680, scale 1:24,000.

OTHER INFORMATION ABOUT THIS MAP

Base modified from U.S. Geological Survey, 1963

10,000-foot grid based on New Mexico coordinate, west zone

1,000-meter Universal Transverse Mercator grid ticks, zone 12

1927 North American Datum

Geology mapped 1971–1973

Edited by Diane E. Lane

Digital database by Darren Van Sistine and Diane E. Lane

Digital cartography by Gayle M. Dumonceaux

Manuscript approved for publication February 11, 2003