Geology of Fort Wingate Quadrangle, McKinley County, New Mexico

By

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Introduction

The Fort Wingate 7ﬁ-min quadrangle lies in McKinley County, northwestern New Mexico. The coordinates at the northwest corner of the quadrangle are 35°30'N latitude and 108°37'30"W longitude. Access to the quadrangle is provided by I–40, which crosses the extreme northeastern corner of the quadrangle, by NM–400, and by several other secondary roads leading from those highways. The only permanent settlements within the quadrangle boundaries are the nearly abandoned village of McGaffey, located near the southeast corner along NM–400 just below McGaffey Lake (reservoir), and the modern village of Fort Wingate, also located on NM–400. The now abandoned Fort Wingate Army Depot (a munitions-storage facility) occupies a total area of nearly 26 mi^2 along the western and northern boundaries of the quadrangle. There are numerous roads leading from the base of operations, located just north of the quadrangle boundary. These roads provide access to the approximately 500 concrete bunkers that formerly stored munitions and small weapons. All the bunkers lie within the quadrangle, and nearly all are built 200–300 ft apart in northeast- or north-trending rows. Most are located on a dip slope of the Sonsela Sandstone Member of the Petrified Forest Formation. Shrapnel and munition hulls or shells are scattered around a site at the west-central margin of the quadrangle as this was the area used for disposal (detonation) of obsolete and surplus munitions or weapons. This area is restricted and likely to remain so even following final settlement of land status of this military withdrawal.

The dominant topographic and structural feature on the quadrangle is the northern segment of the Nutria monocline. It is known locally as "The hogback," and it essentially follows the western margin of the quadrangle. Two major ridges or hogbacks developed on Cretaceous sandstones are commonly present, extending in parallel fashion, approximately 1,000–1,200 ft apart, northward and northwestward to the northern end of the Zuni uplift. The southwest margin of the Zuni uplift is defined by the hogback (Nutria monocline), which locally has as much as 6,000 ft of structural relief (Kelley, 1955) down to the southwest. Dips commonly exceed 60° and locally exceed 80°. The monoclinal belt, which dips in excess of 10°, is cut by a thrust fault in the southwest corner of the quadrangle in secs. 2 and 11 T13N R17W and sec. 35 T12N R17W. This thrust eliminates all Jurassic and Triassic strata and brings Permian rocks against the Dakota Sandstone (Upper Cretaceous). The Permian rocks attain an elevation some 400 ft above the Crevasse Canyon Formation (Upper Cretaceous, Coniacian), and thus structural relief at this point approaches 4,000 ft.

Another monoclinal flexure is present in the southeast corner of the quadrangle. This monocline is the northward continuation of Oso Ridge. The hogback or crestal ridge in this monocline is formed of Permian rock (San Andres and Glorieta Formations), which locally dips as much as 75° to the west. Thus the sense of movement and structural relief are similar to that of the Nutria monocline, the difference being that Oso Ridge is eroded to deeper structural levels; in fact, Precambrian basement rock is exposed in the extreme southeastern corner of the quadrangle, east of McGaffey.

Much of the area between the two monoclines is characterized by gently to moderately incised dip slopes developed on the Glorieta Sandstone or San Andres Limestone in the west half and on sandstones of the Chinle Group in the east half. Northeasterly and to a lesser extent northerly trending low-displacement normal faults locally offset the dip slopes or mesas. Elevations range from a high of 8,291 ft in the southwest corner to approximately 6,750 ft at the northern boundary east of NM–400.

The area is drained by southern tributaries of the south fork of the Puerco River. These tributaries are intermittent, high-gradient streams (100 ft/mi or more) that run briefly in the spring following snow melts and after late summer/early fall convection thunderstorms. A 1-inch rainfall can produce significant flow in some of these tributaries. They discharge into the Puerco River, which itself is intermittent and flows westward to join the Little Colorado River near Holbrook, Arizona. The gradient of the Puerco is moderate for Colorado Plateau streams, maintaining a 16 ft/mi fall throughout its course in New Mexico. It has cut a water gap (the Puerco Gap) through the hogback at a point approximately 4 mi northwest of the northwest corner of the quadrangle. A lip of resistant Dakota Sandstone at stream level in Puerco Gap provides base-level control on the upstream part of the drainage basin.

The climate and vegetation are typical of the southern Colorado Plateau. The climate might be called mild continental; however, the northwestern part of New Mexico always records the lowest winter temperatures of any area in the state; the January mean for the area is 14°F (Tuan et al., 1969), and mid-winter minimums of -40°F or lower have been recorded. The July mean is approximately 74°F for the adjacent San Juan Basin (Tuan et al., 1969). Most of the precipitation falls as rain in late summer, although winter snowfall is important (especially above 7,000 ft) because the slow-release melt allows higher infiltration versus runoff ratios. Annual precipitation for the Fort Wingate area is 14.5 inches (Tuan et al., 1969). This is sufficient to support a piñon (*Pinus edulis*) and juniper (*Juniperus monosperma*) cover down to 6,800–6,900 ft, although complete, unbroken cover is achieved only at elevations of 7,000 ft and above. At 7,500 ft ponderosa pine (*Pinus ponderosa*) are common, mixed with piñon. Above 8,000 – 8,200 ft scattered fir stands (*Abies* sp.) may be seen on steep slopes or locally mixed with ponderosa. The earlier timber industry centered at McGaffey and southward from 1900 to 1926 harvested mostly ponderosa pine.

Economic activity and land use in the area consist primarily of ranching and grazing. No arable land is present within the quadrangle. Mineral extraction, nil at present, has been minimal in the past. Two aggregate pits near the center of the quadrangle have produced material from the San Andres Limestone that was crushed and used for road construction or surfacing. Thin coal beds in the Gallup Sandstone crop out in the hogback in the southwest corner of the quadrangle but are subeconomic due to structural dip and thinness. Thin coal beds are also likely to be present in the overlying Crevasse Canyon Formation within an approximately 2 mi^2 area at the southwestern corner; however, very little coal was noted in outcrop. Conditions are favorable for shallow ground water in the northern and northwestern parts of the quadrangle.

Structure

Spanning nearly the entire length of the quadrangle at its western margin, the Nutria monocline (the hogback) is the dominant geologic structure in the area. With as much as 4,000 ft of structural relief locally, this down-to-the-southwest flexure is abrupt, is generally less than 2 mi wide, and sharply defines the southwestern edge of the Zuni uplift, or Zuni Mountains.

Erosional beveling of the steep limb of the monocline has resulted in excellent outcrops of Jurassic and Upper Cretaceous rocks, the more resistant sandstones forming hogbacks. Attitudes on these sandstones range from 42° to 45° in the northwestern part of the quadrangle to as much as 85° at the southern margin. In this southern location the steeper dips might be related to the influence of a small-scale, west-vergent thrust fault, the Stinking Springs thrust of Edmonds (1961). The thrust has placed Permian rocks over Triassic and Jurassic rocks, the leading edge essentially against basal Cretaceous sandstone in the hogback. This fold–thrust structure is illustrated in cross section B–B', which accompanies the geologic map. Although the plane of the thrust is not exposed it is interpreted as a low- to moderate-angle thrust, dipping 32°–34° to the east on the basis of the observed structural relationships. These observations are: the structural relief, which is approximately 3,500 ft, and the amount of lateral translation or horizontal transport distance, which is roughly 1 mi. The relationship of these two values (3,500 to 5,280) yields the tangent of the dip angle of the thrust plane. The resulting number corresponds to an angle of 33° (with the horizontal).

As Edmonds (1961) pointed out, the thrust clearly postdates the folding of the monocline and may be even considerably younger. Importantly, these two distinct features are perceived as being related to very different stress fields, the earlier one vertical, the later one horizontal (see below). With respect to the latter event, the principal horizontal stress axis, based on the geometry of the upper plate of the thrust sheet, was near east–west.

Additional faulting modifies the monocline locally. Minor strike-slip faulting in a left-lateral wrench system apparently offsets the dual, parallel hogbacks of Cretaceous sandstone immediately south of the apex of the thrust in sec. 2 T13N R17W. This left-lateral slip has occurred along a N 60°W-trending fault (as mapped) and may be as much as 400 ft. No analogous fault was found to the north of the apex, which if present would have defined some differential "riding out" of a central block; however, a dip-slip normal fault was recognized at the north end of the thrust (see map).

Middle and late Tertiary erosion has removed most of the Mesozoic rocks from the crest of the monocline. What remains are the sharply flexed Permian and Mesozoic sedimentary rocks at the base of the structure, which now constitute the hogback. In determining the type of basement faulting responsible for the formation of a monocline or drape fold, it is important to note the presence or absence of overturned beds. There are no overturned beds in the hogback on the Fort Wingate quadrangle or elsewhere along this structure.

If the controlling basement fault was a thrust, overturned beds would be expected in the folded sedimentary sequence, as per Berg (1962). The complete absence of overturned strata at the structural levels exposed by modern erosion suggests that the controlling fault was very high angle (meaning >70°) and either normal or reverse. The prevailing thought is that the Zuni uplift is associated with the Laramide orogeny and that this tectonic event is primarily the result of horizontal compressive stress. We thus interpret the fault as high angle reverse, but we recognize the initial crustal disturbance as being vertical uplift. High-angle reverse movement in response to horizontal compression is perhaps possible only via the utilization of preexisting faults or zones of weakness. Even then it is unlikely that the plane of failure (fault plane) can be at an angle greater than 70° to the axis of principal horizontal stress (Reiter, 1997).

Nonetheless, the observational data support a model of vertical uplift with only local and minimal evidence of crustal shortening or thrusting across the uplift. This supports a tectonic model in which the initial deformation took place as a result of vertical forces, and failure by faulting was at very high angles. Vertical crustal movement may have taken place within a stress field that had a component of horizontal compressive stress; however, the initial yielding was not via thrust faulting in this model. It is the author's (Anderson) interpretation that the upward-directed vertical stress field was driven instead by mid-crustal (or lower) transfer of material to the area of the Zuni block. This may well have involved transfer of subcrustal or lower crustal material away from the area of the developing San Juan Basin southward and toward incipient uplifts because balanced cross sections require that the material come from somewhere. This nonuniform, out-of-the-basin transfer of a significant volume of rock would have influenced all surrounding uplifts. The volume of lower crustal or subcrustal material that had to be removed from the adjacent basin to accommodate lower Tertiary sediments (Laramide) of the Ojo Alamo, Nacimiento, and San Jose Formations is herein estimated at 1,820 mi^3. This is nearly three times the volume of material (680 mi^3) that would be needed to produce the Zuni uplift, so the plausibility of this mechanism is established.

Once crustal integrity in the Zuni structural block was compromised by vertical uplift, the developing stress field related to Laramide horizontal compression became the dominant element in further deformation. It was during this compressive phase that the aforementioned west-vergent Stinking Springs thrust, with as much as 1 mi of overhang, developed. Perhaps other modifications to the monocline also occurred at this time.

Inasmuch as the northeastern margin of the Zuni uplift has no defining monocline as does the southwestern margin, the original uplift was apparently asymmetric, just as it is at present. The degree of asymmetry, however, was likely increased due to later compressive deformation, during which horizontal stress exceeded the vertical component. Vertical displacement utilizing preexisting flaws along the southwest margin of the Zuni block was apparently a necessary precursor to any subsequent thrusting and supracrustal shortening. It was during this later time that the monocline defining the southwest margin of the uplift steepened and the isolated Stinking Springs thrust fault on the Fort Wingate quadrangle developed. For a more regional interpretation of the stress field that evolved during the phase of horizontal compression see Chamberlin and Anderson (1989).

A structural flexure very similar to the Nutria monocline is present exactly 5 mi to the east. The northern end of this structure, called Oso Ridge, extends into the southeast corner of the quadrangle at the village of McGaffey and loses expression approximately 5 mi to the north. It parallels the Nutria monocline for a considerable distance south of the Fort Wingate quadrangle. Structural relief, although similar, tends to be somewhat less on the Oso Ridge structure, perhaps averaging about 2,000 ft, even less for the northern section that extends onto the Fort Wingate quadrangle.

With the similarities in form, geometry, and trend, Oso Ridge monocline is considered to have developed in response to a stress field very similar to that of the Nutria monocline. Specifically, it likewise originated primarily as a vertical uplift that was later modified by a stress field in which horizontal compression was dominant.

Other structure on the quadrangle consists of scattered, small-scale, high-angle normal faults as shown on the map. An analysis of these faults was not undertaken; however, most trend northeastward or eastward and relate to stress patterns at the northern end of the Zuni uplift.

Stratigraphy

Granitic rocks of Precambrian age are overlain by a sedimentary sequence of Permian through Upper Cretaceous strata throughout the Zuni Mountains (Fig. 1). Outcrop of the Precambrian–Permian contact is restricted to the southeastern corner of the Fort Wingate quadrangle where a very small area (<0.2 mi^2) of granitic terrane is exposed in Oso Ridge.

Permian strata

The oldest sedimentary rocks exposed on the Fort Wingate quadrangle are of Permian age and belong to four formations (ascending): Abo, Yeso, Glorieta, and San Andres.

Abo Formation

On the Fort Wingate quadrangle, the Abo Formation (Lee and Girty, 1909) nonconformably overlies the Proterozoic Zuni Mountains granite. It consists of grayish-red and dark reddish-brown mudstone, silty mudstone, siltstone, and minor lenticular sandstone and conglomerate and is as much as 400 ft thick. It is poorly exposed on the southern end of the quadrangle where it underlies heavily vegetated slopes. The base of the Abo Formation on underlying Pennsylvanian marine carbonates is not exposed on the Fort Wingate quadrangle. Therefore, its lowermost Oso Ridge Member (Armstrong et al., 1994), mixed nonmarine clastics and marine carbonates equivalent to the Bursum Formation farther east, is not preserved on the Fort Wingate quadrangle.

No fossils are known from the Abo Formation on the Fort Wingate quadrangle. Tetrapod and plant fossils found farther east and the intertonguing of Abo red beds with marine strata of the Hueco Formation to the southeast indicate the Abo Formation is of Early Permian (Wolfcampian) age (Lucas and Heckert, 1995).

Yeso Formation

On the Fort Wingate quadrangle, the Yeso Formation (Lee and Girty, 1909) conformably overlies the Abo Formation and is orange gypsiferous sandstone and silty sandstone and thin (3–5-ft-thick) beds of dolomite. It underlies heavily vegetated slopes in the southern part of the quadrangle, where it is about 350 ft thick.

We made no effort to subdivide the Yeso into members (see Smith, 1958a,b; Colpitts, 1989) on the Fort Wingate quadrangle because of the generally poor exposures; however, it seems that the three members that Colpitts (1989) identified in the Zuni Mountains can be recognized: basal Meseta Blanca Member overlain by the dolomite beds of

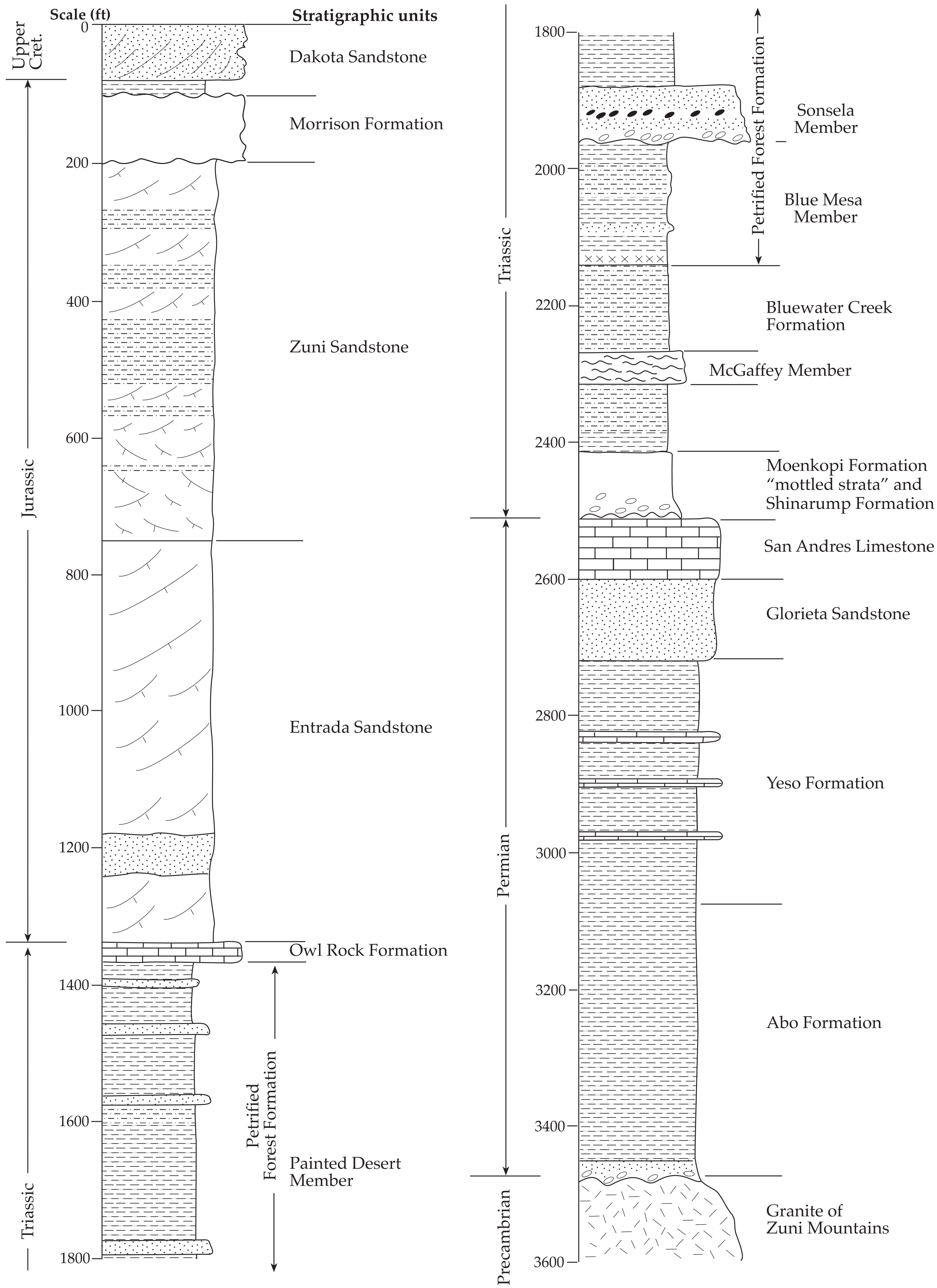

FIGURE 1—Composite stratigraphic section of the Fort Wingate quadrangle.

the Torres Member and capped by the finer-grained Joyita Member. No fossils are known from the Yeso Formation on the Fort Wingate quadrangle. Regional stratigraphic relationships and sparse paleontology suggest an Early Permian (Wolfcampian) age (Colpitts, 1989).

Glorieta Sandstone

On the Fort Wingate quadrangle, the Glorieta Sandstone (Keyes, 1915) conformably overlies the Yeso Formation and is orange to pink supermature quartzarenite. As much as 120 ft thick, the Glorieta is typically crossbedded and very resistant to weathering; therefore, it forms ridges, benches, and canyon walls where exposed, especially in the southern half of the quadrangle.

Although the Glorieta Sandstone in eastern and central New Mexico preserves a diverse array of marginal-marine facies (e.g., Milner, 1978), thickly crossbedded Glorieta strata in west-central New Mexico, such as those preserved on the Fort Wingate quadrangle, probably are of eolian origin (Anderson et al., 1989b). This fits well the concept of a westward gradation of the Glorieta into the fully eolian Coconino Sandstone of Arizona (Baars, 1962). Regional stratigraphic relationships indicate the unfossiliferous Glorieta Sandstone is of Early Permian (Leonardian) age.

San Andres Formation

On the Fort Wingate quadrangle, the San Andres Formation (Lee and Girty, 1909) is as much as 90 ft thick and intertongues with the underlying Glorieta Sandstone. Locally, due to karsting, the San Andres is absent. On the quadrangle, the San Andres consists of gray fossiliferous limestone and grayish-pink dolomitic limestone. Poorly preserved shells of small productoid brachiopods are common.

Baars (1962) reported a mollusc-brachiopod fossil assemblage from the upper 40 ft of the San Andres Formation 3 mi south of Fort Wingate. Kues and Lucas (1989) described fossil assemblages dominated by productoid brachiopods (mostly *Peniculauris bassi* and *Rugatia occidentalis*) but including bivalves, scaphopods, gastropods, and nautiloids from the upper part of the San Andres Formation near Ojo Caliente on the Zuni Pueblo, 44 mi southwest of Fort Wingate. These fossils support correlation of the San Andres Formation in west-central New Mexico with the Fossil Mountain Member of the Kaibab Formation (Leonardian) in Arizona.

Triassic strata

Triassic strata exposed on the Fort Wingate quadrangle are nonmarine, red-bed siliciclastics. They belong to the Moenkopi Formation (Middle Triassic) and overlying Chinle Group (Upper Triassic).

Moenkopi Formation

The Moenkopi Formation is as much as 60 ft thick on the Fort Wingate quadrangle and is dominantly grayish red, trough-crossbedded, micaceous litharenite (Lucas and Hayden, 1989). It rests with profound unconformity on the underlying Early Permian San Andres or Glorieta Formations and is unconformably overlain by the Chinle Group. Moenkopi strata generally are poorly exposed on the quadrangle. The thickest outcrop is just east of NM–400 in the NE⁄ sec. 20 (unsurveyed) T14N R16W.

No fossils are known from the Moenkopi Formation on the Fort Wingate quadrangle; however, fossil vertebrates, especially the capitosauroid amphibian *Eocyclotosaurus*, found elsewhere indicate a Middle Triassic (Anisian) age (Lucas and Hayden, 1989; Morales, 1987). Moenkopi strata on the Fort Wingate quadrangle belong to the Anton Chico Member of Lucas and Hunt (1987) and are correlative with the Holbrook Member of northeastern Arizona (Lucas and Hunt, 1993).

Chinle Group

Lucas (1993a,b) raised Gregory's (1917) Chinle Formation to group status, thereby elevating its members to formational rank and its beds to member rank. He thus modified Lucas and Hayden's (1989) Upper Triassic stratigraphy in west-central New Mexico (including the Fort Wingate quadrangle) to recognize four formational-rank units (ascending): Shinarump, Bluewater Creek, Petrified Forest (includes the Blue Mesa, Sonsela, and Painted Desert Members), and Owl Rock Formations. Anderson and Lucas (1993) named the McGaffey Member of the Bluewater Creek Formation, thus completely establishing the formal nomenclature of Chinle Group strata employed on this map.

"Mottled strata" and Shinarump Formation. In the Fort Wingate quadrangle, the Chinle Group rests disconformably on the Moenkopi Formation. This disconformity is marked by silica-pebble conglomerate and quartzose sandstone of the Shinarump Formation and by biogenically modified siltstones, sandstones, and conglomerates that Stewart et al. (1972) termed the "mottled strata." Shinarump strata on the Fort Wingate quadrangle are best exposed in the NE⁄ sec. 20 (unsurveyed) T14N R16W where they are at least 12 ft of yellowish-gray, trough- and planar-crossbedded quartzose sandstone and silica-pebble (mostly quartzite and jasper) conglomerate. Elsewhere on the quadrangle, the Shinarump Formation is considerably thinner and very discontinuous (lenticular) locally.

The Shinarump Formation is exposed widely across the Colorado Plateau and is typically much thicker and more laterally continuous than on the Fort Wingate quadrangle (Stewart et al., 1972). In southeastern Utah and northeastern Arizona, economically significant uranium oxide deposits were mined in the Shinarump Formation. Fossil plants and regional correlation indicate the Shinarump is of Late Triassic (late Carnian: Tuvalian, about 225 Ma) age (Lucas, 1993).

The "mottled strata" reach their maximum thickness of about 72 ft in west-central New Mexico on the Fort Wingate quadrangle. Here, they consist of sandy siltstone, sandstone, and conglomerate color mottled grayish purple and grayish red purple. Numerous cylindrical burrows in the mottled strata were misidentified by Dubiel et al. (1987) as lungfish burrows (McAllister, 1988) and have been reidentified by Hasiotis and Mitchell (1989) as crayfish burrows. Mottled strata represent a weathering profile (cumulative pedon) developed in Moenkopi strata; therefore, they postdate early

Anisian and probably are of Late Triassic (late Carnian) age. They are widely distributed at the base of the Chinle Group on the Colorado Plateau and are also locally present in other parts of New Mexico, west Texas, western Oklahoma, Colorado, and Wyoming (Lucas, 1993b).

Bluewater Creek Formation. Lucas and Hayden (1989) introduced the term Bluewater Creek Member of Chinle Formation for as much as 270 ft of red-bed sandstone, siltstone, and mudstone that overlies the Shinarump/mottled strata in west-central New Mexico. This unit is widely exposed on the Fort Wingate quadrangle, especially on the army depot. Previously it was informally termed the "lower red member" of the Chinle Formation (Cooley, 1957, 1959; Akers et al., 1958; Repenning et al., 1969; Stewart et al., 1972). Some workers (Ash, 1967, 1969, 1978, 1989; Shomaker, 1971; Dubiel et al., 1993) applied the term Monitor Butte Member to these strata, even though they are lithologically dissimilar to the type section of the Monitor Butte in San Juan County, Utah, where this unit is dominantly greenish-gray, bentonitic claystone and clayey, fine-grained sandstone (Stewart, 1957; Stewart et al., 1972). We prefer to recognize a lithologically distinct Bluewater Creek Formation on the Fort Wingate quadrangle and throughout west-central New Mexico (Lucas and Hayden, 1989; Lucas and Hunt, 1993; Lucas and Heckert, 1994; Heckert and Lucas, 1996).

On the Fort Wingate quadrangle, the lower part of the Bluewater Creek Formation includes a 5-ft-thick lenticular bed of carbonaceous shale that Ash (1978) termed the "Ciniza Lake Beds." Because this unit is so thin and of such limited areal extent, we follow Lucas and Hayden (1989) in abandoning the term Ciniza Lake Beds. Immediately below these strata are steeply dipping sandstones of the lower Bluewater Creek Formation that Ash (1978) interpreted as syndepositional slumping that produced an angular unconformity within the Bluewater Creek Formation. Anderson et al. (1989a) and Lucas and Hunt (1993) questioned this conclusion, arguing that the apparent angular unconformity represents Quaternary slumping and/or Laramide fault blocks; however, at least some of these beds represent syndepositional deformation as was well documented by Dubiel et al. (1993).

On the Fort Wingate quadrangle, the Bluewater Creek Formation can be divided into three members. The lower member is as much as 120 ft of red-bed mudstones and thin sandstones. The overlying McGaffey Member (Anderson and Lucas, 1993), which has its type section on the quadrangle, is as much as 40 ft of ledge- and bench-forming ripple-laminated sandstones. It forms a prominent marker bed throughout the quadrangle and can be recognized well to the east as far as the Lucero uplift in Cibola County (Lucas and Heckert, 1994). The upper member is red-bed mudstones as much as 110 ft thick.

Fossil plants from the lower part of the Bluewater Creek Formation on the Fort Wingate quadrangle belong to Ash's (1980) Dinophyton floral zone of late Carnian age. Fossil tetrapods from the Bluewater Creek Formation, especially the phytosaur *Rutiodon*, the aetosaur *Desmatosuchus*, and a large metoposaurid amphibian, probably *Buettneria*, indicate an Adamanian age, which is also late Carnian (Lucas, 1993b).

Petrified Forest Formation. Most of the Triassic section exposed on the Fort Wingate quadrangle belongs to the Petrified Forest Formation, which is divided into the (ascending) Blue Mesa, Sonsela, and Painted Desert Members. The base of the Blue Mesa Member is a grayish-white, trough-crossbedded, muddy micaceous sandstone above the Bluewater Creek Formation red beds of mudstone and siltstone. The contrast in lithology and color provides an easily mapped contact between the Bluewater Creek and Petrified Forest Formations. Strata of the Blue Mesa Member on the Fort Wingate quadrangle are generally 120 ft in thickness but locally may be as much as 140 ft thick and are mostly purple and greenish-gray smectitic mudstone. No significant fossils are known from the Blue Mesa Member on the Fort Wingate quadrangle, but in the St. Johns area of Arizona and in the Petrified Forest National Park, the Blue Mesa Member yields megafossil plants, palynomorphs, and tetrapods of late Carnian age (Lucas, 1993b).

The Sonsela Member disconformably overlies the Blue Mesa Member and forms the prominent cuestas that flank NM–400 north of the village of Fort Wingate. The Sonsela is as much as 80 ft of light-gray to yellowish-brown, fine-grained to conglomeratic, crossbedded sandstone. Locally fossil logs are abundant. Poorly preserved unionid bivalves (Lucas and Hayden, 1989, fig. 9F-I) also are known from the Sonsela Member on the quadrangle. Changes in lithology from underlying Blue Mesa Member mudstones to Sonsela conglomerate and sandstone characterize the basal contact. Scour-and-fill and stratigraphic relief also characterize this contact. Regional stratigraphic relationships indicate that the base of the Sonsela Member is an unconformity of basinwide extent (Heckert and Lucas, 1996). This unconformity approximates the Carnian–Norian boundary (Lucas, 1993b).

The Painted Desert Member is poorly exposed on the Fort Wingate quadrangle north of the Sonsela cuestas and consists mostly of reddish-brown and grayish-red smectitic mudstone and minor beds of resistant, laminated or cross-bedded micaceous litharenite as much as 550 ft thick. No significant or age-diagnostic fossils are known from the Painted Desert Member on the Fort Wingate quadrangle, but the lower part of the member produces an extensive vertebrate fauna of Revueltian (early Norian) age in the Petrified Forest National Park (Long and Murry, 1995; Hunt and Lucas, 1995).

Owl Rock Formation. The youngest Chinle Group unit exposed on the Fort Wingate quadrangle is the Owl Rock Formation. Here, it has a maximum thickness of 25 ft and consists of laterally persistent beds of pale-red and pale reddish-brown calcareous siltstone, thin-bedded sandy siltstone, and light greenish-gray limestone and nodular limestone. The section from the Owl Rock through the Dakota Sandstone is described in Fig. 2.

Blakey and Gubitosa (1983) and Dubiel (1989a,b) concluded that deposition of the Owl Rock Formation took place in an extensive lake. Lucas and Anderson (1993), however, demonstrated that Owl Rock limestones on the Fort Wingate quadrangle are from stage III to stage VI calcretes and thus are not of lacustrine origin. No fossils are known from the Owl Rock Formation on the Fort Wingate

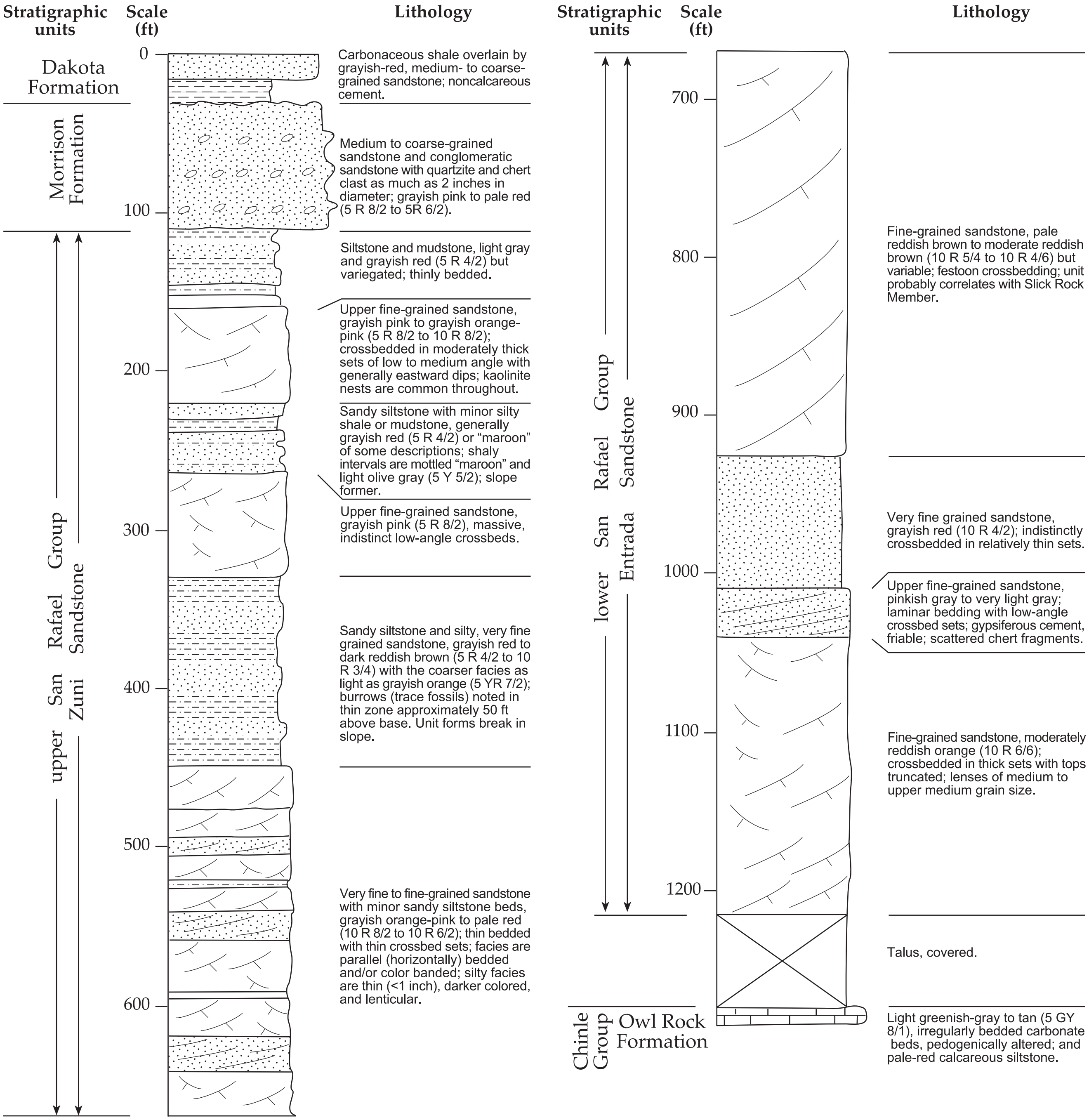

FIGURE 2—Measured stratigraphic section of Triassic to Cretaceous rocks exposed in The Hogback at the west quadrangle boundary and 35°28' north latitude. Colors are, for the most part, those defined in *Rock-color chart* (Goddard et al., 1963).

quadrangle, but fossil vertebrates from the unit in Arizona indicate a Revueltian (Norian) age (Lucas, 1993b).

Middle Jurassic stratigraphy and depositional environments—Entrada and Zuni Sandstones

Resting unconformably on the Owl Rock Formation is the Entrada Sandstone (Middle Jurassic), which forms the base of the San Rafael Group throughout northern New Mexico. Although the basal 40–60 ft of Entrada is commonly covered by colluvium, it appears to be primarily a moderately reddish orange, very fine to fine-grained sandstone. It generally weathers clean as a steep slope or cliff former and is readily identified. The large-scale crossbed sets and the total lack of fluvial characteristics indicate an eolian depositional environment.

Despite minor changes in color and grain size upward through the remainder of the Entrada, the crossbedded nature persists, becoming even larger scale and festoonlike upward. Thus the eolian origin is strongly suggested throughout the entire thickness of approximately 600 ft. The uppermost 250 ft of section exhibits even larger-scale crossbed sets, many exceeding 20 ft in thickness.

The depositional setting for the Entrada has been summarized by a number of workers (Gilluly and Reeside, 1928; Green, 1974; Green and Pierson, 1977; Kocurek and Dott, 1983). All have concluded that eolian systems played a dominant role in Entrada deposition. The vast erg in which the Entrada was deposited developed on an arid coastal plain at the southern margin of a lobe of the Sundance Sea (Kocurek and Dott, 1983). The retreat of this lobe was followed by the northward progradation of the erg; measurement and study of paleotransport (paleowind) direction by Poole (1962) indicate a generally southward transport of sediment during Entrada deposition. Our observations on the Fort Wingate quadrangle and to the north in the Church Rock area are consistent with the conclusions of previous workers in that most crossbed sets in the Entrada have south to southwest dips. This supports the continental drift model, which positions this part of the North American continent at a paleolatitude of approximately 15°N during Middle Jurassic time (Kocurek and Dott, 1983; Dickinson, 1989). At such latitudes wind patterns are dominated by the subtropical high-pressure system resulting in from north to south air mass movement.

Overlying the Entrada with apparent conformity is the Zuni Sandstone, which constitutes the upper part of the San Rafael Group (Fig. 2). This sandstone-on-sandstone contact is picked on the basis of secondary sedimentary features. The Zuni is thinner bedded and more poorly sorted, and facies are both slightly coarser and somewhat finer grained. Minor siltstone breaks are common in the lower part, and this adds to the perception of parallel, horizontal bedding and color banding. Upward in the section, approximately 220–340 ft above the base, are thicker (1–10 ft) lenticular beds of maroon (from dusky-red to grayish-red) siltstone and very fine grained silty sandstone. The thickness of these darker-colored siltstone intervals is locally exaggerated in appearance due to their wasting down the outcrop. It is these so-called “shales,” in reality siltstone and sandstone, that caused previous investigators to assign this part of the section to the “Recapture Member of the Morrison.” It was further envisioned that this part of the Zuni Sandstone (formerly Cow Springs Sandstone of U.S. Geological Survey usage) was intertongued with the “Recapture Member of the Morrison,” or was an eolian facies of the Morrison, because of the presence of the maroon siltstone beds (Condon and Huffman, 1984, p. 127; Condon, 1989, p. E-14). We recognize these darker, finer-grained beds as interdunal deposits and/or fine-grained material that washed into depressions in a sand sheet.

Lithologically the Zuni consists of 61% sandstone and 39% siltstone, sandy siltstone, and very fine grained silty sandstone. The crossbedded, fine-grained nature of the sandstone (125–250 μ), in addition to the lack of fluvial features, suggests that it was deposited by eolian processes. The finer-grained facies, as noted above, may represent fluvial reworking during wet periods or floods. Both facies, however, are consistent with an assignment to the San Rafael Group. San Rafael Group sedimentation in northwestern New Mexico is interpreted to have taken place in arid coastal-plain, sabkha, erg, and paralic-salina environments (Anderson and Lucas, 1994). Inasmuch as the Zuni Sandstone grades northward and basinward into the Summerville and Bluff Formations, units that embody the upper San Rafael Group, the Zuni is regarded as San Rafael Group as well. Thus on the basis of lithology, physical correlation, and lithogenesis, we assign the entire Zuni Sandstone to the San Rafael Group and reject the interpretation or concept that any part of it represents eolian facies of the Morrison Formation. Basal Morrison sediments are classic fluvial-channel deposits, are coarser grained, and rest on a regionally extensive, cut and backfilled scour surface, which we recognize as a sequence boundary (see below).

Upper Jurassic stratigraphy and depositional environments—Morrison Formation

The Morrison Formation (Upper Jurassic) unconformably overlies the Zuni Sandstone on the Fort Wingate quadrangle. At this locality the only part of the Morrison present is the basal Salt Wash Member, formerly called the Westwater Canyon Member (Anderson and Lucas, 1995). The Salt Wash consists of medium- to coarse-grained, pebbly conglomeratic sandstone. Lesser amounts of fine-grained sandstone are present in the upper parts of poorly defined fining-upward sequences. The pebbles consist of chert and quartzite and have a maximum diameter of approximately 2 inches; however, they are generally less than 1 inch. Clay clasts or rip-up clasts are rare, and fossilized remains of woody trash are absent at this locality in contrast to areas northward in the San Juan Basin where both these features are common in basal Morrison sandstones. Total thickness of the Salt Wash, which is an unconformity-bounded unit in this area, is approximately 80 ft, but it thins southward from the measured section (see map) to less than 25 ft near the southern boundary of the quadrangle. At this southern locality it consists of a bleached (white), medium- to coarse-grained sandstone and authigenic kaolinite. This bleached zone is common and widespread at the beveled top of the Morrison beneath the basal Cretaceous unconformity.

All sedimentary features in the Salt Wash Member indicate it was deposited in a vast alluvial system with a sedimentary, and to a lesser extent igneous, source area. Craig et al. (1955) reported that the conglomeratic facies (near Gallup) contained feldspar and granite in addition to the dominant chert and quartzite pebbles. We noted little or no feldspar in the conglomeratic facies exposed on this quadrangle but noted numerous kaolinite nests, primarily in the coarse-grained sandstones. The kaolinite nests apparently are the result of the in situ disintegration of feldspar clasts. Craig et al. suggested a source area that included sedimentary, igneous, and metamorphic rock. The chert and quartzite pebbles could well have been derived from preexisting sedimentary terrane, and thus the argument for a metamorphic provenance is not strong. The inferred presence of feldspar, however, suggests intrusive rocks were present in the source area.

Saucier (1967) reported finding volcanic material such as sanidine (high-temperature K-spar) and doubly terminated bipyramidal quartz crystals. In addition Saucier noted that 90% of the conglomerate clasts consisted of sedimentary rocks (quartzite, chert, and sandstone), the remainder being largely welded tuff or rhyolite. Clasts of volcanic rock are rare in the samples of conglomerate we collected. In our petrographic examinations of samples from nonconglomeratic facies from three areas in and adjacent to the Fort

Wingate quadrangle, we were able to document only minor (<3%) feldspar and lithic fragments.

Paleoflow directions are not well expressed in the Salt Wash Member in this area. All outcrops are in highly tilted strata, further complicating interpretation. Craig et al. (1955), however, indicated that paleoflow in this unit (which they referred to as Westwater Canyon Member) was similar to and an extension of depositional systems in the underlying “Recapture Member,” in which they curiously found evidence of paleoflow and sediment transport to the northeast. Their findings for the “Recapture,” we believe, were based on an inferred source area to the southwest of the thickest “Recapture” and the fact that crossbed-dip directions in eolian strata in this part of the section tend to be eastward and northeastward. Sediment-transport directions in eolian systems are obviously independent of flow and transport directions in fluvial systems, and thus comparison of paleoflow data in the so-called “Recapture Member” with that of the Salt Wash Member is unproductive. We, moreover, recognize the “Recapture” strata as part of the San Rafael Group and thus unrelated to fluvial systems that developed subsequently during Morrison deposition. In spite of Craig et al.’s (1955) observations that “Recapture” strata contrasted with the overlying strata in grain size, bed form, and climatic implications, they nonetheless lumped the two together as Morrison Formation.

Other paleocurrent-direction data and observations exist. Saucier (1967) noted that in the Gallup area the average of a number of readings was N13°E. Our observations in the nearby Church Rock and Thoreau areas indicate east-northeasterly paleocurrent directions in the Salt Wash Member.

Upper Cretaceous stratigraphy

Dakota Sandstone

The Dakota Sandstone (Cenomanian) unconformably overlies the Morrison Formation throughout the San Juan Basin and into the Gallup area. The age of this unconformity may be in excess of 46 Ma, as the lower Cenomanian stage boundary is taken as approximately 96 Ma (Haq et al., 1988), and the Salt Wash Member of the Morrison underlies the Brushy Basin Member, which has an age of 144 Ma (Kowallis et al., 1991).

Lithologically the Dakota is a highly variable unit, particularly in the lower part. The base of the Dakota at our measured-section locality in the northwest part of the quadrangle is composed of a carbonaceous shale unit approximately 12 ft thick. This is overlain by a pale-red to locally grayish orange, medium-grained quartzose sandstone as much as 25 ft thick. Poorly exposed, interbedded sandstone, siltstone, and shaly zones overlie for a total Dakota thickness of approximately 100 ft.

Mancos Shale

Sharply overlying the Dakota is the Whitewater Arroyo Tongue of the Mancos. It is a medium dark-gray marine shale approximately 75 ft thick. Due to the covered contact and obscured relationship to the overlying Twowells Tongue of the Dakota, these two were not mapped as separate units on the Fort Wingate quadrangle. The Twowells has very restricted outcrop; however, on the adjacent Bread Springs quadrangle exposures of the unit reveal a thickness of 18–25 ft. It, moreover, is fossiliferous in that area with an abundance of the bivalves *Exogyra levis* and *Pycnodonte kellumi* in the upper part of the unit. These two units of the intertongued Dakota–Mancos sequence, as well as the overlying, thin platy limestones of the Bridge Creek, are included for mapping purposes with the basal part of the Mancos Shale.

The poorly exposed lower Mancos forms a well-defined strike valley between the parallel hogbacks developed on the Dakota Sandstone and the Gallup Sandstone. Based on exposures in adjacent areas the Mancos is a medium dark-gray shale having silty zones in the basal and upper parts and zones of limestone concretions in the upper 200 ft. Fossils collected locally (Molenaar et al., 1996) in the upper 100 ft include *Inoceramus dimidius. I. dimidius* is indicative of a late Turonian age and is present in the Pescado Tongue of the Mancos, which is recognized southeastward and along depositional strike and southward into the Zuni Basin. Total thickness of the Mancos is approximately 600 ft.

Gallup Sandstone

Overlying the Mancos in a regressive sequence is the Gallup Sandstone. The Gallup exerts considerable influence on the topography throughout the adjacent Gallup–Zuni Basin, and on the Fort Wingate quadrangle it forms a hogback updip and parallel to the Dakota Sandstone hogback. Gallup outcrops are restricted to the hogback structure in the southwestern part of the quadrangle.

The Gallup in outcrops is a pale-orange to grayish-orange, very fine to fine-grained quartzose sandstone; however, shaly intervals comprise a significant part of the total thickness. As a lithologic unit it consists of three distinct sandstones, all very similar in lithology and sedimentary features, separated by fine-grained (silty shales and mudstones), slope-forming intervals as much as 70 ft thick. These shaly-mudstone intervals form small strike valleys within the hogback and thus are poorly exposed; however, at several localities north of Bread Springs Wash, carbonaceous shale or mudstone facies were noted in outcrop and in slump blocks. It would thus appear that marginal marine and nonmarine facies are present within the Gallup. The top of the unit as now picked (see Nummedal and Molenaar, 1995; Anderson and Stricker, 1996; Molenaar et al., 1996) corresponds with the top of the highest littoral sandstone; defined as such, total thickness is approximately 220 ft.

Crevasse Canyon Formation

As originally defined by Sears (1925) the Gallup Sandstone included strata that are currently regarded as pertaining to the Crevasse Canyon Formation. The distinctive, coarse-grained, moderate- to light-red, crossbedded sandstone named the Torrivio Member of the Gallup (Molenaar, 1973) overlies a coal-bearing unit, the Ramah Member (Crevasse Canyon Formation) of Anderson and Stricker (1996). Both of these units were included originally in the uppermost part of the Gallup but now are recognized on the basis of lithology, lithogenesis, and regional correlations to pertain to the nonmarine Crevasse Canyon Formation (Anderson and Stricker, 1996; Molenaar et al., 1996).

The Torrivio is present locally on the Fort Wingate quadrangle but cannot be traced continuously along strike. The underlying Ramah Member is thin and does not crop out, and thus it was mapped with the Torrivio Member. Where present the Torrivio Member is medium- to coarse-grained, crossbedded sandstone in one depositional unit estimated to be 22–24 ft thick.

The overlying Dilco Coal Member (Sears, 1925) crops out in an area of approximately 2 mi^2 in the southwest corner of the quadrangle. The flat-lying rocks in this area, at the base or toe of the monocline, are poorly exposed and are structurally part of the Gallup–Zuni Basin. Little coal was noted in outcrop in this unit. The modern erosion surface is developed on the Dilco, and thus no thickness estimates of the remaining strata are given.

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Description of units

Alluvial deposits (Quaternary)—Gravel, sand, silt, and clay in the major drainages and their tributary systems

Colluvium and landslide debris (Quaternary)

Crevasse Canyon Formation, undivided (Upper Cretaceous)— Mudstone, shale, very fine to medium-grained sandstone, carbonaceous shale, and thin, lenticular coal beds; limited to southwest corner of map where it may be in excess of 400 ft thick

Dilco Member (Coniacian)—Light- to dark-gray variegated shale and siltstone; very pale orange to grayish-orange, very fine to fine-grained sandstone; and lesser amounts of carbonaceous shale and thin (<1.0 ft) lenticular coaly beds. Contact with underlying Torrivio Member generally sharp but mostly not exposed. Unit may be as much as 300 ft thick

Torrivio Member (Coniacian)—Moderate- to light-red and tan to grayish-orange, medium- to coarse-grained sandstone; locally granular (2.0–4.0 mm diam. grains); has small- and medium-scale trough and planar-trough crossbedding; lenticular mudstone beds as much as 1 ft thick are not uncommon. A coaly-carbonaceous interval at the base, locally as much as 50 ft thick, has been designated the Ramah Member of the Crevasse Canyon Formation in the Zuni Basin but here is exposed poorly and not mapped as a separate unit. Torrivio Member as much as 24 ft thick; combined thickness of the two members is approximately 75 ft

Gallup Sandstone (Turonian)—Very pale orange (tan) to grayish-orange, very fine to fine-grained, well-sorted quartzose sandstone; in three beds as much as 20 ft thick separated by poorly exposed silty intervals of lenticular carbonaceous facies that are as much as 70 ft thick. As mapped, Gallup is as much as 220 ft thick and is overlain by Torrivio Member of Crevasse Canyon Formation

Mancos Shale, lower part (Cenomanian and Turonian)—Light- to dark-gray fissile shale and silty shale; scattered thin siltstone and nodular, lenticular limestone or calcarenite beds. Included in lower Mancos is the uppermost unit of interbedded Dakota–Mancos sequence, the Twowells Tongue, which is as much as 25 ft thick. Underlying the Twowells is the Whitewater Arroyo Tongue of the Mancos, which may be as much as 75 ft thick. These two units are unmappable on this quadrangle because overlying Twowells is not exposed everywhere and because of scale limitations in the hogback outcrop area. Overall thickness, which includes intertongued Dakota–Mancos, as much as 700 ft

Dakota Sandstone (Cenomanian)—Very pale orange (tan) and moderately reddish orange, mostly medium grained, well-indurated sandstone and gray to brownish-gray silty shale and carbonaceous shale. Locally, basal 7–15 ft is light gray-weathering, slightly carbonaceous shale. Approximately 100 ft thick

Morrison Formation (Upper Jurassic)—Grayish-pink to grayish-red, medium- to coarse-grained sandstone and conglomeratic sandstone of chert and quartzite pebbles; trough cross stratifica-tion locally prominent; varies in degree of induration; more friable facies correspond to finer-grained intervals or to zones of authigenic clay (kaolinite); unit correlates with type Salt Wash Member of the Morrison Formation; has scoured base that represents a hiatus of unknown duration; 80 ft thick in northwest part of quadrangle, thinning gradually southward to a wedge– edge at the southern boundary

Zuni Sandstone (Middle Jurassic, Callovian)—Sandstone and minor siltstone containing very thin lenses of claystone. Sandstone colors range from grayish pink or grayish orange pink to light greenish gray and moderately reddish brown; horizontal color banding common; very fine to fine grained; crossbedding in thinner sets than in the underlying Entrada Sandstone; many reactivation (dune truncation) surfaces. Fine-grained facies are from pale-red to pale reddish-brown moderate slope-forming intervals, and this facies has been called incorrectly “Recapture Member of Morrison” by previous investigators. Silt- and claystone-rich facies represent deposition in shallow water in interdunal ponds and playas during the waning stages of desert thunderstorms; trace fossils (burrows and tubes) found in fine-grained facies 266 ft above base; as much as 560 ft thick

Entrada Sandstone (Middle Jurassic, Callovian)—Moderately reddish orange to grayish orange-pink, very fine to fine-grained, large-scale crossbedded sandstone; foresets generally have south to southwest dip directions; friable; calcareous cement. Silty facies in lower half correlates with Dewey Bridge Member; scattered floating white to pink chert grains larger than the sandstone framework noted. As much as 600 ft thick

Owl Rock Formation (Upper Triassic, Norian)—Pale-red or grayish orange-pink to grayish red-purple silty limestone; interpreted as pedogenic carbonate rock because of sedimentary structures described as rhizoliths; it is as much as 40 ft thick to the north where individual silty carbonate beds are as thick as 12 ft; on this quadrangle from 0 to 25 ft thick

Petrified Forest Formation, undivided (Upper Triassic)—As much as 750 ft of mudstone, sandstone, siltstone, and minor, thin, lenticular limestone

Painted Desert Member (Norian)—Pale reddish-brown, moderately red, and light greenish-gray mudstone, sandstone, and siltstone; smectitic facies common in mudstones; relatively thin sandstones (<20 ft) have both horizontal laminae and thin sets of trough cross-beds; sandstones also have intraformational conglomeratic lenses that contain mudstone and carbonate clasts. *Unio* sp. (fresh-water bivalve) is common in the thin sandstones in lower 30 ft of this member, particularly at latitude 35°27'05" and longitude 108°36'28". Generally 500–550 ft thick

Sonsela Member (Norian)—Yellowish-gray and pale-olive sandstone and conglomeratic sandstone; relatively thin mudstone interbeds, some of which are grayish red purple weathering. Conglomeratic sandstones contain both extrabasinal facies (chert and quartzite pebbles) and intrabasinal facies (carbonate and calcareous mudstone clasts); thin to medium sets of trough crossbeds common throughout, indicating west and northwest paleoflow directions. *Unio* sp. common in upper part; as much as 80 ft thick but generally less

Blue Mesa Member (Carnian)—Pale red-purple, grayish-red, and pale-red, locally mottled mudstone, siltstone, sandstone, and minor, lenticular carbonate beds; mudstones are smectitic and moderate to gentle slope formers; siltstones and sandy siltstones are moderate to steep slope formers; light-colored smectitic claystone at base serves as marker bed for base of Petrified Forest Formation throughout the quadrangle. Unit is as much as 140 ft thick

Bluewater Creek Formation (Upper Triassic)—Pale reddish-brown, pale-red, and dark reddish-brown mudstone and silty mudstone, commonly smectitic, and pale-red to grayish-red, fine-grained, ripple-laminated sandstone having microlaminae of siltstone that give rise to color streaks. Contains zones of calcrete nodules, minor intraformational conglomerate facies, poorly preserved casts of *Unio* sp., and fragments of petrified wood. Amphibian and phytosaur bone fragments locally common, most of which are thought to pertain to *Buettneria* sp. or *Rutiodon* sp. May be as thick as 270 ft

Upper part (Carnian)—Pale reddish-brown and pale-red mudstone; calcrete nodules and fragments of casts of *Unio* and of petrified wood are common; as much as 110 ft thick

McGaffey Member (Carnian)—Pale-red to grayish-red, fine-grained, ripple-laminated sandstone; microlaminae of siltstone produce color streaking visible on fresh exposures; basal part has carbonate-clast conglomerate locally; unit is as much as 40 ft thick but generally much less; locally not recognized

Lower part (Carnian)—Pale reddish-brown and pale-red mudstone and thin, grayish-red, fine-grained sandstone beds that locally contain calcrete nodules. As much as 120 ft thick

Moenkopi Formation, "mottled strata," and Shinarump Formation, undivided (Middle and Upper Triassic)—Moenkopi is moderately reddish orange, massive to thinly laminated, and ripple- laminar siltstones interspersed with very fine grained sandstones of the same color; thickness varies from less than 10 ft to 100 ft. Unconformably overlying Moenkopi strata is the Shinarump Formation, a chert- and quartzite-pebble conglomerate and conglomeratic sandstone that is not mappable at this scale. The Shinarump lies on or within a unit termed "mottled strata" (Stewart et al., 1972), which consists of pedogenically altered grayish-purple, very dusky purple, pale reddish-brown, grayish-orange sandy siltstone and pale-pink to brownish-black mudstone; mottled strata are locally as much as 70 ft thick

San Andres Limestone (Leonardian)—Gray and very light gray, coarsely crystalline, fossiliferous limestone and grayish-pink to grayish orange-pink dolomitic limestone; specimens of small productoid brachiopods common, as are bellerophont gastropods and small bivalves; base commonly intertongued with Glorieta Sandstone. As much as 90 ft thick; locally absent due to karst dissolution

Glorieta Sandstone and Yeso and Abo Formations, undivided (Permian)—Shown in cross section A– A' only

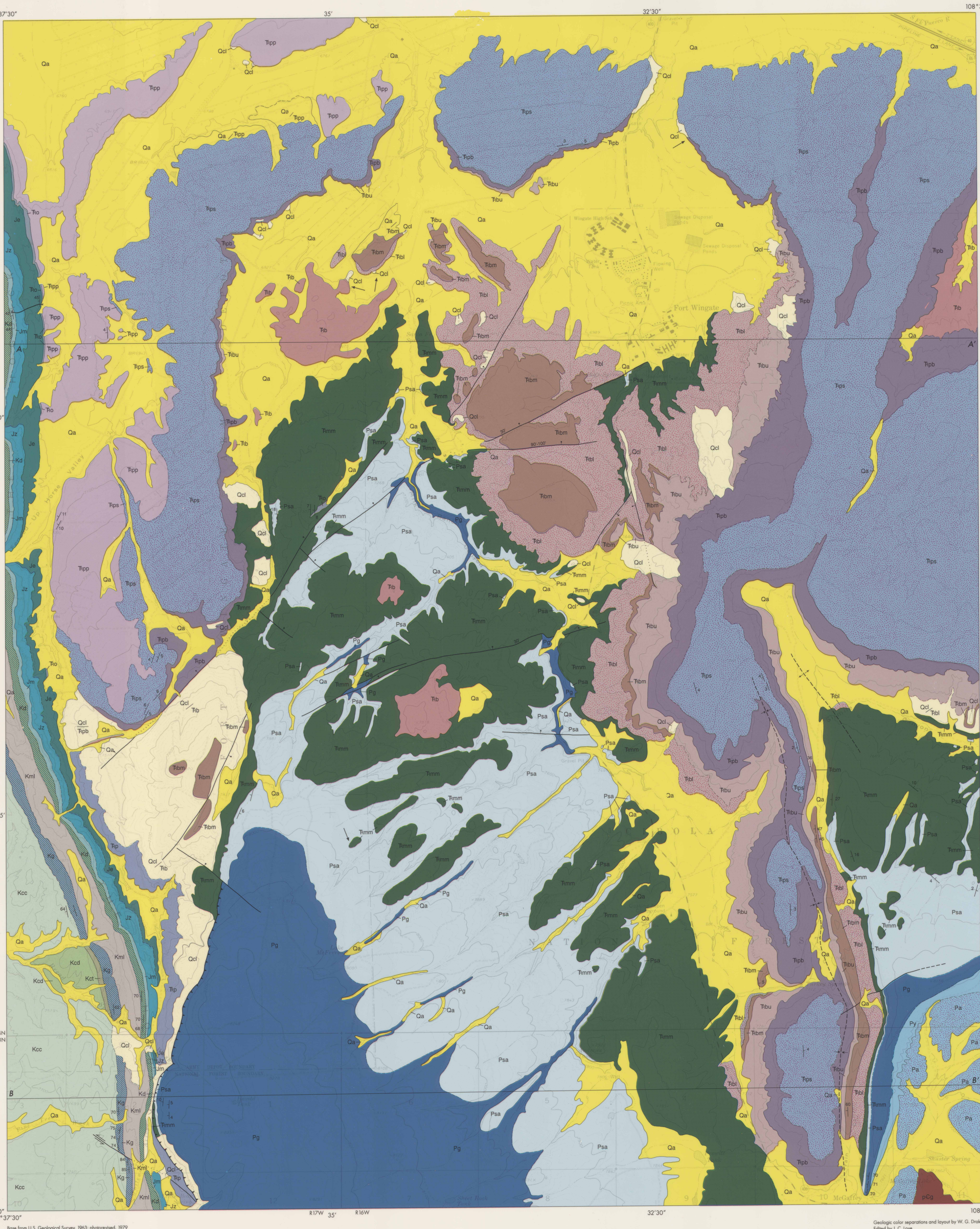
Glorieta Sandstone (Leonardian)—Light-orange to moderately orange pink and very pale orange, well-sorted, well-rounded, lower medium- to upper fine-grained quartzose sandstone; both flat and low-angle crossbedding present, as well as areas of moderately thick to thick sets of tabular and trough crossbeds. As much as 120 ft thick but generally much less

Yeso Formation (Leonardian)—Dark-orange and moderately reddish orange, lower very fine grained gypsiferous sandstone and silty sandstone. Locally three light-gray carbonate beds may be recognized within the unit approximately 100 ft, 150 ft, and 200 ft above base; carbonate beds are dolomitic and range from 3 ft to 5 ft in thickness; they contrast with San Andres beds in being much less fossiliferous. Total thickness 350 ft

Abo Formation (Wolfcampian)—Grayish-red, very fine grained silty sandstone, arkosic at base through an interval 3–12 ft thick; generally flat bedded; noncalcareous; as much as 400 ft thick

Granite of Zuni Mountains (Early Proterozoic)—Biotite granite, medium grained, equigranular

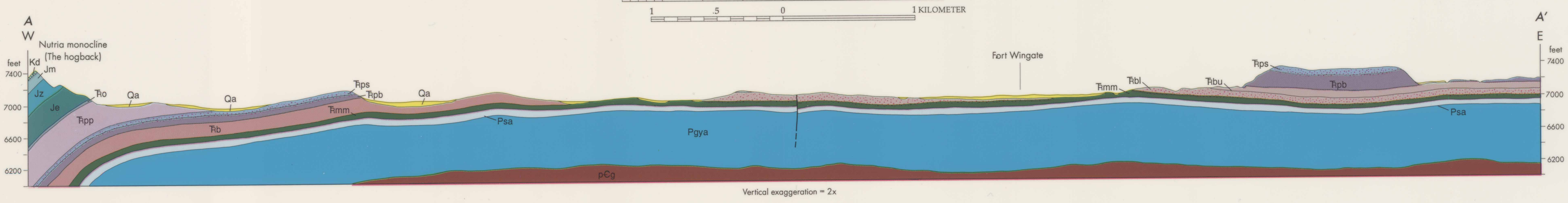
NEW MEXICO BUREAU OF MINES & MINERAL RESOURCES A DIVISION OF NEW MEXICO INSTITUTE OF MINING & TECHNOLOGY



Base from U.S. Geological Survey, 1963; photorevised, 1979
Geology by O. J. Anderson and C. H. Maxwell, 1992–93

Geologic color separations and layout by W. G. Drake
Edited by J. C. Love

Scale 1:24,000



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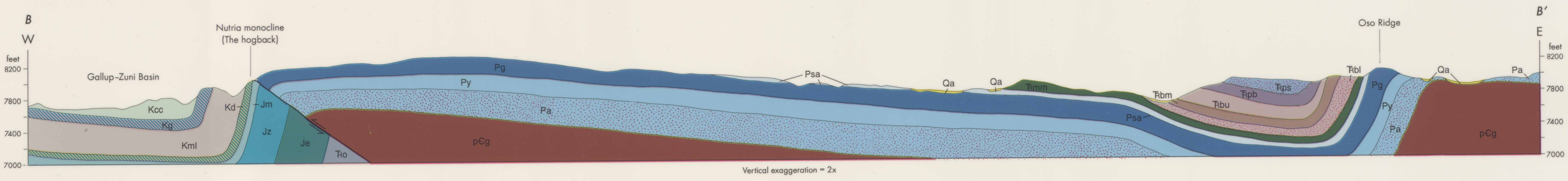

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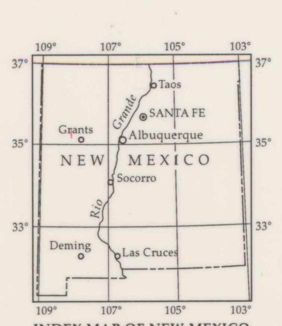
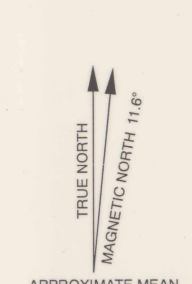
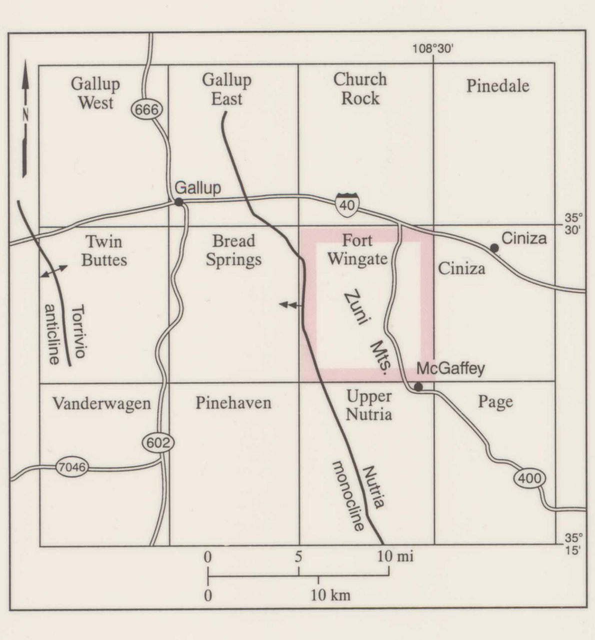
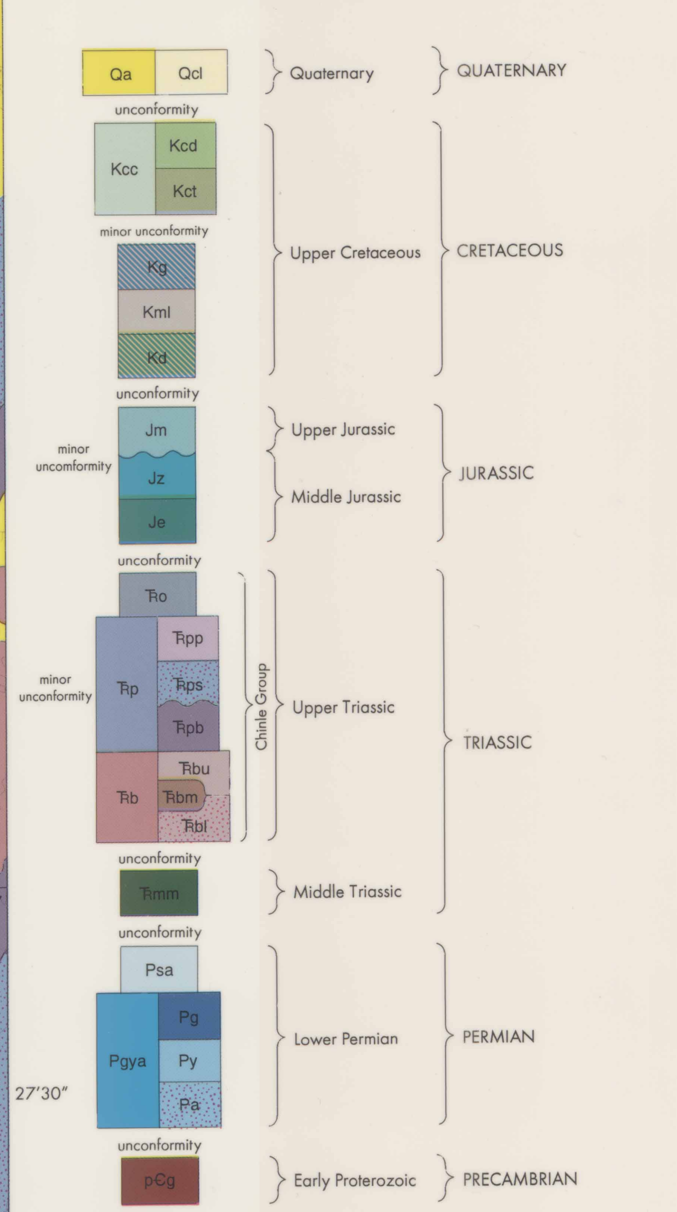




APPROXIMATE MEAN DECLINATION, 1997



CORRELATION OF UNITS



DESCRIPTION OF UNITS

Qa **Alluvial deposits (Quaternary)**—Gravel, sand, silt, and clay in the major drainages and their tributary systems

Qcl **Colluvium and landslide debris (Quaternary)**

Kcc **Crevasse Canyon Formation, undivided (Upper Cretaceous)**—Mudstone, shale, very fine to medium-grained sandstone, carbonaceous shale, and thin, lenticular coal beds; limited to southwest corner of map where it may be in excess of 400 ft thick

Kcd **Dilco Member (Coniacian)**—Light- to dark-gray variegated shale and siltstone; very pale orange to grayish-orange, very fine to fine-grained sandstone; and lesser amounts of carbonaceous shale and thin (<1.0 ft) lenticular coaly beds. Contact with underlying Torrivio Member generally sharp but mostly not exposed. Unit may be as much as 300 ft thick

Kct **Torrivio Member (Coniacian)**—Moderate- to light-red and tan to grayish-orange, medium- to coarse-grained sandstone; locally granular (2.0–4.0 mm diam. grains); has small- and medium-scale trough and planar-trough crossbedding; lenticular mudstone beds as much as 1 ft thick are not uncommon. A coaly-carbonaceous interval at the base, locally as much as 50 ft thick, has been designated the Ramah Member of the Crevasse Canyon Formation in the Zuni Basin but here is exposed poorly and not mapped as a separate unit. Torrivio Member as much as 24 ft thick; combined thickness of the two members is approximately 75 ft

Kg **Gallup Sandstone (Turonian)**—Very pale orange (tan) to grayish-orange, very fine to fine-grained, well-sorted quartzose sandstone; in three beds as much as 20 ft thick separated by poorly exposed silty intervals of lenticular carbonaceous facies that are as much as 70 ft thick. As mapped, Gallup is as much as 220 ft thick and is overlain by Torrivio Member of Crevasse Canyon Formation

Kml **Mancos Shale, lower part (Cenomanian and Turonian)**—Light- to dark-gray fissile shale and silty shale; scattered thin siltstone and nodular, lenticular limestone or calcarenite beds. Included in lower Mancos is the uppermost unit of interbedded Dakota–Mancos sequence, the Twowells Tongue, which is as much as 25 ft thick. Underlying the Twowells is the Whitewater Arroyo Tongue of the Mancos, which may be as much as 75 ft thick. These two units are unmappable on this quadrangle because overlying Twowells is not exposed everywhere and because of scale limitations in the hogback outcrop area. Overall thickness, which includes intertongued Dakota–Mancos, as much as 700 ft

Kd **Dakota Sandstone (Cenomanian)**—Very pale orange (tan) and moderately reddish orange, mostly medium grained, well-indurated sandstone and gray to brownish-gray silty shale and carbonaceous shale. Locally, basal 7–15 ft is light gray-weathering, slightly carbonaceous shale. Approximately 100 ft thick

Jm **Morrison Formation (Upper Jurassic)**—Grayish-pink to grayish-red, medium- to coarse-grained sandstone and conglomeratic sandstone of chert and quartzite pebbles; trough cross stratification locally prominent; varies in degree of induration; more friable facies correspond to finer-grained intervals or to zones of authigenic clay (kaolinite); unit correlates with type Salt Wash Member of the Morrison Formation; has scoured base that represents a hiatus of unknown duration; 80 ft thick in northwest part of quadrangle, thinning gradually southward to a wedge-edge at the southern boundary

Jz **Zuni Sandstone (Middle Jurassic, Callovian)**—Sandstone and minor siltstone containing very thin lenses of claystone. Sandstone colors range from grayish pink or grayish orange pink to light greenish gray and moderately reddish brown; horizontal color banding common; very fine to fine grained; crossbedding in thinner sets than in the underlying Entrada Sandstone; many reactivation (dune truncation) surfaces. Fine-grained facies are from pale-red to pale reddish-brown moderate slope-forming intervals, and this facies has been called incorrectly "Recapture Member of Morrison" by previous investigators. Silt- and claystone-rich facies represent deposition in shallow water in interdunal ponds and playas during the waning stages of desert thunderstorms; trace fossils (burrows and tubes) found in fine-grained facies 266 ft above base; as much as 560 ft thick

Je **Entrada Sandstone (Middle Jurassic, Callovian)**—Moderately reddish orange to grayish orange-pink, very fine to fine-grained, large-scale crossbedded sandstone; foresets generally have south to southwest dip directions; friable; calcareous cement. Silty facies in lower half may correlate with medial silty member; scattered floating white to pink chert grains larger than the sandstone framework noted. As much as 600 ft thick

Tro **Owl Rock Formation (Upper Triassic, Norian)**—Pale-red or grayish orange-pink to grayish red-purple silty limestone; interpreted as pedogenic carbonate rock because of sedimentary structures described as rhizoliths; it is as much as 40 ft thick to the north where individual silty carbonate beds are as thick as 12 ft; on this quadrangle from 0 to 25 ft thick

Trp **Petrified Forest Formation, undivided (Upper Triassic)**—As much as 750 ft of mudstone, sandstone, siltstone, and minor, thin, lenticular limestone

Trpp **Painted Desert Member (Norian)**—Pale reddish-brown, moderately red, and light greenish-gray mudstone, sandstone, and siltstone; smectitic facies common in mudstones; relatively thin sandstones (<20 ft) have both horizontal laminae and thin sets of trough crossbeds; sandstones also have intraformational conglomeratic lenses that contain mudstone and carbonate clasts. *Unio* sp. (fresh-water bivalve) is common in the thin sandstones in lower 30 ft of this member, particularly at latitude 35°27'05" and longitude 108°36'28". Generally 500–550 ft thick

Trps **Sonsela Member (Norian)**—Yellowish-gray and pale-olive sandstone and conglomeratic sandstone; relatively thin mudstone interbeds, some of which are grayish red purple weathering. Conglomeratic sandstones contain both extrabasinal facies (chert and quartzite pebbles) and intrabasinal facies (carbonate and calcareous mudstone clasts); thin to medium sets of trough crossbeds common throughout, indicating west and northwest paleoflow directions. *Unio* sp. common in upper part; as much as 80 ft thick but generally less

Trpb **Blue Mesa Member (Carnian)**—Pale red-purple, grayish-red, and pale-red, locally mottled mudstone, siltstone, sandstone, and minor, lenticular carbonate beds; mudstones are smectitic and moderate to gentle slope formers; siltstones and sandy siltstones are moderate to steep slope formers; light-colored smectitic claystone at base serves as marker bed for base of Petrified Forest Formation throughout the quadrangle. Unit is as much as 140 ft thick

Trb **Bluewater Creek Formation (Upper Triassic)**—Pale reddish-brown, pale-red, and dark reddish-brown mudstone and silty mudstone, commonly smectitic, and pale-red to grayish-red, fine-grained, ripple-laminated sandstone having microlaminae of siltstone that give rise to color streaks. Contains zones of calcrete nodules, minor intraformational conglomerate facies, poorly preserved casts of *Unio* sp., and fragments of petrified wood. Amphibian and phytosaur bone fragments locally common, most of which are thought to pertain to *Buettneria* sp. or *Rutiodon* sp. May be as thick as 270 ft

Trbu **Upper part (Carnian)**—Pale reddish-brown and pale-red mudstone; calcrete nodules and fragments of casts of *Unio* and of petrified wood are common; as much as 110 ft thick

Trbm **McGaffey Member**—Pale-red to grayish-red, fine-grained, ripple-laminated sandstone; microlaminae of siltstone produce color streaking visible on fresh exposures; basal part has carbonate-clast conglomerate locally; unit is as much as 40 ft thick but generally much less; locally not recognized

Trbl **Lower part**—Pale reddish-brown and pale-red mudstone and thin, grayish-red, fine-grained sandstone beds that locally contain calcrete nodules. As much as 120 ft thick

Trmm **Moenkopi Formation, "mottled strata," and Shinarump Formation, undivided (Middle and Upper Triassic)**—Moenkopi is moderately reddish orange, massive to thinly laminated, and ripple-laminar siltstones interspersed with very fine grained sandstones of the same color; thickness varies from less than 10 ft to 100 ft. Unconformably overlying Moenkopi strata is the Shinarump Formation, a chert- and quartzite-pebble conglomerate and conglomeratic sandstone that is not mappable at this scale. The Shinarump lies on or within a unit termed "mottled strata" (Stewart et al., 1972), which consists of pedogenically altered grayish-purple, very dusky purple, pale reddish-brown, grayish-orange sandy siltstone and pale-pink to brownish-black mudstone; mottled strata are locally as much as 70 ft thick

Psa **San Andres Limestone (Leonardian)**—Gray and very light gray, coarsely crystalline, fossiliferous limestone and grayish-pink to grayish orange-pink dolomitic limestone; specimens of small productoid brachiopods common, as are bellerophont gastropods and small bivalves; base commonly intertongued with Glorieta Sandstone. As much as 90 ft thick; locally absent due to karsting

Pgya **Glorieta Sandstone and Yeso and Abo Formations, undivided (Permian)**—Shown in cross section A–A' only

Pg **Glorieta Sandstone (Leonardian)**—Light-orange to moderately orange pink and very pale orange, well-sorted, well-rounded, lower medium- to upper fine-grained quartzose sandstone; both flat and low-angle crossbedding present, as well as areas of moderately thick to thick sets of tabular and trough crossbeds. As much as 120 ft thick but generally much less

Py **Yeso Formation (Wolfcampian)**—Dark-orange and moderately reddish orange, lower very fine grained gypsiferous sandstone and silty sandstone. Locally three light-gray carbonate beds may be recognized within the unit approximately 100 ft, 150 ft, and 200 ft above base; carbonate beds are dolomitic and range from 3 ft to 5 ft in thickness; they contrast with San Andres beds in being much less fossiliferous. Total thickness 350 ft

Pa **Abo Formation (Wolfcampian)**—Grayish-red, very fine grained silty sandstone, arkosic at base through an interval 3–12 ft thick; generally flat bedded; noncalcareous; as much as 400 ft thick

p€g **Granite of Zuni Mountains (Early Proterozoic)**—Biotite granite, medium grained, equigranular

text begins on back

MAP SYMBOLS

Contact—Dashed where approximately located

Fault—Dashed where approximately located; dotted where concealed

Normal fault—Bar and ball on downthrown side

Thrust fault—Sawteeth on upper plate

Strike-slip fault—Arrows show relative direction of movement

Anticlinal axis—Dashed where approximately located

Synclinal axis—Dashed where approximately located

Strike and slip of beds

Paleoflow directions based on crossbed sets

Measured-section locality

Geology of Fort Wingate quadrangle, McKinley County, New Mexico

by Orin J. Anderson[1], Charles H. Maxwell[2], and Spencer G. Lucas[3], 1998

[1]New Mexico Bureau of Mines and Mineral Resources, Socorro, NM 87801
[2]U.S. Geological Survey, retired, Denver, CO 80225
[3]New Mexico Museum of Natural History and Science, 1801 Mountain Road NW, Albuquerque, NM 87104