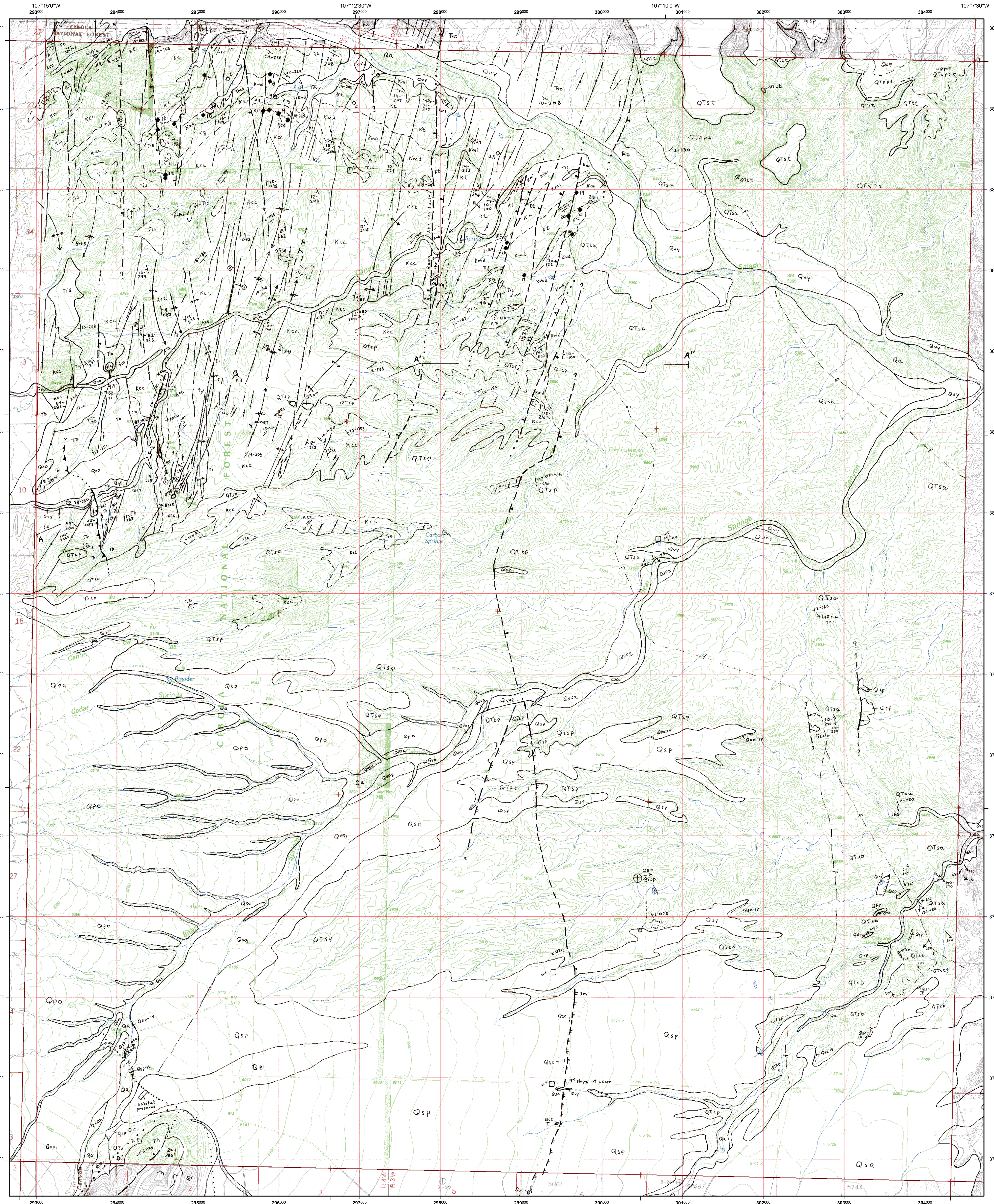
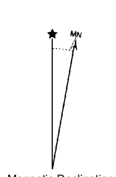


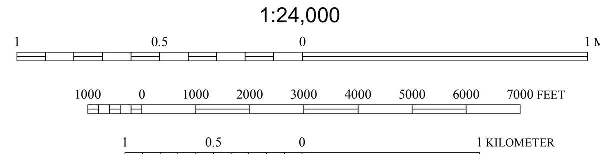
Base from U.S.Geological Survey 1995, from photographs taken 1991 and field checked in 1995.
1927 North American datum, UTM projection -- zone 13N
1000- meter Universal Transverse Mercator grid, zone 13, shown in red

QUADRANGLE LOCATION



Magnetic Declination
April, 2006
9º 57' East
At Map Center

1:24,000



CONTOUR INTERVAL 20 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

This draft geologic map is preliminary and will undergo revision. It was produced from either scans of hand-drafted originals or from digitally drafted original maps and figures using a wide variety of software, and is currently in cartographic production. It is being distributed in this draft form as part of the bureau's Open-file map series (OFGM), due to high demand for current geologic map data in these areas where STATEMAP quadrangles are located, and it is the bureau's policy to disseminate geologic data to the public as soon as possible.

After this map has undergone scientific peer review, editing, and final cartographic production adhering to bureau map standards, it will be released in our Geologic Map (GM) series. This final version will receive a new GM number and will supercede this preliminary open-file geologic map.

DRAFT

New Mexico Bureau of Geology and Mineral Resources
Open-file Map Series
OF-GM 165

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http://geoinfo.nmt.edu/publications/maps/geologic/ofgm/home.html

Geologic map of the Carbon Springs quadrangle, Socorro County, New Mexico.

May 2008

by
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COMMENTS TO MAP USERS

A geologic map displays information on the distribution, nature, orientation, and age relationships of rock and deposits and the occurrence of structural features. Geologic and fault contacts are irregular surfaces that form boundaries between different types or ages of units. Data depicted on this geologic quadrangle map may be based on any of the following: reconnaissance field geologic mapping, compilation of published and unpublished work, and photogeologic interpretation. Locations of contacts are not surveyed, but are plotted by interpretation of the position of a given contact onto a topographic base map; therefore, the accuracy of contact locations depends on the scale of mapping and the interpretation of the geologist(s). Any enlargement of this map could cause misunderstanding in the detail of mapping and may result in erroneous interpretations. Site-specific conditions should be verified by detailed surface mapping or subsurface exploration. Topographic and cultural changes associated with recent development may not be shown.

Cross sections are constructed based upon the interpretations of the author made from geologic mapping, and available geophysical, and subsurface (drillhole) data. Cross-sections should be used as an aid to understanding the general geologic framework of the map area, and not be the sole source of information for use in locating or designing wells, buildings, roads, or other man-made structures.

The map has not been reviewed according to New Mexico Bureau of Geology and Mineral Resources standards. The contents of the report and map should not be considered final and complete until reviewed and published by the New Mexico Bureau of Geology and Mineral Resources. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the State of New Mexico, or the U.S. Government.

DESCRIPTION OF MAP UNITS

CENOZOIC ERATHEM

Post-Santa Fe Group Deposits

Qa **Active channel deposits (upper Holocene) —** Active channel deposits and low floodplains of larger tributaries to the Rio Grande; includes the Rio Salado, Baca Canyon, Canon de las Cabras and Bear Springs Canyon. Consists mostly of sand and gravel with minor mud. Thickness 0-10 m.

Qe **Eolian deposits (Holocene to middle Pleistocene) —** Light gray to pale red, fine-grained, well-sorted, wind-blown sand and loess. Small dune fields locally cap older surfaces near the mouth of Bear Springs Canyon and on the north side of La Jencia Creek (SE quadrant of map area). Thin eolian sand veneers (<0.3m), on graded piedmont slopes, are mapped as piedmont deposits (i.e., *Qpo*). Thickness 0–3 m.

Qc **Colluvium and minor alluvium (Holocene to lower Pleistocene) —** Blocky angular talus, colluvium, and gravelly slope wash on steep to moderate slopes. Locally includes minor alluvium. Ridges of welded tuff are the primary source of loose angular debris on steep slopes near the mouth of Bear Springs Canyon. *Qc* is shown primarily where it masks important structural or stratigraphic relationships. Usually 0.3-3 m thick, locally as much as 10 m thick.

Qvy **Younger valley alluvium (Holocene to uppermost Pleistocene) —** Low terrace and alluvial-fan deposits of arroyos tributary to the Rio Salado. Includes minor active alluvial deposits in narrow drainages. Consists of poorly sorted, nonindurated, sandy gravel, sand, silt, and clay. Associated with low graded surfaces formed during last major episode of valley entrenchment and backfilling, about 2-3 m above grade. Thickness 0–10 m.

Qpy **Younger piedmont-slope alluvium (Holocene to uppermost Pleistocene) —** Minor debris flow and sheet flood deposits shed from the steep flank of the Southern Bear Mountains. Thickness 0-3 m.

Qvo **Older valley-fill alluvium (middle to upper Pleistocene) —** High level terrace and terrace-fan deposits of tributary arroyos associated with valley entrenchment and backfilling in Rio Salado valley and along Bear Springs Canyon. Most units occur 10-20 m above modern drainages. Consists of poorly to moderately sorted volcanic-rich gravel, gravelly sand and muddy silts. Mostly non-indurated to poorly indurated however, uppermost beds beneath graded surfaces are locally cemented by stage II or stage III calcic soils. Locally divided into older (Qvo_1) and younger (Qvo_2) terrace deposits. 0–10 m thick, average thickness 6 m.

Qpo **Older piedmont-slope alluvium and eolian deposits (middle to upper Pleistocene) —** Volcanic-rich gravels and pebbly to sandy alluvial-fan deposits of ancestral Cedar spring Canyon. Graded to older terrace deposits along Bear Springs Canyon (Qvo_1). Probably 10-30 m thick.

Santa Fe Group

Intermontane basin fill of the Rio Grande rift — Includes the Pliocene and Pleistocene valley and local bolson fill of the Sierra Ladrones Formation (Machette, 1978), which is assigned to the upper Santa Fe Group. Bolson-fill deposits of the Miocene Popotosa Formation (Denny, 1940) are apparently not exposed in the Carbon Springs quadrangle.

Upper Santa Fe Group

Qs/ QTs_ **Sierra Ladrones Formation (lower Pleistocene to Pliocene) —** Late-stage sedimentary fill of the La Jencia Basin. Characterized by two distinct conglomeratic piedmont facies shed from the volcanic-cored Bear Mountains (*QTspv*) and Paleozoic sediments from the western Ladron Mountains (*QTsps*), a well sorted axial-fluvial facies (*QTsa*) interpreted as ancestral Rio Salado beds, and a fine-grained basin-floor facies (*QTsb*). The latter two facies are well exposed near Ligon Ranch. A widespread travertine deposit ("Riley travertine" of Barker, 1983) forms a hard marker bed along the southeast-trending basin axis of late (?) Pliocene age. Buried and exhumed calcic soils (*Qsc* and *Qsb*) at the top of the Sierra Ladrones Formation form marker horizons. Thickness of Sierra Ladrones Formation in the western La Jencia Basin maybe as much as 1000 m.

Qsp **Sierra Ladrones Formation, Bear Springs Canyon geomorphic surface, (lower Pleistocene) —** Remnants of a broad alluvial-fan surface preserved between the mouth of Bear Springs Canyon and the northeast-trending late-stage axis of La Jencia basin. From an elevation of 6200 feet at Bear Springs Canyon the depositional surface slopes at about 120 feet per mile to the basin axis near La Jencia Creek. Overlaps *QTsb* near Ligon ranch. Forms top of the Sierra Ladrones Formation in this area. Tentatively correlated with the Las Canas and Sedillo Hill surfaces of McGrath and Hawley (1987). Thin veneers of upper Pleistocene eolian sands are generally not mapped separately.

Qsa **Sierra Ladrones Formation, La Jencia Creek geomorphic surface, (lower Pleistocene) —** Volcanic-rich gravels, sandstones and mudstones that underlie a gentle slope that descends to the NNE on west side of La Jencia Creek, locally cemented by stage IV calcrete near Ligon Ranch. Tentatively correlated with the Las Canas and Sedillo Hill surfaces of McGrath and Hawley (1987). Thin veneer of eolian sand is not mapped separately. 0-3 m thick.

Qsc **Sierra Ladrones Formation, calcic soil horizons (lower Pleistocene) —** Stage III to stage V calcic soil horizons (calcretes) ranging from 30 cm to 2 m thick, locally exposed along the dissected margins of the Bear Springs Canyon (*Qsp*) and La Jencia Creek (*Qsa*) geomorphic surfaces, near the Ligon Ranch. Stage IV calcrete is also well exposed on the footwall of the La Jencia fault scarp about 3 km southwest of Ligon Ranch.

QTsb **Sierra Ladrones Formation, basin-floor facies (Pliocene to lower Pleistocene) —** Light gray sand to poorly cemented sandstones, siltstones and interbedded pale red to red mudstones. Bedding is tabular to indistinct; poorly cemented nodular sandstones probably associated with weakly developed soils. Locally contains thin lenses of *QTsa*. Maximum exposed thickness near Ligon Ranch is about 36 m.

QTst **Sierra Ladrones Formation, travertine and massive carbonate beds, "Riley travertine" (upper Pliocene to lower Pleistocene) —** Mesa-capping to ledge-forming, light gray to white, massive to banded, and locally vuggy to brecciated, high-calcium carbonate beds, informally referred to as the "Riley travertine" (Barker, 1983). As much as 7-9 m thick where it caps mesa north of the Rio Salado. Discontinuously exposed, ledge-forming, banded limestone and marl beds (10-35 cm thick) near Ligon Ranch occur within upper part of "*QTsb*" and apparently represent the projected western distal margin of the southern sector of the "Riley travertine" (*QTsbc* of Cather and Read, 2003). The Riley travertine is a non-pedogenic secondary carbonate deposit of complex origin (Barker, 1983), which includes ostracod-bearing spring deposits (Cather and Read, 2003) and silty carbonate beds (marls) formed by displacive calcite cementation.

QTsa **Sierra Ladrones Formation, axial-fluvial deposits–ancestral Rio Salado beds (Pliocene to lower Pleistocene, possibly as old as late Miocene) —** Light brownish gray, well sorted, trough cross bedded to planar bedded, conglomeratic sandstones and sandstones that commonly fine upwards into pale reddish brown muddy siltstones. Well-sorted conglomeratic sandstones occur in tabular beds about 1-2 m thick and are locally stacked, conglomerate on conglomerate. A wide variety of volcanic pebbles dominate the conglomerates, but light to medium gray dacite porphyry pebbles speckled with black hornblende and biotite, are relatively abundant (10-25%) and occur along with sparse (2-5%) pebbles of light brown sandstones and pale red sandstone of Cretaceous and Triassic affinity. Light gray dacite porphyry clasts are typical components of syneruptive volcaniclastic strata in the Eocene Dog Springs Formation, which forms high cliffs along the north flank of the Datil Mountains, at the headwaters of the Rio Salado. Paleocurrent directions are dominantly to the southeast (130°-160°). Provenance, paleocurrent observations, bed forms and axial position are consistent with deposition by a southeast flowing river, here interpreted as the ancestral Rio Salado. The ancestral Rio Salado may have reached the western margin of the Socorro Basin near San Lorenzo Canyon, where lithologically similar conglomerates are assigned to the uppermost Popotosa Formation ("*Tpcu*" of Chamberlin, 2004). Maximum thickness, estimated from cross section, is about 240 m.

QTsp **Sierra Ladrones Formation, piedmont facies, volcanic-rich (Pliocene to lower Pleistocene) —** Pale purplish gray to dark gray conglomerates and conglomeratic sandstone beds that are crudely bedded and poorly sorted. Nearly all cobbles and pebbles are of volcanic origin. Dark gray basaltic andesites are dominant clast type; pale red to light gray quartz-bearing rhyolite ignimbrites (densely welded tuffs) are also common clast lithologies. Poorly indurated gravels occur near the top and poorly exposed muddy sandstone beds occur throughout. Buried pedogenic carbonate horizons are locally present. Paleocurrent observations are to the northeast (060°-075°). Clast lithologies and paleocurrent directions are consistent with a piedmont-slope conglomerate facies shed from the northern Bear Mountains (ancestral Bear Springs-Hells Mesa bajada).

QTsps **Sierra Ladrones Formation, piedmont facies, sedimentary-clast rich (Pliocene to lower Pleistocene) —** Light gray limestone and sandstone cobble to pebble conglomerates locally with minor to moderately abundant volcanic pebbles. Crudely bedded and poorly sorted, southwesterly to southerly paleocurrent directions. Apparently shed mostly from the western flank of the Ladron Mountains, exposed mainly north of the modern Rio Salado. Exposed thickness approximately 98 m.

Eocene-Oligocene volcanic rocks of the Mogollon-Datil field

Th **Hells Mesa Tuff (lower Oligocene) —** Mostly pale reddish to purplish gray, densely welded, phenocryst-rich (40–50%), quartz-rich, rhyolite ignimbrite. Typically contains abundant medium grained (1–3 mm) phenocrysts of sanidine, plagioclase, quartz and minor biotite. Quartz is minor component (1-2%) only in thin basal zone. Mean $^{40}Ar/^{39}Ar$ age (bulk sanidine) is 32.27 ± 0.1 Ma; paleomagnetic polarity is reverse (McIntosh, *et al.* 1991). Large volume ignimbrite (1,200 km^3) erupted from Socorro caldera (Chamberlin, *et al.*, 2004: McIntosh , *et al.* 1991). Correlation is based on distinctive lithology and relative stratigraphic position. Maximum thickness is 150 m.

Ts **Spears Formation (upper Eocene) —** Purplish gray, light brownish gray and light gray volcaniclastic conglomerates, sandstones, siltstones and reddish mudstones derived from intermediate composition volcanic highlands. Subrounded to subangular, purplish gray to medium gray, andesite and dacite porphyry clasts range from boulders to pebbles; they are common in lenticular to tabular conglomeratic beds, usually 1-3m thick. Phenocrystic quartz is typically absent. Age range from K/Ar dates of volcanic clasts and interbedded tuffs is approximately 39-33 Ma (Osburn and Chapin, 1983). Basal contact with Baca Formation is gradational, locally intertonguing over interval of 30m. Correlation based on lithology and relative stratigraphic position. Estimated thickness in northern Bear Mountains is 270m (Massingill 1979, C-C').

Conglomerates associated with Laramide uplift

Tb **Baca Formation (Eocene) —** Grayish to reddish brown, arkosic conglomerates conglomeratic sandstones, sandstones and red mudstones. Basal conglomerate contains abundant pebbles to cobbles of granite and limestone. Lower half is dominantly sandstone and conglomerate; mudstones and siltstones dominate the upper half. Petrified wood is locally present in the upper Baca Formation. Basal contact is a sharp erosional disconformity characterized by sharp downward decrease in grain size, such as from conglomeratic coarse sandstone Baca beds to fine-grained sandstone and mudstone beds of the Crevasse Canyon Formation. Estimated thickness in northern Bear Mountains is 300 m (Massingill, 1979, C-C', with projected fault).

Oligocene intrusive rocks

Ti (–o–) **Mafic dikes (upper Oligocene) —** Dark to medium gray to greenish gray, massive to locally vesicular, phenocryst poor (1-5%) to moderately phenocryst rich (10-20%) mafic dikes of basaltic to andesitic composition. Small phenocrysts (1-2 mm) are more apparent on weathered surfaces. Sparse small phenocrysts of olivine are commonly altered to yellowish serpentine; phyric pyroxene is commonly black and fresh, especially in the cores of dikes. Most dikes are basaltic and lack phyric plagioclase; a few dikes are andesitic and contain 2-10% phenocrystic plagioclase. Nearly all dikes contain carbonate and fizz vigorously when tested with dilute HCl. Carbonate preferentially replaces olivine and augite crystals and is usually more abundant at dike margins; some unaltered dike cores lack carbonate. Ubiquitous carbonate alteration is probably the product of high-temperature CO_2 metasomatism by magmatic gases trapped in the dikes below the Oligocene land surface (Dimeo, 2008). One analcime-bearing dike (lamprophyric dike) is also present in the Baca Canyon area. Most dikes are steeply dipping (75º to vertical) and trend NNE to NNW. The thickness of dikes ranges from about 1 to 9 m. Dull gray chilled margins are usually 10-15 cm thick and tend to be more resistant to erosion than the coarser grained core of some dikes. $^{40}Ar/^{39}Ar$ age determinations of 5 dike samples from the Carbon Springs quadrangle range from 26.6 to 29.2 Ma (Table 1; Dimeo, 2008). Dikes are shown on the map as a fine line with a solid dot within the line.

Tis **Mafic sills (upper Oligocene) —** Dark gray diabasic sills about 2-10 m thick and with strike lengths as much as 1 km. Compositionally similar to the mafic dikes that are common the Baca Canyon area. Gently dipping sills commonly cap cuestas in the Mancos Shale. The mafic sills must be fed by mafic dikes, thus they are presumed to be of upper Oligocene age.

Early Tertiary weathering zone

Kcco **Early Tertiary Weathering Zone (Paleocene?) —** Ancient weathering profile (oxidation zone) developed on the Crevasse Canyon Formation. Characterized by light purplish gray, light gray and maroon shales often mottled with yellowish brown; interbedded with white, light gray, bluish gray, lavender, and pale red to brick red sandstones. Sandstones are fine- to medium-grained and locally contain small concretions of hematite (after early diagenetic iron sulfide concretions). Sandstones commonly exhibit large low-angle crossbeds and may contain silicified logs. Upper contact of this stratiform zone is a sharp erosional unconformity and the base is a gradational alteration boundary (dashed contact). A narrow greenish-gray chloritic zone that parallels sandstone-shale contacts commonly marks the basal alteration boundary (redox front). However, the basal redox boundary also locally cuts across bedding (Chamberlin, 1981). Large tabular, dense blocks of colliform and polygonally cracked hematite as much as 2-5 cm thick locally occur as float near the top of the weathering zone about 1 km south of Baca Canyon. These heavy hematite masses are interpreted as slightly reworked fragments of a lateritic soil that capped the oxidation zone prior to deposition of the overlying Baca Formation. This regional stratiform zone of altered rocks, usually 30-60 m thick, is interpreted as the subsolum of a pre-Baca lateritic soil (Chamberlin, 1981). Small uranium deposits are known to occur at the basal redox boundary of this ancient weathering zone in the Datil Mountains (Chamberlin, 1981; Chamberlin, 1989). The weathering zone is apparently absent on the thrust block of Crevasse Canyon Formation exposed about 1 km west of FR 354, which suggests that the weathering zone was locally truncated by uplift and erosion at the toe of the thrust, prior to Baca deposition. A previous study of uranium potential in the Riley area (Chapin, *et al.,* 1979), did not recognize the presence of the pre-Baca weathering zone in the Carbon Springs quadrangle. Thickness 0-30 m.

MESOZOIC ERATHEM

Nomenclature of Upper Cretaceous stratigraphy follows that of Hook, *et al.* (1983), and Hook and Cobban (2007). See Mesozoic correlation diagram for stratigraphic position of key fossils; localities for Cretaceous fossils are listed in Table 2. "D number" refers to USGS collection of Cretaceous fossils stored in Denver, Colorado.

Kcc **Crevasse Canyon Formation (lower Coniacian-Santonian?) —** Sandstone, shale, and coal-bearing formation that consists of three members: the basal nonmarine Dilco Coal member, 30 m (100 ft) thick; the medial marine Dalton Sandstone member 1.5 m (5 ft) thick; and the upper nonmarine Gibson Coal member, at least 266 m (866 ft) thick. The Dalton Sandstone member (*Kcd*) is shown on the map as spot outcrops marked with solid diamonds. The lower contact with Gallup Sandstone is sharp; the upper contact with Baca Formation is erosional. A 1 m (3.5 ft) seam of mineable coal occurs 18 m (58 ft) above the base of the Dilco Coal member. Another 1 m (3 ft) thick seam of coal occurs about 60 m (200 ft) above the base of the Gibson Coal member. Marine fossils from a conspicuous, 30 cm (1 ft) thick, orange-weathering, resistant, ledge-forming sandstone bed at the top of the 1.5 m (5 ft-thick) Dalton Sandstone member at USGS Mesozoic Locality D14627. Fossils include the oyster *Crassostrea soleniscus* (Meek), and the bivalves *Pleuriocardia pauperculum* (Meek) and *Phelopteria* sp. This faunal assemblage is interpreted to be lower Coniacian on the Sevilleta National Wildlife Refuge, 40 km (25 mi) to the east by Hook and Cobban (2007, fig. 3). The extremely thin Dalton Sandstone suggests that the mapped area was at or very near the transgressive maximum of the "Dalton Sea."

An abandoned coal mine in the SW1/4 SW1/4 section 26, T. 2 N., R. 4 W. produced minor amounts of coal from a 1.5 m-thick bed. Analyses of three coal samples from the Dilco Coal member near this mine indicate that the coals range from lignitic to sub-bituminous, yielding heat values of 5,137, 7,179 and 9,083 BTU/lb. (Massingill, 1979, p. 155; Chapin et.al., 1979, table 3-1). Thicknesses of the Dilco and Gibson Coal Members are estimated from Massingill's (1979, p.73- 87) measured section of the undifferentiated Mesa Verde Formation.

Kg **Gallup Sandstone (lower Coniacian) —** Cliff-forming, yellow to light-brown-weathering, marine sandstone, 15 m (47 ft) thick, that coarsens upward from fine to coarse sand. Sandstone beds thicken upward from medium to thick bedded; the uppermost bed is cross stratified. Individual sandstone beds may be bioturbated, but do not contain conspicuous burrows. The lower contact with the D-Cross Tongue is gradational; the upper contact with the Dilco Coal member is sharp. No body fossils have been found in the Gallup Sandstone on the Carbon Springs quadrangle. However, Hook and Cobban (2007, figure 3, D14467) report the lower Coniacian bivalve *Cremnoceramus deformis erectus* (Meek) from the Gallup Sandstone on the Sevilleta National Wildlife Refuge, 40 km (25 mi) to the east. Here the Gallup/D-Cross section is similar stratigraphically to that on the Carbon Springs quadrangle. *Cremnoceramus deformis erectus* has been reported from the Gallup Sandstone at Puertecito, 18 km (11 mi) northeast by Hook, *et al.* (1983, sheet 1, sections 58A, D10278). Thickness and physical description of the Gallup are modified from Massingill (1979, p. 74-76).

Kmd **D-Cross Tongue of the Mancos Shale (middle Turonian-lower Coniacian) —** Gray, slope-forming, noncalcareous, clay shale, 95 m (290 ft) thick that contains two thin sandstones less than 3m (10 ft) thick in the upper third; a medial, 8 m (25 ft) thick zone of large, fossiliferous, limestone concretions; and a conspicuous, 30 cm (1ft) thick, sandy, orange-weathered limestone near the base. The lower contact with the Fite Ranch Sandstone member of the Tres Hermanos Formation is sharp; the upper contact with the Gallup Sandstone is gradational. Fossils from the orange limestone, 5 m (15 ft) above the base (D10289) and a calcarenite bed 1.5 m (5 ft) higher (D14779), yield a middle Turonian fauna that includes the bivalve *Inoceramus dimidius* (White) and the ammonite *Scaphites warreni* (Meek and Hayden). The 8 m (25 ft) thick limestone concretion zone, which begins approximately 20 m (60 ft) above the base of the D-Cross, has yielded a middle Turonian fauna from several localities that includes the bivalve *Inoceramus perplexus* (Whitfield) (D14774) and the ammonite *Prionocyclus novimexicanus* (Marcou) (D14775). The 1-1.6 m (3-5 ft) thick sandstone, approximately 30 m (100 ft) below the base of the Gallup Sandstone, has yielded the large (Coniacian) form of the distinctive upper Turonian-lower Coniacian oyster, *Nicaisolopha sannionis* (White) at several localities including D10291, D10292, D10351, D14626, D14638, and D14643. Hook, *et al.* (1983, sheet 1, sections 58A & 58B) correlate this thin sandstone with the "E" sandstone of the Gallup Sandstone at Puertecito. Total thickness of the D-Cross Tongue of the Mancos Shale is from Massingill (1979, p. 66-69).

Kt **Tres Hermanos Formation (middle Turonian) —** Heterolithic unit of fine-grained, yellow-to-brown weathering sandstone and gray-to-green weathering shale, 76 m (231 ft) thick, that splits the Mancos Shale into two tongues, the D-Cross Tongue above and the (informal) lower tongue below. Fittingly, the Tres Hermanos is divided into three members: the lower, regressive, marine Atarque Sandstone member, 14 m (44 ft) thick; the Carthage member, a medial, nonmarine, sandstone and shale (with minor coal seams) 44 m (134 ft) thick; and the upper, transgressive, marine, Fite Ranch Sandstone member, 18 m (53 ft) thick. The Atarque and Fite Ranch Sandstones form bold cliffs; whereas, the Carthage member forms hummocky topography between the two sandstone members. The dense array of vertical and horizontal burrows in the Fite Ranch easily distinguishes it in isolated outcrops from the Gallup Sandstone. The lower contact of the Tres Hermanos Formation with the lower shale tongue of the Mancos is gradational; the upper contact with the D-Cross Tongue is sharp. Large, dark brown-weathered, calcareous sandstone concretions in the middle of the Atarque Sandstone have yielded the middle Turonian ammonite *Collignoniceras woollgari woollgari* (Mantell) at USGS Locality D10288. Hook, *et al.* (1983, sheet 1, section 58B, D 10596) record the middle Turonian oyster *Nicaisolopha bellaplicata* (Shumard) from near the top of the Fite Ranch Sandstone on the quadrangle. Thickness of the Tres Hermanos Formation is from Massingill (1979, p. 58-65).

Kml **Lower tongue of the Mancos Shale (middle Cenomanian-lower Turonian) —** Gray, slope-forming, calcareous and noncalcareous, clay shale, 174 m (570 ft) thick, that contains minor amounts of siltstone, sandstone, and limestone. The 14 m (45 ft) thick, Bridge Creek Limestone beds, 116 m (380 ft) above the base, split the unit into three parts. The lower shale, 116 m (380 ft) thick, consists of about 30 m (100 ft) of interbedded non-calcareous shale and thin sandstone beds followed by a calcareous shale and bentonite interval. The base of Bridge Creek Limestone beds is marked by an 20-30 cm (8-12 inch) thick nodular limestone bed; its top, by about 2m (6 ft) of interbedded shale and thin, medium-brown weathered, resistant calcarenites. The intervening beds are primarily highly calcareous shale. The thin nodular limestone beds at the base of the Bridge Creek beds and the thin calcarenites at the top form minor ridges in shale valleys between the Dakota Sandstone and Tres Hermanos Formation. A 18 cm (7 inch) thick bentonite, 17 m (55 ft) above the top of the Bridge Creek beds marks the boundary between calcareous shale below ("Greenhorn") and noncalcareous shale above ("Carlile") in the upper shale. Limestone concretions developed in and just above this bentonite are formed around the large, distinctive, horned ammonite, *Morrowites depressus* (D14748). The basal contact of the lower tongue with the Dakota is abrupt and unconformable; the upper contact with the Tres Hermanos Sandstone is gradational. The oldest fossils from the Carbon Springs quadrangle come from a 15 cm (6 inch) thick sandy bed in the lower part of the lower tongue (D5800) and include the middle Cenomanian bivalve *Inoceramus rutherfordi* (Warren). Less than 1.5 km (1 mi) northwest of the quadrangle, a thin sandstone bed 7 m (22 ft) above the Dakota yielded the older middle Cenomanian bivalve *Inoceramus prefragilis prefragilis* (Stephenson)(D14790). This clam is indicative of the Thatcher fauna, the oldest middle Cenomanian fauna known from the Western Interior of the United States. Another thin sandstone, 21 m (69 ft) above the Dakota contained the middle Cenomanian oyster *Ostrea beloiti* (Logan), the bivalve *Inoceramus arvanus* (Stephenson), and the ammonite *Turillites acutus americanus* (Cobban and Scott)(D14784). These fossils indicate that the upper portion of the sandstone and shale interval correlates with the 5 m (15 ft) thick, ridge-forming sandstone that Robinson (1981, p. 27-33) mapped as the Paguate Tongue of the Dakota Sandstone on the D-Cross Mountain quadrangle, 35 km (22 mi) northwest of Carbon Springs.

The easily identifiable, upper Cenomanian oyster *Pycnodonte newberryi* (Stanton) has been collected at several localities (D10286, D14772, and D14778) from the nodular limestones and interbedded calcareous shales at the base of the Bride Creek Limestone beds. The ammonite *Euomphaloceras septemseriatum* (D5798), a key upper Cenomanian guide fossil in the Western Interior, occurs in the basal limestone. The Cenomanian/Turonian boundary is drawn at the top of a 15 cm (6 inch) thick limestone, containing the uppermost upper Cenomanian bivalve *Mytiloides hattini* (Elder)(D14788), about 2 m (6 ft) above the base of the Bridge Creek. The lower Turonian bivalve *Mytiloides mytiloides* (Mantell) occurs abundantly as fragmented shells in the calcarenites at the top of the Bridge Creek (D5779, D14773). The very distinctive lower Turonian ammonites *Morrowites depressus* (Powell) and *Tragodesmoceras socorroense* (Cobban and Hook) (D14748) occur in limestone concretions in the upper shale that are developed on the 18 cm (7 inch) thick bentonite that marks the calcareous/noncalcareous shale contact below the Tres Hermanos Formation.

A 42 cm (16 inch) thick bentonite exposed in calcareous shale under a sill about a 0.75 km (0.5 mi) north of the quadrangle in the SW1/4, NE1/4, SW1/4 sec. 22, T. 2 N., R. 4 W., may be the upper middle Turonian "X" bentonite, which is widespread in the Western Interior. We have not found this thick bentonite at any other locality and there are no key lithologic units exposed nearby to put it into more precise stratigraphic context. It is shown questionably on Figure 1 in its relative stratigraphic position. A complete section of "*Kml*" does not crop out on the quadrangle; total thickness is modified from Massingill's (1979, p. 44-50) composite measured section of his "Alamito Tongue" of the Mancos Shale.

Kd **Dakota Sandstone (?lower Cenomanian?) —** Dark brown-weathered, ridge-forming, quartz sandstone with minor shale, 3-9 m (10-30 ft) thick. Often cross-stratified, it is generally composed of fine-sized sand grains that are rounded, well sorted, and cemented by silica. No body fossils have been collected from it. The lower contact of the Dakota Sandstone is disconformable on the Triassic. The upper contact is probably an unconformity as well. Massingill (1979, p. 31) reports that the "...Dakota thins, disappears, and reappears within a distance of about 1 mi (1.6 km)…" about 10 km (6 mi) northwest of the quadrangle. Where the Dakota is absent, the Mancos rests unconformably on the Triassic. This relationship, plus the suggestion of a minor amount of relief on the Dakota dipslope beneath the sharp contact with the Mancos, strongly suggests an erosional unconformity between the Dakota and the Mancos. A sporadically developed chert-pebble conglomerate at the top of the Dakota dipslope may mark this unconformity or it may be an older pebble bed in the Dakota.

Massingill (1979, p. 30-35) interpreted the Dakota to be transitional into the lower tongue of the Mancos and drew its upper boundary at the last clean, noncalcareous sandstone above which occurs dark gray, noncalcareous shale of the Mancos. We interpret this upper contact to be an unconformity and draw the boundary at the top of the Dakota dipslope, which is also the base of a 1.5 m (5 ft) thick, black, fissile, noncalcareous shale. We have included this shale and the overlying 15 m (50 ft) of interbedded thin sandstones and shale of Massingill's Dakota, in our Mancos. Dakota Sandstone is not exposed on the Carbon Springs quadrangle, but it is shown on this map where exposed at the south margin of the Riley Quadrangle.

Triassic

Ꞩc **Chinle Group (Upper Triassic) —** Red, gray and maroon fluvial mudstone with subordinate sandstone, limestone-pebble conglomerate, and limestone. Forms slopes and valleys. Kelley and Wood (1946) report a thickness of 1,000 feet (300 m) on the adjacent Lucero uplift.

Ꞩu **Triassic rocks, undivided —** Chinle Group and Shinarump Conglomerate; thickness of 1,300 feet (390 m) is from Kelley and Wood (1946). Shown in cross section only.

Permian

Pu **Permian rocks, undivided —** Shown in cross section only.

Explanation of Map Symbols:

Depositional contact, dashed where approximately located. Dip and dip direction (azimuth) shown where observed. Most Quaternary contacts are approximately located; they are shown as continuous lines to aid map legibility.

Gradational lateral facies boundary in the Sierra Ladrones Formation

Fossiliferous marker bed (Dalton Sandstone–Kcd) in the Crevasse Canyon Formation

Pedogenic carbonate layer in the uppermost Sierra Ladrones Formation (Qsc)

Mafic dike (Ti) showing dip and dip azimuth.

Normal fault showing dip and dip azimuth, dashed where approximately located, dotted where concealed. Ball on downthrown side, or where concealed, U= upthrown side and D= downthrown side.

Laramide thrust fault showing dip and dip azimuth, dotted where concealed.

Strike, dip, and dip azimuth of sedimentary bedding or compaction foliation in welded tuffs.

Horizontal bedding.

Anticline, showing approximate trend of crest line and direction of plunge.

Syncline, showing approximate trend of trough line and direction of plunge.

General direction of paleocurrents (± 30°) based on pebble imbrication or trough axis. Observation point at base of arrow or nearest bedding observation.

Sample location for $^{40}Ar/^{39}Ar$ age determination of mafic dike (number refers to Table 1).

Fossil locality, open symbol indicates location is approximate, ± 200 m (number refers to Table 2)

Spring

Water well

Water tank

Earthen berm

REFERENCES

Cather, S. M. and Read, A. S., 2003, Preliminary Geology of the Silver Creek 7.5 minute quadrangle, New Mexico: *New Mexico Bureau of Geology and Mineral Resources Open-file Geologic Map OF-GM-75,* 1:24,000.

Chamberlin, R. M., 1981, Uranium potential of the Datil Mountains–Pie Town area, Catron County, New Mexico: *New Mexico Bureau of Mines and Mineral Resources*, Open-file Report 138, 51 p., (map scale 1:250,000).

Chamberlin, R. M., 1989, Criteria for the recognition of a pre-Eocene lateritic weathering profile, west-central New Mexico: *New Mexico Geological Society, Guidebook 40*, p. 34–35.

Chamberlin, R. M., 1983, Cenozoic domino-style crustal extension in the Lemitar Mountains, New Mexico: A summary: *in:* Chapin, C. E., and Callender, J. F. (*eds.*), *Socorro Region II: New Mexico Geological Society, Guidebook 34*, p. 111–118.

Chamberlin, R. M., McIntosh, W. C. and Eggleston, T. L., 2004, $^{40}Ar/^{39}Ar$ geochronology and eruptive history of the eastern sector of the Oligocene Socorro Caldera, central Rio Grande Rift, New Mexico: *in:* Cather, S. M., McIntosh, W. C., and Kelley, S.A. (*eds.*), *Tectonics, Geochronology and Volcanism in the Southern Rocky Mountains and Rio Grande Rift:* New Mexico Bureau of Mines and Mineral Resources Bulletin 160.

Chapin, C. E., Osburn, G. R., Hook, S. C., Massingill, G. L., and Frost, S. J., 1979, Coal, uranium, oil and gas potential of the Riley-Puerticito area, Socorro County, New Mexico: *New Mexico Bureau of Mines and Mineral Resources Open-file Report 103*, 38p.

Denny, C. S., 1940, Tertiary geology of the San Acacia area, New Mexico: *Journal of Geology*, v. 48, pp. 73–106.

Dimeo, M. I. 2008, *Geology, geochemistry, and geochronology of Oligocene mafic dikes near Riley New Mexico* (M.S. Thesis): New Mexico Institute of Mining and Technology, Socorro, NM, 135p.

Hook, S. C., Molenaar, C. M., and Cobban, W. A., 1983, Stratigraphy and revision of nomenclature of upper Cenomanian to Turonian (Upper Cretaceous) rocks of west-central New Mexico: *in:* Hook, S. C. (*comp.*), *Contributions to mid-Cretaceous paleontology and stratigraphy of New Mexico – part II:* New Mexico Bureau of Mines and Mineral Resources Circular 185, pp. 7-28.

Hook, S. C. and Cobban, W. A., 2007, A condensed middle Cenomanian succession in the Dakota Sandstone (Upper Cretaceous), Sevilleta National Wildlife Refuge, Socorro County, New Mexico: *New Mexico Geology*, v. 29, no. 3, p. 75-99.

Kelley, V. C., and Wood, G. H., 1946, Geology of the Lucero Uplift: *U.S. Geological Survey, Oil and Gas Investigations, Preliminary Map 47*, scale 1:63,360.

Machette, M. N., 1978, Geologic map of the San Acacia quadrangle, Socorro County, New Mexico: *U.S. Geological Survey, Geologic Quadrangle Map, GQ 1415*, scale 1:24,000.

Massingill, G. L., 1979, *Geology of Riley-Puertecito area, southeastern margin of Colorado Plateau, Socorro County, New Mexico* (Ph.D. dissertation): University of Texas, El Paso 207 p. (available as NMBGMR Open-file report 107).

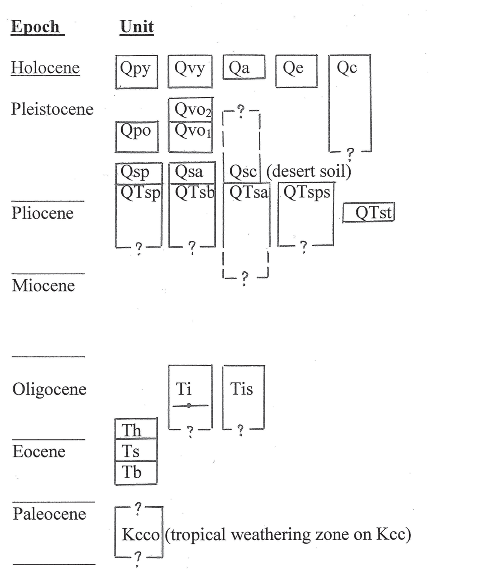
McGrath, D. B., and Hawley, J. W., 1987, Geomorphic evolution and soil-geomorphic relationships in the Socorro area, central New Mexico: *in:* McLemore, V. T., and Bowie, M. R. (*eds.*), *Guidebook to the Socorro area:* New Mexico Bureau of Mines and Mineral Resources, pp. 55–67.

McIntosh, W. C., Kedzie, L. L., and Sutter, J. F., 1991, Paleomagnetism and $^{40}Ar/^{39}Ar$ ages of ignimbrites, Mogollon-Datil volcanic field, southwestern New Mexico: *New Mexico Bureau of Mines and Mineral Resources, Bulletin 135,* 79 p.

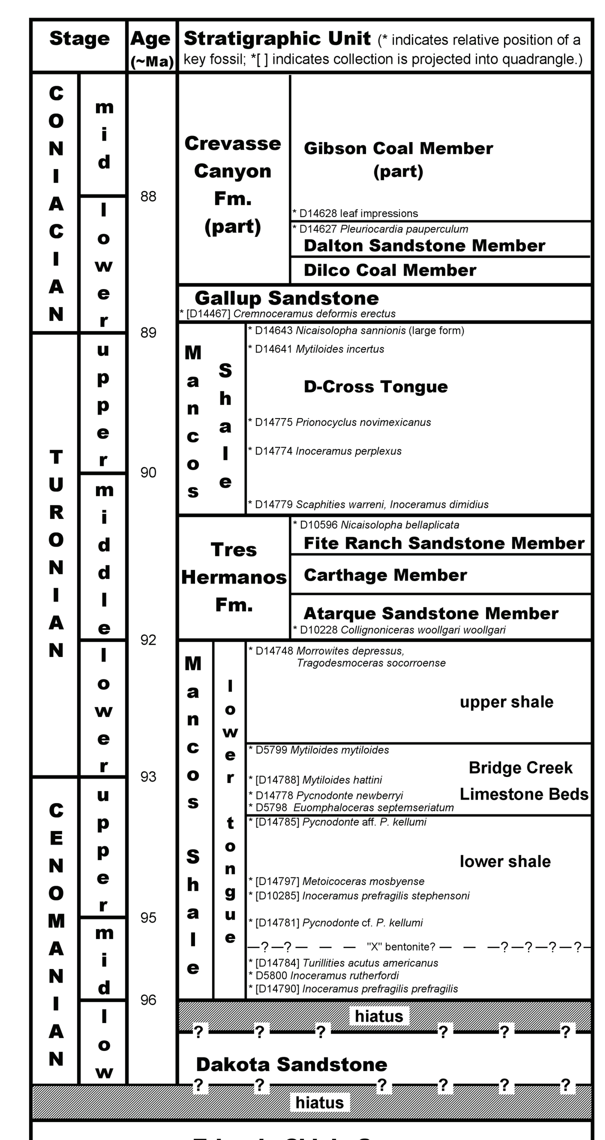
Osburn, G. R., and Chapin, C. E., 1983, Nomenclature for Cenozoic rocks of northeast Mogollon-Datil volcanic field, New Mexico: *New Mexico Bureau of Mines and Mineral Resources, Stratigraphic Chart 1.*

Robinson, B. R., 1981, *Geology of the D Cross Mountain quadrangle, Socorro and Catron Counties, New Mexico*: University of Texas at El Paso, unpublished D.G.S. dissertation, 213 p.

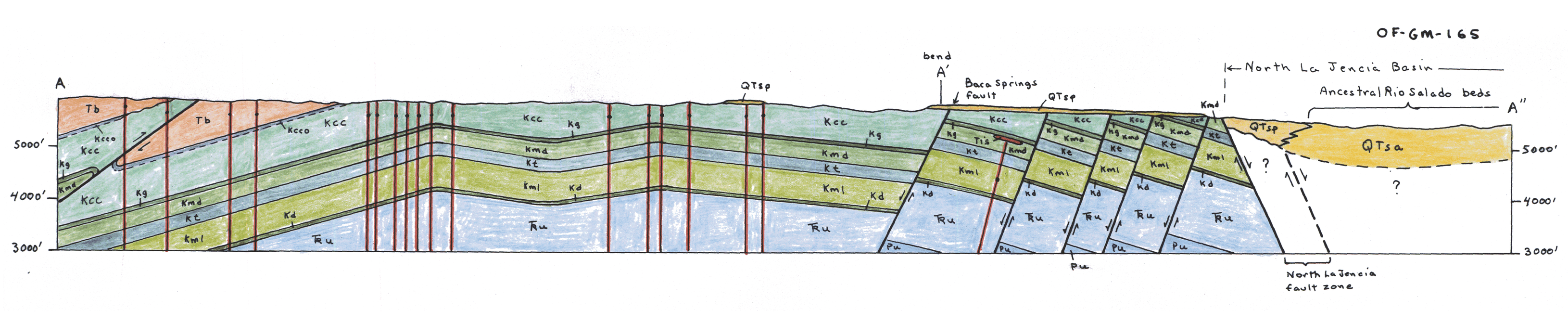
Correlation of Cenozoic Map Units:



Correlation of Mesozoic Strata



GEOLOGIC CROSS SECTION



Mapping responsibilities