Geologic Map of the Madrid Quadrangle, Santa Fe County, New Mexico

By

S.R. Maynard, D. Sawyer, and J. Rogers

May, 2001

New Mexico Bureau of Geology and Mineral Resources
Open-file Digital Geologic Map OF-GM 40

Scale 1:24,000

This work was supported by the U.S. Geological Survey, National Cooperative Geologic Mapping Program (STATEMAP) under USGS Cooperative Agreement 06HQPA0003 and the New Mexico Bureau of Geology and Mineral Resources.

New Mexico Bureau of Geology and Mineral Resources
801 Leroy Place, Socorro, New Mexico, 87801-4796

GEOLOGIC MAP OF THE
MADRID 7.5-MINUTE QUADRANGLE
SANTA FE AND SANDOVAL COUNTIES, CENTRAL NEW MEXICO

by

Stephen R. Maynard
Consulting Geologist
4015 Carlisle, NE
Suite E
Albuquerque, NM 87107

David Sawyer
U.S. Geological Survey
MS 913 Box 25048
Denver, CO 80225

and

John Rogers
Consulting Geologist
3417 Purdue Place NE
Albuquerque, NM 87106

New Mexico Bureau of Mines and Mineral Resources
A Division of the New Mexico Institute of Mining and Technology

Open-File Report DM-40
May 2001

INTRODUCTION

Location, land status, and terrain

The Madrid 7.5-minute quadrangle comprises an area of about 158 km^2 (61 mi^2) east of the Rio Grande Valley in Santa Fe County and a narrow strip of Sandoval County, New Mexico. The study area covers a portion of the Santo Domingo Pueblo Indian Reservation, lands administered by the Bureau of Land Management, land administered by the Bureau of Reclamation (at the Galisteo Dam), state lands, and land administered by Santa Fe County (the Cerrillos Hills Historic Park). The majority of the land is privately owned; most of it is within the Ortiz Mine Grant and the Mesita de Juana López Grant. The towns of Madrid and Cerrillos lie in the Madrid quadrangle. NM-14 (the Turquoise Trail) is the major highway on the quadrangle, crossing it from the southern boundary to the northeast corner. County road 22 crosses the extreme southwestern corner of the quadrangle. County road 52 crosses the northern part of the quadrangle. The Santa Fe Railroad tracks run east to west, roughly parallel to Galisteo Creek, across the northern part of the quadrangle.

Elevations range from 1,630 m (5380 ft), on Galisteo Creek in the northwestern corner of the quadrangle; to 2,113 m (6976 ft), on Grand Central Mountain, in the Cerrillos Hills, and 2,152 m (7100 ft), on a spur of the Ortiz Mountains, in the southeastern part of the quadrangle. South of Galisteo Creek, north-trending ridges of igneous rocks or sandstone or broad, gently sloping gravel-capped mesas characterize the landscape. The central and north-central part of the quadrangle, is a low, relatively flat area underlain by shale. Dissected upland punctuated by steep, roughly conical hills forms the Cerrillos Hills. Galisteo Creek is the major drainage of the quadrangle. All arroyos and gulches in the quadrangle drain to Galisteo Creek, which itself empties into the Rio Grande.

Note to 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 are based on reconnaissance field geologic mapping, compilation of published and unpublished work, and photogeologic interpretation. Locations of contacts are not surveyed, but are plotted by interpretation onto a topographic base map; therefore, the accuracy of contact locations depends on the scale of mapping and the interpretation of the geologist. 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 structures. Site-specific conditions should be verified by detailed surface mapping or subsurface exploration. The topographic base for the geologic map is the Madrid 7.5-minute topographic quadrangle, published by the United States Geological Survey at a scale of 1:24,000 (one inch equals 2000 feet). Topographic and cultural changes associated with recent development may not be shown.

Mapping of this quadrangle was funded by a matching-funds grant from the 1999-2001 STATEMAP program of the U.S. Geological Survey, National Cooperative Geologic Mapping Program, to the New Mexico Bureau of Mines and Mineral Resources (Drs. Charles E. Chapin (formerly Director) and Peter A. Scholle, Director; Dr. Paul W. Bauer, P.I. and Geologic Mapping Program Manager). The quadrangle map has been placed on open file in order to make it available to the public as soon as possible. The map has not been reviewed according to the New Mexico Bureau of Mines and Mineral Resources standards. Revision of the map is likely because of the on-going nature of work in the region. *The report and map should not be considered final and complete until they are published by the New Mexico Bureau of Mines and Mineral Resources.*

PRINCIPAL GEOLOGIC AND PHYSIOGRAPHIC FEATURES

Galisteo Creek Monocline

An east-dipping monocline exposes the stratigraphic section from the upper part of the Chinle Group to the Paleocene Diamond Tail Formation in the Madrid quadrangle. Best exposures are along Galisteo Creek and along the cut of the Santa Fe Railroad from the Rosario gypsum mine to the town of Cerrillos. The Galisteo Monocline is part of a regional eastward tilt related to opening of the Albuquerque Basin. The Galisteo Monocline is disrupted by doming of the Cerrillos Hills Intrusive-Extrusive Complex.

Cerrillos Hills Intrusive-Extrusive Complex

The southwestern and south-central part of the Cerrillos Hills lie in the northwestern part of the Madrid quadrangle. The Cerrillos Hills are composed of andesite-porphyry laccoliths and augite-hornblende (+/-biotite) monzonite stocks, and subordinate feldspar-porphyry latite dikes and plugs that are probably between 34 Ma and 30 Ma. These intrusive rocks intruded and produced doming in the Mesozoic and Cenozoic sedimentary section. The intrusive complex is overlain by and intrudes the Espinaso volcanics. Aphanitic and porphyritic dikes radiate from the Cerrillos Hills. Lead-zinc-silver veins and porphyry copper mineralization represent the last stages of magmatic activity. Doming resulted in high-angle tilting of the layered sedimentary rocks around the Cerrillos Hills. Though the tilting is most noticeable on the southeast side of the Cerrillos Hills, beds of Mancos Shale, Mesa Verde Group sandstone and shale, and Diamond Tail Formation sandstone, along with concordant bodies of andesite porphyry are tilted to near vertical on both side of Galisteo Creek west of the town of Cerrillos. Moderately to shallowly southwest- and west-dipping strata of the Morrison Formation, Dakota Formation, and the Mancos Shale indicated doming in the southwestern and western parts of the Cerrillos Hills as well. The degree of tilting around the Cerrillos Hills is generally greater on the eastern side. If the 20 to 25 degree average dip of the Galisteo Monocline is subtracted from dips of beds on the eastern side of the Cerrillos Hills and added to dips of beds on the western side, the degree of doming are approximately equal.

Johnson (1903) considered the Cerrillos Hills Intrusive-Extrusive Complex to be laccolithic in nature and recognized two principal stages of intrusive activity, though he indicated no floor to the presumed laccolith and mapped all intrusive rocks as one.

Stearns (1953b) proposed that the Morrison Formation outcrops in the southwestern and northwestern part of the Cerrillos Hills constituted the remains of the original roof of the intrusive complex, and that the steeply inclined, concordant bodies of andesite porphyry along the western and southern margins of the Cerrillos Hills (e.g. Devil’s Throne) were injected from below, as dikes. Their concordance with bedding at the present-day erosion levels is therefore coincidental, and would not persist at depth.

Disbrow and Stoll (1957) concluded that the concordant andesite porphyry were sills, or tongue laccoliths emanating from a central feeder.

Laccoliths

Four - 30 Ma laccoliths of andesite porphyry intrude the Cretaceous Mancos Shale and the Mesa Verde Group in the southern half of the Madrid quadrangle. The Cedar Mountain laccolith, which is the highest in terms of stratigraphic position, intrudes the

Menefee Formation of the Upper Cretaceous Mesa Verde Group and the lower part of the Paleocene Diamond Tail Formation. The Madrid laccolith intrudes the Menefee Formation and forms the ridge immediately to the east of the town of Madrid. The Cerro Chato laccolith intrudes lower in the Menefee Formation and forms the ridge to the west of Madrid. The Juana López laccolith intrudes the lower part of the Mancos Shale and forms a prominent ridge about 5 km (3 mi) west of Madrid. These laccoliths appear to be relatively uniform in thickness over distances of several miles. No feeder has been observed for these bodies; they may be feed by high-angle structures underneath, or may have been propagated from a central stock in the Ortiz Mountains.
The Cerrillos Hills laccolith consists of multiple bodies of andesite porphyry. It appears to be considerably thicker than the laccoliths on the Madrid quadrangle south of Galisteo Creek. The Cerrillos Hills laccolith has multiple sills and may have formed a "Christmas Tree" type laccolith. It intrudes Jurassic through Cretaceous rocks. Later intrusions and faulting cut the Cerrillos Hills laccolith.

Lead-zinc-silver veins

Narrow fissure quartz veins containing argentiferous galena and minor sphalerite are common in the northern part of the Cerrillos Hills and in a broad area of the southwestern part of the Cerrillos Hills, southwest of Grand Central Mountain. In the northern part of the Cerrillos Hills, veins are typically north-south to north-northeast trending. In the southwestern part of the Cerrillos Hills, veins trend N30E to N50E. Of the veins occurring on the Madrid quadrangle, only the northern group had significant production (Disbrow and Stoll, 1957).

Faults

The study area includes the southern exposures of the **La Bajada fault system**, in the western part of the quadrangle, which juxtaposes the Eocene Galisteo Formation sandstone and mudstone, Oligocene Espinaso volcanics, and unconsolidated sediments of the Santa Fe Group with Triassic and Jurassic sedimentary rocks. It forms the eastern boundary of the Santo Domingo sub-basin of the Albuquerque Basin. The La Bajada Fault strikes from 350 to 010 azimuth and appears to dip steeply to the west. Jurassic strata are sharply folded into the fault, forming a tight, faulted anticline adjacent to the La Bajada Fault. Movement on the La Bajada Fault probably began in the early Miocene. Pleistocene movement on the La Bajada Fault is indicated by Tuerto Gravel capping small mesas on the fault's east side lying about 12 m (40 ft) higher than the gravel-capped mesa on the west side in the southwestern part of the quadrangle. This displacement is less apparent to the south, but may be expressed as a subtle change in the slope of the constructional surface of the Tuerto Gravel. The La Bajada Fault does not appear to cut recent terrace deposits along Galisteo Creek. However, older terrace gravels (Qt1 and Qt2) appear to be truncated by the La Bajada Fault. Latest fault movement can be bracketed by these terraces.

The **Budaghers Fault**, identified by Connell and others (2000), strikes east-northeast, has normal displacement, and serves as a transfer fault between the San Francisco and La Bajada Faults. It juxtaposes slightly to moderately tilted older Santa Fe group deposits on the south side against subhorizontal to slightly tilted Santa Fe group deposits on the north side.

The **Tano Fault** strikes north northeast and cuts Santa Fe Group sediments and the Tuerto Gravel in the southwestern part of the Madrid quadrangle. Offset of the Tuerto Gravel is approximately 20 m (70 ft) along the Tano Fault. The Tano Fault also cuts Quaternary stream terrace deposits near the center of section 19, T14 N, R 8 E.

Another, **unnamed fault** places gently dipping Santa Fe Group sediments against moderately to steeply dipping agglomerate beds of the Espinaso Volcanics and sandstones and mudstone beds of the Galisteo Formation between the Tano and La Bajada Faults in the southwestern part of the quadrangle. This fault does not appear to have cut the Tuerto Gravel.

Northeast-trending faults form a small horst in the Cerrillos Hills. This horst may be related to late-stage intrusive activity.

Ortiz Surface

The Plio-Pleistocene Tuerto Gravel caps the extensive north and northwest-sloping mesas in the southwestern and southeastern parts of the Madrid quadrangle, and the flanks of the Cerrillos Hills. A few narrow outlier mesas extend into the area to the north of the town of Madrid. The Tuerto Gravel was deposited by on erosion surfaces flanking the Ortiz Mountains and the Cerrillos Hills and contains detritus derived from them (Koning and others, 2001). The constructional top of the Tuerto Gravel forms the Ortiz Surface as defined by Ogilvie (1905) and Kelley (1977). The Ancha Formation, a gravel deposit containing granitic and metamorphic clasts from the Sangre de Cristo Mountains, as well as minor clasts from the Cerrillos Hills, forms a similar surface on the north side of the Galisteo Creek.

Alluvial deposits of Galisteo Creek

Galisteo Creek is the most important drainage on the Madrid quadrangle. Active and ancient alluvial deposits record the down-cutting of Galisteo Creek in Pleistocene to Holocene time. Six sets of terrace deposits have been identified. The terraces can be roughly correlated based on criteria of aerial photographic interpretation, visual line of sight in the field, limited hand-level measurements, elevations derived from the topographic base map (20-ft contour intervals), and terrace deposit characteristics (e.g. thickness and degree of caliche development). The likely existence of a significant knick point formed by resistant Morrison and Dakota strata at the present site of the Galisteo Dam makes correlation of terraces upstream and downstream of the dam tenuous.

Changes in the terrace stratigraphy from one side of the fault to the other imply late Quaternary movement on the La Bajada Fault. On the downstream side of the fault, the highest terrace preserved in Qt3. Qt1 and Qt2 are not present. Qt3 downstream correlates with Qt3 upstream based on the height of the terraces above the modern Galisteo Creek channel. Qt3 upstream and downstream are fill terraces with cemented bases. The base of Qt3 downstream is 2.1 m (7 ft) above the grade of the modern channel, while the base of Qt3 upstream is 5.5 m (18 ft) above grade. This 3.3 m (11 ft) elevation difference in the height of the base is nearly equal to the difference in thickness of the two terrace deposits. One explanation is that 3.3 m (11 ft) of displacement occurred on the La Bajada Fault, followed by 3.3 m (11 ft) of stripping. The presence of Qt4 on the upstream side and its absence on the downstream side of the fault complicate this scenario. Terrace stratigraphy is roughly similar after Qt5 time, suggesting that disruptive fault movement occurred post Qt2 and prior to Qt5.

Quaternary Pediment deposits

Extensive incised pediment deposits, composed of thin (less than 1.5 m (5 ft)) accumulations of soil, wind-blown sand, and material reworked mainly from the Tuerto Gravel, blanket a large portion of the region known as La Bolsa, north and south of Galisteo Creek, and the low-lying area south of Galisteo Creek west of the La Bajada Fault. These pediment deposits may be roughly correlated with terrace deposits along Galisteo Creek. In the La Bolsa area, two pediment deposits can be distinguished on the basis of their heights above the grade of Galisteo Creek and their degrees of incision.

The oldest and highest pediment, Qp1, lies lower than the oldest terrace of Galisteo Creek and lies above Qp4. Qp1 appears to grade into Qt2 and, in some locations, appears to lie at the same elevation as Qt3.

MINERAL PRODUCTION AND RESOURCES

The Cerrillos Hills contain some of the earliest mining sites in New Mexico and the United States. Mining of turquoise and ochre began in pre-Columbian times. During Spanish colonial times lead and silver were produced from the Mina del Tiro (just off the Madrid quadrangle). Widespread prospecting of lead-zinc-silver veins and intensified turquoise production began in the late 19th century (Milford, 2000; Simmons 1995). Elston (1967) states that the zinc-oxide plant at Waldo used local anthracite coal, but obtained zinc-carbonate ore from Mexico, Colorado, and other parts of New Mexico. It was operated from 1917 to 1921. The Cerrillos Hills have been prospected in the late 20th century for porphyry copper-gold deposits (Giles, 1991; Akright, 1979; Wargo, 1964). Mining continues at the turn of the century with construction aggregate production at sites just outside of the Madrid quadrangle in the western and central part of the Cerrillos Hills.

Coal

The Cerrillos coalfield, which includes the Miller Gulch, Waldo Gulch, and Madrid area mines, saw coal mining begin about 1835 and continue to 1953. Total production of coal is summarized in Table 1.

Table 1. Coal production from Cerrillos Coal Field. Data from Lee (1913) and Read and others (1950), as quoted by Beaumont (1979) and Elston (1967); and Beaumont (1979). Anthracite and bituminous are not distinguished in available production figures.

Years of production	**Part of field**	**Production**
1835 - 1882	Madrid area	Unknown but small. Coal sent to Dolores to run gold mill in 1835. Civil War–era production from Government Mine.
1882 - 1890	Entire Cerrillos field	408,568 short tons
1892 - 1897	Miller Gulch	15,000 short tons, bituminous coking coal
1897 – 1931	Entire Cerrillos field	> 3,000,000 short tons
1931 - 1940	Entire Cerrillos field	1,325,315 short tons
1940 - 1948	Entire Cerrillos field	577,700 short tons
1948 - 1953	Madrid area	150,000 short tons
Total production		**Approximately 5,500,000 short tons**

Bituminous and anthracite coal of the Cerrillos coalfield occurs in the Cretaceous Menefee Formation (Mesa Verde Group). The more valuable anthracite coal was produced by heat given off by the adjacent Madrid sill. Read and others (1950) estimated original reserves to have been 46.5 million short tons of bituminous coal and 11.4 million short tons of anthracite coal for a total of 57.9 million short tons. Beaumont (1979) considered that the mineable resource might only be one tenth of that figure.

Metals

Lead, zinc, and silver have been mined from veins in two principal groups in the Cerrillos Hills (Disbrow and Stoll, 1957; Elston, 1967; Milford, 2000). The northern group includes the Pennsylvania, Tom Payne, and Black Hornet Mines contains veins generally striking north to north-northeast. The southern group strikes mainly northeast. Total metal production from the entire Cerrillos Mining District (including portions lying outside of the Madrid quadrangle) for the years 1909 – 1957 was 26,816 short tons of ore containing 1.6 million pounds of lead, 1.9 million pounds of zinc, 181,000 pounds of copper, 28,000 ounces of silver, and 734 ounces of gold for a total value of $423,000 (Elston, 1967).

Gypsum

The Kaiser Gypsum Company produced wallboard (sheet rock) at its Rosario gypsum mine and plant intermittently from 1959 to the 1980s. Total production is unknown. The plant and mine are presently owned by the Santo Domingo Pueblo. A potentially large resource of gypsum is contained in the Tonque Arroyo Member of the Jurassic Todilto Formation in the western part of the Madrid quadrangle.

Construction Aggregate

The volumetrically abundant andesite porphyry sills in the Cerrillos Hills and south and west of Madrid represent a considerable resource of aggregate for the construction industry. Aggregate was produced from pits in Ancha Formation gravels along county road 52 in the northern part of the quadrangle. The mesa-capping Tuerto Gravel in the southern part of the Madrid quadrangle may constitute economic aggregate resources.

PREVIOUS WORK

General Geology and Stratigraphy

Geologic observations of the area of the Madrid quadrangle began with Hayden (1869), who described outcrops what are now known as the Galisteo and Diamond Tail Formations along Galisteo Creek. Johnson (1903) described the laccolithic nature of the Cerrillos Hill. Stearns (1943, 1953a, b, and c) mapped much of the Galisteo-Tonque area and defined several of the most important formations and geologic relationships of the region Disbrow and Stoll (1957) mapped the Cerrillos Hills and vicinity, described and characterized its mineral deposits, and formulated a paragenesis for the igneous rocks of the range. Rankin (1944) named the Juana López Member of the Mancos Shale for its type locality on the Mesita de Juana López in the Madrid quadrangle. Kauffman (1977) refined understanding of Juana López Member. Black and Molenaar (1971) and Bachman (1971) measured the Cretaceous section along the Santa Fe Railroad tracks and along Galisteo Creek, respectively. Bachman (1975) mapped the Madrid 15-minute quadrangle. Lucas and others (1999 and 1998) measured and described the Jurassic and Middle Cretaceous sections exposed in the Galisteo Dam area. Lucas and others (1997) separated the Diamond Tail Formation from the Galisteo Formation.

Economic Geology

Lee (1913), Beaumont (1964 and 1979) and Beaumont and others (1976) described the setting of coal deposits and their potential at Madrid. Lindgren and Graton (1906) and Lindgren and others (1910) described mineral deposits in the Cerrillos Hills. Elston (1967) summarized mineral resources and production in the area.

Relationship of Present Study to Previous Studies

Studies by Stearns (1943, 1953a, b, and c), Disbrow and Stoll (1957), and Bachman (1975) represent seminal works in the area of the Madrid quadrangle and in adjacent areas. Their work served as a guide in the present study. The present work is largely an attempt to refine the concepts and field relations advanced by them and to compile and synthesize stratigraphic and economic geology data. In addition, the present study reflects efforts by the authors to bring the understanding and description of the geology of the Madrid quadrangle into conformity with knowledge gained by their studies in related areas (Ortiz Mine Grant – Maynard, Cretaceous rocks – Sawyer, and Quaternary geology of the Galisteo Creek area, and its relationship to similar deposits along the Rio Grande – Rogers). Contacts of the Mancos Shale units are largely taken from Bachman (1975).

DESCRIPTION OF MAP UNITS

CENOZOIC ERATHEM

Neogene and Quaternary System

Colluvial, eolian, and anthropogenic deposits

Thin surficial deposits derived from wind and mass-movement processes, or extensive areas disturbed by gypsum or coal mining, or construction operations.

af **artificial fill (Historic)** – Dumped fill and areas affected by human disturbances. Locally mapped where areally extensive or geologic contacts are obscured. Includes the Galisteo Dam, mine dumps in Madrid area, and the bed of the Santa Fe railroad.

Qae **Eolian sand and stream alluvium, undivided (Holocene to upper Pleistocene)** - Unconsolidated to very poorly consolidated, moderately to well sorted, light reddish-brown to light-brown, fine- to medium-grained sand and silty sand with scattered pebbles that commonly forms a relatively thin, discontinuous mantle over broad upland areas. Mapped only where areally extensive or thick. Variable thickness, ranging from 0-16 ft (0-5 m), but commonly less than 5 ft (1.5 m) thick .

Qcg – Gypsiferous colluvium – Lies on hill slope surfaces on and down-slope from exposures of the Todilto Formation. Composed of soil and colluvium cemented by gypsum. Characterized by crunchy and “hollow” feel underfoot and poor vegetation.

Qca – undivided colluvium and alluvium, including colluvium consisting of fluvial gravel from adjacent, higher terraces.

Qf – Alluvial fan deposits not covered by Qa and Qca.

Qp – Pediment gravels.

Qpo – Older(?) pediment gravel found on upland surfaces west of La Bajada Fault. Inset into Tuerto Gravel. Includes minor alluvium and colluvium.

Qp1- Widespread incised pediment deposit in La Bolsa area north and south of Galisteo Creek, and in low area south of Galisteo Creek, west of the La Bajada Fault. Composed of thin (less than 1.5 m (5 ft)) accumulations of soil, wind-blown sand, and material reworked mainly from the Tuerto Gravel and the Santa Fe Group. In the La Bolsa area, this pediment lies on shale and sandstone of the Mancos Shale. Lies below base of terrace deposit Qt1 and above Qt4. In La Bolsa area Qp1 grades into Qt2 and, in some locations, appears to lie at the same elevation as Qt3. West of the La

Bajada Fault, Qp1 lies on Santa Fe Group sediments and grades into terrace deposit Qt3.

Qp2 – Pediment deposits limited to small areas north and south of Galisteo Creek in the northeast quarter of the Madrid quadrangle. Composition similar to that of Qp1, but with more material derived from the Mancos Shale. Qp2 lies below grades of all Galisteo Creek terrace deposits except Qt6, into which it grades. On the map Qp2 may include terraces of tributary drainages, and youngest terraces of Galisteo Creek.

Alluvium and terrace deposits

Qa – Alluvium. Modern channel, floodplain, very low terraces (**Qt7**), some alluvial fans and colluvium at valley margins. May include terraces and colluvium in tributary drainages.

Qt – Terrace deposits of Galisteo Creek

Upstream of La Bajada Fault trace (footwall)

Qt7 - Fill terrace, top less than 2 m (6 ft) above grade of Galisteo Creek. Lowest terrace, may be considered part of modern flood plain of Galisteo Creek. In many areas included in map designation **Qa**.

Qt6 – Fill terrace, top 3.7 – 5.5 m (12-18 ft) above grade of Galisteo Creek.

Qt5 – Strath terrace with large axial gravel cap, 2.7 m (9 ft) thick, top 9.4 m (31 ft) above grade of Galisteo Creek. Deposited on faulted Mesozoic outcrop.

Qt4 – Strath terrace, 2.7 m (9 ft) thick, top 13.7 m (45 ft) above grade. Deposited on Chinle Grp.

Qt3 – Fill(?) terrace, 5.8 m (19 ft) thick, top 19.2 m (63 ft) above grade. Deposited on Mesozoic rocks.

Qt2 – Fill/strath(?) terrace, 4.0 m (13 ft) thick, top 30.4 m (100 ft) above grade. Base of deposit is cemented sand and gravel 0.5 m (1.5 ft) thick. Deposited on Chinle Grp.

Qt1 – Fill-cut(?) terrace, 16.7 m (55 ft) thick, top 56.2 m (185 ft) above grade, base of deposit 39.5 m (130 ft) above grade. Base of deposit is cemented sand and gravel 1.5 m (5.0 ft) thick. Deposited on Chinle Grp.

Qt1a – Fill-cut(?) terrace, top 48.9 m (161 ft) above grade, base of deposit 39.5 m (130 ft) above grade. Base of deposit is cemented sand and gravel 1.5 m (5.0 ft) thick.

Qt1b – Fill-cut(?) terrace, top 56.2 m (185 ft) above grade, base of deposit 45.0 m (148 ft) above grade. Base of deposit is cemented sand and gravel 1.5 m (5.0 ft) thick. Deposited on Chinle Grp.

Downstream of La Bajada Fault trace (hanging wall)

Qt6 – Fill terrace, top 3.7 m (12 ft) above grade of Galisteo Creek.

Qt5 – Strath terrace with large axial gravel cap, 2.7 m (9 ft) thick, top 8.5 m (28 ft) above grade of Galisteo Creek. Deposited on Santa Fe Group sediments.

Qt3 – Fill(?) terrace, 9.4 m (31 ft) thick, top 19.8 m (65 ft) above grade. Deposited on Santa Fe Group sediments.

Qtt – Terrace deposits of tributary drainages. May be variously correlated with terraces of Galisteo Creek. Locally includes alluvium and colluvium.

Basin-fill deposits

Santa Fe Group (upper Oligocene-lower Pleistocene) - The Santa Fe Group comprises the syntectonic sedimentary fill and associated volcanic rocks of basins within the Rio Grande Rift of central Colorado, New Mexico, and northern Chihuahua (Bryan, 1938; Chapin and Cather, 1994). In the Madrid quadrangle, the Santa Fe Group consists of lower piedmont-slope deposits **(Tsf)** on the eastern part of the Santo Domingo sub-basin and unconformably overlying piedmont-slope deposits that were laid down on erosion surfaces outside the structural boundaries of the sub-basin. The piedmont-slope deposits are correlative with the Blackshare Formation of Connell (2001). The upper group is known by two formations, the Tuerto Gravel (**QTt**) and the Ancha Formation (**QTa**), which caps a well-defined erosion surface flanking and sloping away from the Ortiz Mountains and the Cerrillos Hills, and the southwestern part of the Sangre de Cristo Mountains, respectively. The Tuerto Gravel caps mesas in the southern, south-central, and eastern parts of the Madrid quadrangle, and partly flanks the Cerrillos Hills; the Ancha Formation is exposed on the northern margin of the quadrangle. The Galisteo Creek divides the two units and appears to have been the division of their original deposition.

The ages of the upper units are deduced from field relations and isotopic dating techniques. Spiegel and Baldwin (1963) suggested a correlation between the Ancha Formation and the Tuerto Gravel. Age dating of interfingering Cerros del Rio basalts

(Bachman and Mehnert, 1978) and overlying lower Bandelier pumice (J. Winick, 1999, unpublished NM Geochronological Laboratory Internal Report, IR-78) indicates that the upper part of the Ancha Formation is between 2.8 and 1.6 Ma old. Both units rest unconformably on older tilted Santa Fe Group (Stearns, 1979).

Upper Santa Fe Group (Pliocene (?) – lower Pleistocene)

QTt – Tuerto Gravels of Stearns (1953b) and Koning and others (2001) (lower Pleistocene to upper Pliocene) – Yellowish to reddish-brown and yellowish-red moderately consolidated and caliche cemented, moderately to well stratified pebble to cobble conglomerate and pebbly to cobbly sandstone with scattered boulders and muddy sandstone interbeds. Matrix is fine- to very coarse-grained, very poorly sorted sandstone, and gravel clasts contain abundant subrounded to subangular clasts derived from the Ortiz Mountains and Cerrillos Hills (andesite porphyry and augite monzonite; black, reddish-brown, and banded hornfels; and lesser quartzite, chert, and petrified wood. The Tuerto Gravel contains no material derived from the Sangre de Cristo Mountains in its exposures on the flanks of the Ortiz Mountains. Flanking the Cerrillos Hills the Tuerto Gravel interfingers with the Ancha Formation and may contain up to 20% pink granite, schist, and gneiss derived from the Sangre de Cristo Mountains. Bedding in the Tuerto Gravel is subhorizontal. The unit is locally faulted by the La Bajada Fault and the Tano Fault.

QTa – Ancha Formation of Spiegel and Baldwin (1963) and Koning and others (2001) - (lower Pleistocene to upper Pliocene) – Yellowish to reddish-brown and yellowish-red moderately consolidated and caliche cemented, moderately to well stratified pebble to cobble conglomerate and pebbly to cobbly sandstone with scattered boulders and muddy sandstone interbeds. Matrix is fine- to very coarse-grained, very poorly sorted sandstone, and gravel. Clasts are at least 20% pink granite, schist, and gneiss derived from the Sangre de Cristo Mountains and the Cerrillos Hills (andesite porphyry and augite monzonite similar to that found in the Ortiz Mountains, and subordinate shale and sandstone).

Lower Santa Fe Group (Miocene – Pliocene (?))

Tsf – Santa Fe Group (undivided) (Miocene – Pliocene (?)) – Interbedded sandstone, conglomerate, and thin mudstone beds exposed west of the La Bajada Fault are correlated with the Blackshare Formation of the Santa Fe Group of Connell (2001).

Igneous Rocks

Neogene igneous rocks in the Madrid quadrangle are limited to a small portion of the Cerros del Rio basalts that occurs along the northern edge of the map area and basaltic (limburgite) dikes that intrude Mesozoic sedimentary rocks in the north-central and western parts of the quadrangle.

Pliocene Epoch

Tbj – Basaltic lavas of the Mesita de Juana vent – (Cuerbio basalt flow of Stearns (1943)). Cap mesa on the northern edge of the quadrangle. Source was cinder cone about 2 miles (3 km) north of the northern boundary of the quadrangle. Part of the Cerros del Rio volcanic field, which contains hawaiite, andesite, and basaltic andesite flows (Aubele, 1979) (Sawyer. et. al., in prep). Initial lavas were basanite. Later lavas were hawaiites. Flows of the Cerros del Rio volcanic field range in age from 2.6 +/- 0.4 Ma to 2.5 +/- 0,2 Ma (Bachman and Mehnert, 1978).

Miocene Epoch

Tld – Limburgite dikes. Nearly orthogonal east-northeast and north-south striking outcrop pattern. Dikes range from 0 to 2 m thick, averaging less than 1 m. Black to dark gray, aphanitic. Described as basalt dikes by Stearns (1953b) and related to limburgite flows at La Cieneguilla by Disbrow and Stoll (1957). Most of these dikes intrude the Mancos Shale west of the Cerrillos Hills; some can be found intruding the Morrison Formation and the Dakota Formation near the Galisteo Dam. La Cieneguilla limburgite cuts and overlies Espinaso volcanics and is overlain by Abiquiu formation (basal Santa Fe Group) in the La Cieneguilla area (Stearns, 1953b). At Espinaso Ridge, an olivine basalt flow of similar appearance occurs near the basal contact of Santa Fe Group sediments (Tano formation of Connell, 2001). The flow has been K-Ar dated at 25.1 +/- 0.7 Ma (Kautz and others, 1981). 40Ar/39Ar dating gives it an age of 25.41 +/- 0.32 Ma (Cather and others, 2000; Peters, 2001).

Paleogene System

Oligocene Epoch

Igneous Rocks

Oligocene igneous rocks occurring in the Madrid quadrangle are part of the Ortiz Porphyry Belt, which extends from South Mountain to the Cerrillos Hills. In the Ortiz Porphyry Belt, earliest igneous rocks are quartz-bearing andesite-porphyry laccoliths, which are intruded by quartz-poor monzonite and latite stocks. Major movement on the Tijeras-Cañoncito fault in the Ortiz Mountains occurred after the intrusion of the andesite porphyry sills and before the intrusion of quartz-poor stocks (Maynard, 2000; in prep). Andesite porphyry **(Tap)** forms laccoliths and sills that intruded the Cretaceous Mancos Shale and the Mesa Verde Group west, south, and east of Madrid. In the Cerrillos Hills a large laccolith, apparently Christmas-Tree type (Corry, 1988), intrudes Jurassic and Cretaceous section and causes marked doming of the sedimentary section. The local landmark known as Devil's Throne, located about 1 km (0.6 mi) northwest of the village of Cerrillos, is formed by a sill of andesite porphyry intruding the lower part of the Mancos Shale. The Devil's Throne sill and the surrounding shale beds are rotated to a near vertical position by the underlying large Cerrillos Hills laccolith. The Garden of the Gods area, along NM-14 east of Cerrillos, provides another example of strata tilted by an underlying laccolith.

Stocks of augite-hornblende+/-biotite monzonite **(Tam, Thm, Tbm)** pierce sedimentary rocks and andesite-porphyry sills, forming prominent hills in the Cerrillos Hills, e.g. Grand Central Mountain and Lucera Hill. Northeast-trending feldspar-porphyry latite dikes **(Tl)** cut andesite porphyry in the Cerrillos Hills. Bodies of coarse andesine-porphyry latite **(Tfpl)** occur as phases of feldspar-porphyry latite **(Tl)** in the northwestern part of the Cerrillos Hills, in the northeastern corner of the Madrid quadrangle. The feldspar-porphyry latite **(Tl** stock in the in the northwestern part of the Cerrillos Hills, in the northeastern corner of the Madrid quadrangle**)** texturally resembles a subvolcanic intrusion in the Ortiz Mountains. This observation, coupled with steeply to vertically inclined beds of Jurassic and Cretaceous sedimentary rocks on the latite stock's western and southwestern flanks, suggests that it represents a subvolcanic intrusion that domed and pierced the sedimentary cover, likely reaching the surface as a volcano (Stearns, 1953a and b). Trachytic dikes **(Tt)** also cut feldspar-porphyry latite. Aphanitic and porphyritic dikes **(Td)**, arrayed in a radial fashion from the Cerrillos Hills and from the Ortiz Mountains, extend several miles from their respective centers. The Espinaso Volcanics **(Te)** represent the extrusive equivalents of the Ortiz Porphyry Belt.

K-Ar and ^{40}Ar/^{39}Ar dating of the andesite porphyry of the Ortiz Mountains and the Cerrillos Hills yield ages from 34 to 30 Ma. Quartz-poor stocks in the Ortiz Mountains have yielded ages ranging from 28 to 30 Ma. Mineralization in the Ortiz Mountains has yielded ^{40}Ar/^{39}Ar ages of 30 Ma. (Bachman and Mehnert, 1978; Kautz and others, 1982; Sauer, 2000; Maynard, in prep; W. McIntosh, written communication, 2000). These ages are considered to be representative of ages of rocks in the Cerrillos Hills.

Tap – andesite porphyry – Grayish green to gray on fresh surfaces, fine-to medium grained, porphyritic. Described as hornblende quartz latite porphyry by Stearns (1953b) and hornblende monzonite porphyry by Disbrow and Stoll (1957). In similar rocks in the Ortiz Mountains (Coles, 1990), phenocrysts of plagioclase, lesser hornblende, and rare quartz make up 40 to 60 percent of the rock. Groundmass is gray and aphanitic. Subhedral andesine plagioclase makes up about 75 percent of the phenocrysts and ranges 0.5 to 2 mm. Black euhedral hornblende phenocrysts (0.6-5 mm) constitute nearly all the rest of the phenocryst assemblage. Clear, highly resorbed quartz makes up perhaps 1 % of the phenocrysts. Plagioclase, orthoclase, and quartz, and trace allanite, zircon, and rutile form the groundmass. Hornblende-rich (augite-cored?) xenoliths 2 to 10 cm in diameter are commonly found in the andesite porphyry. Rare xenoliths of basement granitic gneiss have been observed in the southwestern part of the Cerrillos Hills. Andesite porphyry forms laccoliths, sills, dikes, and irregular masses. Thermal metamorphism of surrounding sedimentary rocks is limited to a narrow contact zone usually less than 10 cm wide, except for the conversion of bituminous coal to anthracite at Madrid.

Tam augite – Thm (hornblende) Tabm (+/-biotite) monzonite- Gray to dark gray, medium-grained, equigranular to porphyritic. Readily pulls a hand magnet. Disbrow and Stoll (1957) report the rock to be composed of 45 percent subhedral andesine 1-5 mm, commonly with rims of orthoclase; anhedral and interstitial orthoclase, 40 percent; 10 percent euhedral to subhedral augite, 1 to 5 mm; anhedral 0.5 – 1.5 mm biotite; and trace sphene. Stocks of augite monzonite form the highest parts of the Cerrillos Hills.

Tl – feldspar-porphyry latite – Gray to tan, with tabular euhedral orthoclase phenocrysts 1.0 to 3.0 cm long in light gray groundmass. Commonly shows a trachytic texture. Forms stock-like bodies in the northwestern part of the Cerrillos Hills and a northeast-trending dike in southern part of the Cerrillos Hills on the eastern boundary of the Madrid quadrangle. Described as augite-biotite syenite-trachyte porphyry Disbrow and Stoll (1957).

Tfpl – coarse andesine porphyry latite – Small irregular masses of latite containing distinct euhedral andesine (?) phenocrysts ranging in length from 3.0 to 10 cm occur within and on the margins of augite – (hornblende) (+/-biotite) monzonite and feldspar-porphyry latite bodies in the northwestern part of the Cerrillos Hills. This unit does not correspond to the large andesine augite-biotite monzonite porphyry described by Disbrow and Stoll (1957).

Td – aphanitic and porphyritic dikes – Hornblende- and feldspar-porphyry dikes. Range from hundreds of meters to several kilometers in length. Appear to radiate from Cerrillos and Ortiz igneous complexes. Commonly stand in topographic relief relative to intruded sedimentary rocks.

Te – Espinaso Volcanics of Stearns (1953a) Regionally the Espinaso Volcanics conformably overlie the Galisteo Formation and are unconformably overlain by Santa Fe Group sediments. In the northeastern portion of the Madrid quadrangle, the Espinaso Volcanics rest unconformably on Mancos Shale. Steeply west-dipping agglomerate beds of the Espinaso volcanics are exposed along the La Bajada Fault in the southwest quarter of the Madrid quadrangle. The latter exposure of the Espinaso Volcanics is in fault contact with Santa Fe Group sediments and is unconformably overlain by Tuerto Gravel. In the northeastern portion of the quadrangle, original volcanic textures are obscured by strong propylitic alteration (chlorite, epidote, and pyrite).

Sedimentary Rocks

Eocene Epoch

Tg – Galisteo Formation – Steeply west-dipping beds of pebbly sandstone and red mudstone of the Galisteo Formation are exposed in small, discontinuous outcrops on the west side of the La Bajada Fault in the northwestern and southwestern parts of the Madrid quadrangle. Regionally, an angular unconformity separates the Galisteo Formation from the underlying Diamond Tail Formation. The Galisteo Formation has a gradational contact with the overlying Espinaso Volcanics.

Paleocene Epoch

Tdt – Diamond Tail Formation Yellow, orange, and gray, medium- to coarse-grained arkose and subarkose that is commonly trough-cross bedded and variegated gray to maroon mudstone. Regionally the unit is locally conglomeratic and locally contains petrified wood in small fragments and ironstone concretions. In the area north of Madrid conglomerate is notably rare. Well-sorted pebbles in conglomerate beds are composed of white and gray quartzite and chert. Disconformably overlies the Menefee Formation of the Mesa Verde Group. Regionally, the Diamond Tail Formation is overlain by the Galisteo Formation. The Diamond Tail Formation was divided out of the Galisteo Formation of Stearns (1943) and Lucas (1982) by Lucas and others (1997). Its upper contact with the Galisteo Formation is not exposed on the Madrid quadrangle. The Diamond Tail Formation was deposited in alluvial channels and broad floodplains in a northeast-trending Laramide basin. The Diamond Tail Formation is approximately 820 m (2700 ft) thick between Madrid and Galisteo Creek. This thickness is considerably greater than the thickness reported by Lucas and others at its type locality in the Hagan Basin (442 m (1459 ft)), by Lisenbee and Maynard (2001) east of the Ortiz Mountains (90 m (300 ft) or by Lucas (1982) in the southeastern part of the Cerrillos Hills (353 m (1,158 ft)). Lucas' (1982) lower sandstone unit of the Galisteo Formation may be correlated with the Diamond Tail Formation.

MESOZOIC ERATHEM

CRETACEOUS

Upper Cretaceous

Mesa Verde Group

Menefee Formation – contains three informally named members in the Madrid quadrangle. Combined thickness of the Menefee Formation is approximately 380 m (1270 ft) in the area north of Madrid. The Chace Oil Company's Piñon No. 1 well, drilled in the southeastern part of the quadrangle, intersected 233 m (768 ft) of Menefee Formation.

Kmf – Menefee Formation undivided – west and south of Madrid, the Harmon sandstone member is not mapped; therefore the unit is combined as one.

Kmfu – upper Menefee member – gray, tan to orange-tan, cross-bedded, and laminated to thick-bedded siltstone and sandstone; dark-gray to olive-gray and black shale; dull, dark-brown to shiny black coal; and maroon to dark-brown iron concretions. The upper Menefee member hosts the most important coal seams in the Madrid coal field. Thickness 110 m (360 ft).

Kmh – Harmon sandstone member – light-gray to buff or gray-tan fluvial, medium-grained, well-sorted, cross bedded, quartz sandstone. The unit forms a prominent ridge between Miller and Waldo Gulches, north of Madrid. Thickness estimated at 100 m (340 ft).

Kmfl – lower Menefee member – similar to upper Menefee member. The lower Menefee member hosts the Miller coal seam. The lower contact with the Point Lookout Sandstone is gradational. Thickness of the lower member is estimated at 170 m (570 ft) in Miller Gulch.

Kpl – Point Lookout Sandstone – Gray-tan to light-tan and drab-yellow, upward coarsening, very fine- to medium-grained, quartz sandstone with limonitic sandstone lenses and interbedded thin gray shale. The unit forms a ridge on the west side of Miller Gulch, north of Madrid. Its lower contact with the upper Mancos shale is gradational. Thickness estimated at 90 m (300 ft). In the Piñon No. 1 well, 70 m (230 ft) of Point Lookout Sandstone was intersected.

Mancos Shale
Contains five members in the area of the Madrid quadrangle. Combined thickness of the Mancos Shale, as measured by Bachman (1971), along Galisteo Creek, is 643.5 m (2117 ft). In the Piñon No. 1 well, on the eastern margin of the Madrid quadrangle, a combined thickness of 620 m (2040 ft) of Mancos Shale was intersected.

Km – Mancos Shale, undivided – In isolated exposures determination of Mancos Shale member was not possible.

Kmn – Niobrara Shale Member – Upper part (above the sandstone lentil) is a medium yellowish brown to grey thin-bedded, sandy, marine shale containing prominent medium yellowish brown calcareous concretions, some of which are more than 60 cm (2 ft) in diameter. Thickness of the lower part, along Galisteo Creek, is 84 m (277 ft). Thickness of the upper part, along Galisteo Creek, is about 409 m (1344 ft). **Kmns – Niobrara Shale Member, sandstone lentil** – fine grained, even-bedded, light yellowish gray sandstone. Thickness 33.4 m (110 ft) along old railroad grade, 102 m (336 ft) along present railroad grade.

Kmj- Juana López Member – Fetid, bioclastic limestone. 1.8 m (6 ft) thick along old and present railroad grades.

Kmc – Carlile Shale Member - Poorly exposed medium gray thin-bedded shale. 93 m (305 ft) thick along old railroad grade, 112.5 m (370 ft) thick along present railroad grade.

Kmg – Greenhorn Member – Thin-bedded medium gray marine argillaceous limestone containing interbeds of calcareous shale 6 m (19 ft) thick along old railroad grade, 12.2 m (40 ft) thick along present railroad grade.

Kmgr – Graneros Member – Thin-bedded medium gray marine shale. 57 m (188 ft) thick along old railroad grade, 52.3 m (172 ft) thick along present railroad grade.

Middle Cretaceous

Dakota Formation – divided into three mappable units in the ridge north and south of the Galisteo Dam. Thicknesses were measured and member identifications were made by Lucas and others (1998) at the Galisteo Dam. Members were not broken out in exposures in the Cerrillos Hills.

Kdu – Dakota Formation undivided The combined thickness of the Dakota Formation at the Galisteo Dam is 36 m (119 ft). In the Piñon No. 1 well, 35 m (116 ft) of Dakota Formation was intersected.

Kdc – Cubero Sandstone member – yellow-orange, fine- to medium-grained, slabby- and thin-bedded bioturbated sandstone. Thickness measured at 10 m (33 ft) at the Galisteo Dam. Appears to thin to the south.

Kdosh – Oak Canyon member shale - carbonaceous siltstone and interbedded, spheroidally weathering, very fine grained silty sandstone. Thickness at the Galisteo Dam exposure is 23.5 m (78 ft).

Kdoss – Oak Canyon member sandstone - The basal sandstone of the Oak Canyon member is a fine to coarse grained, cross bedded, and locally bioturbated sandstone. Conglomerate occurs at its base at the Galisteo Dam section, but also higher in its section elsewhere. The basal sandstone lies disconformably on the Jackpile Member of the Morrison Formation. It measures 2.5 m (8.3 ft) thick at the Galisteo Dam but is generally thinner in exposures to the south.

JURASSIC

Lucas and others (1999) measured and described Upper and Middle Jurassic rocks at the Galisteo Dam. Their descriptions and nomenclature are synopsized and used here. The stratigraphic sections measured by Lucas and others (1999) are located on the geologic map. The nomenclature proposed by Lucas and others (1999) for the Jurassic differs from that used in northern New Mexico by the US Geological Survey.

Upper Jurassic

Morrison Formation – divided into three members in the ridge north and south of the Galisteo Dam. Undivided in exposures in the Cerrillos Hills.

Jmu - Morrison Formation undivided

Jmj – Jackpile Member – White to yellowish gray and very pale orange, trough-cross bedded, kaolinitic subarkosic sandstone with some interbeds of greenish mudstone. The upper part of the Jackpile Member is easily distinguished in the field by its white appearance compared to sandstone of the overlying Dakota Formation. The Jackpile member measures 77 m (254 ft) at the Galisteo Dam.

Jmb – Brushy Basin Member – variegated green and brown mudstone and subordinate thin, brown, lithic subarkosic sandstone. Thickness of the Brushy Basin member is 82 m (271 ft) at the Galisteo Dam.

Jms – Salt Wash Member – Yellow, gray, and brown arkosic sandstone and conglomerate, with common rip ups. Green mudstone lenses and beds in upper part. Thickness measured at 113 m (373 ft).

Js – Summerville Formation – The Summerville Formation consists of brownish-gray shale with limestone nodules and ripple-laminated brown sandstone. The base of the Summerville Formation rests on the "agate bed" marking the top of the Todilto Formation. Thickness of the Summerville Formation measured 16.7 m (55.1 ft) near the Galisteo Dam. Corresponds to Wanakah Formation of US Geological Survey usage (Sawyer, in prep).

Middle Jurassic
San Rafael Group

Jt – Todilto Formation – The Todilto Formation contains two distinct members, which are mapped together in this study. The lower Luciano Mesa member, a thin-bedded, dark gray, fetid limestone as much as 3.1 m (10.2 ft) thick, rests disconformably on the Entrada Sandstone. The overlying Tonque Arroyo Member, 46.8 m (154.5 ft) thick, consists of a lower unit of massive gypsum and an upper unit of interlayered limestone and gypsum beds capped by a thin bed of limestone with reddish agate nodules (the "agate bed"). The thickness of the Todilto Formation can vary greatly. In the subsurface, the gypsum member is usually composed of anhydrite. Gypsum from the Todilto Formation was mined for the manufacture of wallboard (sheetrock) at the mine at Rosario, northwest of the Galisteo Dam.

Je – Entrada Sandstone – contains two members which are not distinguished on the map. The upper Slick Rock Member consists of fine- to coarse-grained, very pale orange quartzarenite with large trough crossbeds and measures 10 m (33 ft) thick. The underlying Dewey Bridge Member is 24 m (79 ft) thick and is composed of very fine grained, light brown silty sandstone. The upper part of the Dewey Bridge Member exhibits a color change from light brown to pale orange. The Dewey Bridge Member lies with a disconformity on the Petrified Forest Formation of the Chinle Group.

TRIASSIC

Upper Triassic

TR – Triassic, undivided (cross sections only) – Includes Chinle Group, Moenkopi Formation

TRc – Chinle Group, undivided – In the map area, the Chinle Group is represented by red mudstones and subordinate silty sandstone of the Petrified Forest Formation. Less than 50 m (165 ft) of the Chinle Group is exposed in the Madrid Quadrangle, all of it in the area of Galisteo Creek below the Galisteo Dam.

PALEOZOIC ERATHEM

PERMIAN

P – Permian, undivided (cross sections only) – Includes San Andres Formation, Glorieta Sandstone, Yeso, and Abo Formations

PENNSYLVANIAN and MISSISSIPPIAN

lPM– Pennsylvanian and Mississippian, undivided (cross sections only) – Includes Madera Formation, Sandia Formation (?), and Mississippian Arroyo Peñasco Group (?).

PRECAMBRIAN ERATHEM

pC – Precambrian, undivided (cross sections only) – Includes metamorphic and granitic rocks. Rare xenoliths of gneissic granite of probable basement origin occur in the Cerrillos Hills laccolith.

REFERENCES

Aubele, J.C., 1979, The Cerros del Rio volcanic field: New Mexico Geological Society, Guidebook 30, pp. 243-252.

Bachman, G.O., 1971, Composite section measured on “Bolsa” south of Galisteo Creek, Madrid quad, N.Mex.: unpublished stratigraphic section.

Bachman, G.O., 1975, Geologic map of the Madrid Quadrangle, Santa Fe and Sandoval Counties, New Mexico: U.S. Geological survey Geologic Quadrangle Map GQ-1268, scale 1:62,500.

Bachman, G.O., and Mehnert, H.H., 1978, New K-Ar dates and the late Pliocene to Holocene geomorphic history of the central Rio Grande region, New Mexico: Geological Society of America, Bulletin, v. 89, p. 283-292.

Beaumont, E.C., 1964, Geology of the anthracite coal deposits of the Madrid area, New Mexico: unpublished report, 21 pp.

Beaumont, E.C., 1979, Geology of the Cerrillos coal field, Santa Fe County, New Mexico: New Mexico Geological Society, Guidebook 30, p. 269-274.

Beaumont, E.C., Shomaker, J.W., Stone, W.J., and others, 1976, Guidebook to the coal geology of northwest New Mexico: New Mexico Bureau of Mines and Mineral Resources, Circular 54, 58 pp.

Black, B.A., and Molenaar, C.M., 1971, Cretaceous surface section, Railroad Gap, Santa Fe County, New Mexico: unpublished stratigraphic section.

Cather, S.M., Connell, S.D., and Black, B.A., 2000, Preliminary geologic map of the San Felipe Pueblo NE 7.5-minute quadrangle, Sandoval County, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Open-file Digital Map DM-37, scale 1:24,000.

Connell, S.D., 2001, Stratigraphy of the Albuquerque Basin, Rio Grande Rift, New Mexico: a progress report: *minipaper in* Stratigraphy and tectonic development of the Albuquerque Basin, central Rio Grande Rift: New Mexico Bureau of Mines and Mineral Resources, Open-File Report 454A.

Corry, C.E., 1988, Laccoliths; mechanics of emplacement and growth: Geological Society of America, Special Paper 22, 110 pp.

Disbrow, A.E., and Stoll, W.C., 1957, Geology of the Cerrillos area, Santa Fe County, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bulletin 48, 73 pp.

Elston, W.E., 1967, Summary of the mineral resource of Bernalillo, Sandoval, and Santa Fe Counties, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bulletin 81,81 pp.

Hayden, F.N., 1869, Third annual report of the United States geological survey of the territories embracing Colorado and New Mexico, including a report by Persifor Frazer, Jr., titled "On mines and minerals of Colorado": Department of the Interior, Washington, D.C.

Hook, S.C, and Cobban, W.A., 1980, Reinterpretation of type section of Juana Lopez member of Mancos Shale: New Mexico Geology, vol. 2, No. 2.

Johnson, D.W., 1903, The geology of the Cerrillos Hills, New Mexico: School of Mines Quarterly, Vol. 24, pp. 173-246, 303-350, 456-500; vol. 25, 00. 69-98.

Kauffman, F.E., 1977, Illustrated guide to biostratigraphically important Cretaceous macrofossils, Western Interior Basin, U.S.A., The Mountain Geologist, v. 3 and 4, p. 225-274, 32 pls.

Kelley, V.,C., 1977, Geology of the Albuquerque Basin, New Mexico: New Mexico Bureau of Mines and Minerals Resources Memoir 33, 60 p.

Koning, D.J., Connell, S.D., Pazzaglia, F.J., and McIntosh, W.C., 2001, Stratigraphy of the Tuerto and Ancha Formations (Upper Santa Fe Group), Hagan and Santa Fe embayments, north-central New Mexico: *minipaper in* Stratigraphy and tectonic development of the Albuquerque Basin, central Rio Grande Rift: New Mexico Bureau of Mines and Mineral Resources, Open-File Report 454A, pp., I1-I10.

Lee, W.T., 1913, The Cerrillos coalfield, Santa Fe County, New Mexico: U.S. Geologic Survey, Bulletin 531e, pt. II, pp. 285-312.

Lindgren, W., and Graton, L.C., 1906, A reconnaissance of the mineral deposits of New Mexico: U.S. Geologic Survey, Bulletin 285, p. 74-86.

Lindgren, W., Graton, L.C., and Gordon, C.H., 1910, The ore deposits of New Mexico: U.S. Geologic Survey, Professional Paper 68, 316 pp.

Lucas, S.G., Anderson, O.J., and Estep, J.W., 1998, Stratigraphy and correlation of Middle Cretaceous rocks (Albian-Cenomanian) from the Colorado Plateau to the southern High Plains, north-central New Mexico: Lucas, S.G., Kirkland, J.I., and Estep, J.W., eds., 1998, Lower and Middle Cretaceous Terrestrial Ecosystems. New Mexico Museum of Natural History and Science Bulletin No. 14, p 57-66.

Lucas, S.G., Estep, J.W., and Anderson, O.J., 1999, Correlation of Jurassic strata from the Colorado Plateau to the High Plains, across the Rio Grande rift, north-central New Mexico: New Mexico Geological Society Guidebook, 50th Field Conference, Albuquerque Geology, pp. 317-326.

Maynard, S.R., 2000, Preliminary geologic map of the Golden 7.5-minute quadrangle, Santa Fe and Sandoval Counties, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Open-file Digital Map DM-36, scale 1:24,000.

Maynard, S.R., in prep., Geology and mineral resources of the Ortiz Mine Grant, Santa Fe County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin.

Milford, H.E., 1994, History of the Los Cerrillos mining area: New Mexico Abandoned Mine Land Bureau Report 1994-2.

Molenaar, C.M., 1983, Major depositional cycles and regional correlations of Upper Cretaceous rocks, southern Colorado Plateau and adjacent areas: M.W. Reynolds and E.D. Dolly, eds., Rocky Mountain Section S.E.P.M., Mesozoic paleogeography of west-central United States.

Ogilvie, I.H., 1905, The high-altitude conoplain: a topographic form illustrated in the Ortiz Mountains: American Geologist, v. 22, p. 901-904.

Peters, L., 2001, ^{40}Ar/^{39}Ar geochronology results from San Felipe, Capilla Peak, and Tome NE quadrangles [unpubl.data]: New Mexico Geochronological Research Laboratory, Internal Report NMGRL-IR135, 3 p., appendices.

Rankin, C.H., 1944, Stratigraphy of the Colorado Group, Upper Cretaceous, in northern New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bull. 20, 27 pp., 6 figs.

Read, C.B., Duffner, R.T., Wood, G.H., and Zapp, A.D., 1950, Coal resources of New Mexico: U.S. Geological Survey, Circular 89, 24 pp.

Sawyer, D.A., Shroba, R.R., Minor, S.A., Thompson, R.A., and Blossom, J.C., in prep. Preliminary geologic map of the Tetilla Peak quadrangle, Santa Fe and Sandoval Counties, New Mexico: U.S.Geological Survey, Open File Report 98- .

Spiegel, Z., and Baldwin, B., 1963, Geology and water resources of the Santa Fe area, New Mexico: U.S. Geological Survey, Water-Supply Paper 1525, 25 p.

Stearns, C.E., 1943, The Galisteo Formation of north-central New Mexico: Journal of Geology, v. 51, p. 301-319.

Stearns, C.E., 1953a, Early Tertiary vulcanism in the Galisteo-Tonque area, north-central New Mexico: American Journal of Science, v. 251, p. 415-452.

Stearns, C.E., 1953b, Tertiary geology of the Galisteo-Tonque area, north-central New Mexico: Geological Society of America, Bulletin, v. 64, p. 459-508.

Stearns, C.E., 1953c, Upper Cretaceous rocks of the Galisteo-Tonque area, north-central New Mexico: American Association of Petroleum Geologists, Bulletin, v. 37, p. 961-974.