GEOLOGIC MAP OF THE
PICTURE ROCK 7.5-MINUTE QUADRANGLE
SANTA FE COUNTY, CENTRAL NEW MEXICO

by

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

Alvis L. Lisenbee
South Dakota School of Mines and Technology
Rapid City, SD 57701-3995

and

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

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

Open-File Report DM-49
May 2002

INTRODUCTION

Location, land status, and terrain

The Picture Rock 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, New Mexico. The study area includes lands administered by the Bureau of Land Management, the New Mexico State Land Office, and Santa Fe County (the Cerrillos Hills Historic Park). The majority of the land is privately owned. The eastern-most part of the village of Cerrillos lies in the Picture Rock quadrangle.

The San Marcos Pueblo Grant occupies about 2.5 square miles in the central part of the Picture Rock quadrangle. The Ortiz Mine Grant covers about 7.5 square miles in the southwest corner of the quad.

NM-14 (the Turquoise Trail) is the major highway on the quadrangle, crossing it from the town of Cerrillos in the west-central boundary to the northeast corner. Various Santa Fe County-maintained roads link ranches and subdivisions to NM-14. In particular, county road 55 (Gold Mine Road) leads to subdivisions in the southwestern corner of the quadrangle and to the Cunningham Hill gold mine, road 55A leads to property along Galisteo Creek from its junction with NM-14 in the south-central part of the quadrangle, road 42 (Camino de los Abuelos) links NM-14 to the village of Galisteo in the central part of the quadrangle, and roads 44 and 45 meet NM-14 near the northern boundary of the quadrangle. The Santa Fe Railroad tracks run east-southeast to west-northwest, roughly parallel to Galisteo Creek.

Galisteo Creek is the principal drainage in the Picture Rock 7.5-minute quadrangle; it traverses the quadrangle from the southeast corner to its west-central edge. Other important drainages include Gallina Arroyo, San Marcos Arroyo, and Cañada de la Cueva on the north side of Galisteo Creek; and Dolores Gulch, Arroyo Viejo, Arroyo de la Vaca, Cunningham Gulch, and Arroyo Chorro on the south side. Except for a small area on the north side of the Cerrillos Hills, in the northwest corner of the quadrangle, all surface drainage in the quadrangle flows into Galisteo Creek. Galisteo Creek falls from an elevation of about 1793 m (5880 ft) at the quadrangle's southeast corner to 1726 m (5660 ft) at the village of Cerrillos, along the quadrangle's western edge.

The greatest relief in the quadrangle occurs in the Cerrillos Hills and the vicinity of the village of Cerrillos in the northwestern part of the quadrangle. Elevations range from 1726 m (5660 ft) on Galisteo Creek to 2111 m (6923 ft) on El Cerro de la Cosena, and 2107 m (6910 ft) on the eastern end of Grand Central Mountain, in the Cerrillos Hills in the northwestern part of the quadrangle. In the rest of the quadrangle, north and south of Galisteo Creek, broad, gently sloping gravel-capped mesas characterize the landscape. These mesas are locally dissected by tributaries to Galisteo Creek.

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 Picture Rock 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 2000-2002 STATEMAP program of the U.S. Geological Survey, National Cooperative Geologic Mapping Program, to the New Mexico Bureau of Geology and Mineral Resources, Drs. Charles E. Chapin (former 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 Geology 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 Geology and Mineral Resources.*

PRINCIPAL GEOLOGIC AND PHYSIOGRAPHIC FEATURES

Cerrillos Hills Intrusive-Extrusive Complex

The eastern part of the Cerrillos Hills lies in the northwestern part of the Picture Rock 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 old. These intrusive rocks produced doming in the Mesozoic and Cenozoic sedimentary section, including, in part, the contemporaneous Espinaso Volcanics. The intrusive complex is also partly overlain by 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, notably in the vertical to overturned beds of the Mesa Verde Group, and

Diamond Tail and Galisteo Formations on the southeast side of the Cerrillos Hills, east of the village of Cerrillos. 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 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.

A laccolith of andesite porphyry intruding the Cretaceous Mancos Shale and Mesa Verde Group, and the Paleocene Diamond Tail Formation in the northwestern part of the Picture Rock quadrangle. This laccolith is part of the larger Cerrillos Hills laccolith, a "Christmas Tree" type laccolith (Corry, 1983). It is one of more than a dozen laccoliths of similar composition that occur throughout the Ortiz Porphyry Belt (Maynard, in prep). The Cerrillos Hills laccolith appears to have formed mostly within the Jurassic section in the Madrid quadrangle, to the west of the Picture Rock quadrangle. Later intrusions and faults cut the Cerrillos Hills laccolith.

Tijeras-Cañoncito Fault System

The southeastern corner of the quadrangle is deformed by faults and folding associated with the northeast-trending Tijeras-Cañoncito fault system. In this quadrangle the fault system marks the southern termination of the Santa Fe embayment of the Rio Grande rift. South of Galisteo Creek one fault ends in a complex anticline whose breached core exposes the erosional edge of the Point Lookout Sandstone. This erosion is related to Laramide uplift to the northeast. Within approximately two kilometers (1.2 mi) of the dominant fault strands the strata are rotated to steeper northwest dips and a small in-line graben of the system is present.

Santa Fe Embayment (Rio Grande rift)

The axis of the Santa Fe Embayment extends northward from steeply dipping strata exposed in the southeast corner of the quadrangle along the Tijeras-Canoncito Fault System. Oligocene Espinaso Volcanics occupy the axial zone of a broad, gently north-plunging syncline with limbs dipping generally less than 10^{o}. In the northern half of the quadrangle the axis continues beneath unconsolidated and undeformed beds of the Ancha Formation.

Ancha and Ortiz Surfaces

The Plio-Pleistocene Tuerto Gravel caps the extensive north and northwest-sloping mesas in the southwestern and southeastern parts of the Picture Rock quadrangle, and the flanks of the Cerrillos Hills. The Tuerto Gravel was deposited on erosion surfaces flanking the Ortiz Mountains and the Cerrillos 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 is dominantly siltstone with a cap of gravel containing granitic and metamorphic clasts from the Sangre de Cristo Mountains, as well as minor clasts from the Cerrillos Hills. North of Galisteo Creek, the Ancha forms a surface similar to that of the Tuerto Gravels south of the river.

Alluvial deposits of Galisteo Creek

Galisteo Creek is the most important drainage on the Picture Rock 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).

Quaternary Pediment deposits

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 mantle limited areas south of Galisteo Creek. These pediment deposits may be roughly correlated with certain terrace deposits. North of Galisteo Creek pediments underlain by gravel, silt and sand occupy the lower slopes of the Ancha-capped ridges.

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. Widespread prospecting of lead-zinc-silver veins and intensified turquoise production began in the late 19^{th} century (Milford, 2000; Simmons 1995). The Cerrillos Hills have been prospected in the late 20^{th} century for porphyry copper-gold deposits (Giles, 1991; Akright, 1979; Wargo, 1964). Mining continued until recent years at the turn of the century with construction aggregate production at sites just outside of the Picture Rock 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, on the Madrid 7.5-minute quadrangle, saw coal mining begin about 1835 and continue to 1953. Bituminous and anthracite coal of the Cerrillos coalfield occurs in the Cretaceous Menefee Formation (Mesa Verde Group). Only a small part of the Cerrillos coalfield occurs on the Picture Rock quadrangle, where the coal-bearing Menefee Formation crops out in the southeastern part of the Cerrillos Hills. A handful of prospects with unknown, but probably small, production lie in this area.

Porphyry copper (gold) mineralization

A small porphyry copper-gold deposit lies in the southeastern part of the Cerrillos Hills, in the northwestern part of the Picture Rock Quadrangle. As summarized by Giles (1991), the mineralized body forms a ring 30 to 180 m wide about two-thirds of the way around a 360 m diameter barren monzonite plug. The plug intrudes earlier intrusive phases and Mancos Shale. It is a low-grade (about 0.3% Cu) MoS_2-poor, low total-sulfide system with a high chalcopyrite/pyrite ratio. Strong stockwork fracturing, local vein and replacement silicification, and potassic alteration (secondary and K-feldspar) are present. Primary sulfide minerals are chalcopyrite and pyrite, with trace amounts of bornite, marcasite, enargite, and molybdenite. Magnetite occurs as significant veinlets and breccia cement. Gold occurs as electrum and appears to be associated with higher copper concentrations.

The Cerrillos porphyry copper-gold deposit has been explored by Bear Creek Mining Co and Occidental Minerals (Wargo, 1964; Akright, 1979) and Placer Dome Mining (Giles, 1995). Occidental Minerals sank a shaft and several wells in an effort to study the feasibility of an in-situ leach copper recovery operation during the late 1970s (Akright, 1979).

Lead-zinc-silver veins

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). 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, on the Madrid quadrangle. In the eastern part of the Cerrillos Hills, on the Picture Rock quadrangle, veins trend typically north-northeast. The lead-zinc-silver veins cut across the porphry-copper deposit and show no zonation controlled by the porphyry (Giles, 1991).

The best known of these veins were exploited in the Mina del Terra (or Mina del Tiro) and the Cash Entry Mine. The Mina del Terra is believed to be the oldest metal – producing mine in the United States. In the southwestern part of the Cerrillos Hills, veins trend N30E to N50E. Production figures for the Mina del Terra and Cash Entry Mines are unknown. Total metal production from the entire Cerrillos Mining District (most of which lies outside of the Picture Rock 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).

Turquoise

Cerrillos turquoise has been identified in artifacts from central Mexico dated at 700 AD. Spanish explorers' descriptions of the workings at Mt Chalchihuitl, in the northwestern part of the Picture Rock quadrangle, indicate that the mine was the largest mine of any kind in North America at the time of their arrival in 1535 (Bauer and Giles, 1995). Giles (1995) estimates that about 15,000 tons of rock had been removed from Mt Chalchihuitl using stone tools before 1700.

Turquoise ($CuAl_6(PO_4)_4(OH)_8.5H_20$) commonly occurs with variscite ($Al(PO_4).2H_2O$) in the Cerrillos Hills. It is a supergene mineral, formed by intense acid leaching of wall rocks. The acid, produced by oxidation of pyrite, was strong enough to leach phosphorous from apatite.

Turquoise in the Cerrillos Hills occurs in patches in strongly argillized and weakly tourmalinized intrusive and volcanic rocks (Giles, 1991 and 1995). Three mines contributed the lion's share of turquoise in the Cerrillos District: Turquoise Hill (on the Turquoise Hill quadrangle) (Koning, 2001), and Mt Chalchihuitl and the Blue Bell Mine, on the Picture Rock quadrangle.

Construction Aggregate

The volumetrically large andesite porphyry sills in the Cerrillos Hills represent a considerable resource of aggregate for the construction industry. The mesa-capping Tuerto Gravel and Ancha Formation may also constitute economic aggregate resources. Aggregate has been produced in recent years by Cerrillos Sand and Gravel in the area of the porphyry-copper deposit.

Clay

A clay pit was operated in the southern part of Section 17, T14N, R 8E, about 1500 ft east of the village of Cerrillos and on the north side of the Burlington – Santa Fe Railroad tracks, by Kinney Brick Co., of Albuquerque. An unknown amount of material was mined from the Mancos Shale for manufacture of brick.

Hydrocarbon exploration and resources

Along Galisteo Creek, in the southeast portion of the quadrangle, a total of 10 petroleum exploration wells have been drilled to test the Cretaceous section at the southern margin of the Santa Fe Embayment. Most of these holes bottomed in the Jurassic Morrison Formation at depths ranging from 380 m (1600 ft) to 3340 m (7450 ft). Black (1979) noted that most tests in the region reported oil and gas shows: one of the 10 wells in the quadrangle, the Black Ferrill #1 was completed with production of eight barrels per day (Mickey, 1986). For many of the tests, crooked holes caused major drilling problems (Mickey, 1986). The interaction of Laramide thrusting (Black, oral communication, 1997) and Rio Grande Rift deformation resulted in steep dips and multiple repeats of portions of the stratigraphic section.

PREVIOUS WORK

General Geology and Stratigraphy

Geologic observations of the area of the Picture Rock quadrangle began with Marcou (1857). Hayden (1869) described outcrops of 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. Bachman (1975) mapped the Madrid 15-minute quadrangle. Lucas and others (1997) separated the Diamond Tail Formation from the Galisteo Formation in the region. Koning (2002) Ancha Fm. Spiegel and Baldwin (1960)

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. The small porphyry copper deposit in the eastern part of the Cerrillos Hills was described by Wargo (1964), Akright (1979), and Giles (1991 and 1995).

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 Picture Rock 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 Picture Rock quadrangle into conformity with knowledge gained by their studies in related areas (Ortiz Mine Grant – Maynard, Galisteo–La Joya area – Lisenbee, and Quaternary geology of the Galisteo Creek area– Rogers).

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 mine dumps in the Cerrillos Hills area and the beds of the Santa Fe railroad and NM - 14.

Qal Alluvium: Cobbles, sand, silt, and clay transported by seasonal flooding or in active channels. Coarser clasts are dominated by quartz and granitic material.

Qca – Undivided colluvium and alluvium, including colluvium consisting of fluvial gravel from adjacent, higher terraces. Along Galisteo Creek, may include pediment-covering deposits that grade to the Cerrillos Surface formed by terrace deposit Qt_6. Also may include colluvium consisting of fluvial gravel from adjacent, higher terraces.

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

Qp – Pediment gravels. Deposits of gravel, sand and silt cover surfaces cut to a base level above the present Galisteo Creek. Most of the material is derived from the Tuerto Gravels or Ancha Formation.

Qc– Colluvium**:** Unconsolidated sand, silt and clay deposits along upper hill slopes or broad, flat hill crests. A few meters in maximum thickness.

Qe– Eolian deposits: Tan to light pink, wind blown silt and clay lying on gently inclined upland areas. Much of the area has a thin deposit of this material incorporated with the soil.

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.

Qp – Pediment gravels— Deposits of gravel, sand and silt cover surfaces cut to a base level above the present Galisteo Creek. Most of the material is derived from the Ancha Formation

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.

Terrace deposits

Qt – Terrace deposits of Galisteo Creek. The numbering system for terrace deposits on Galisteo Creek was developed during the mapping of the Madrid quadrangle and has been applied to the Picture Rock quad.

Qt6 – Fill terrace. The youngest terrace unit in the area (late Holocene?). The top of this paired fill unit is roughly 10 to 20 feet above the modern channel. The village of Cerrillos is built on this surface; it is therefore informally known as the Cerrillos Surface.

Qt5 – Strath terrace. Described on the Madrid quadrangle, was not identified on the Picture Rock quad.

Qt4 – Strath terrace. Poorly defined fill-cut terrace deposit lying roughly 40 feet above grade of Galisteo Creek. Correlation with Qt_4 or (possibly) Qt_5 in the Madrid quad is tenuous.

Qt3 – Fill(?) terrace. Strath terrace deposit lying roughly 60 ft above grade, this being the sole determinant in correlating with the Madrid Qt_3.

Qt2 – Fill/strath(?) terrace. Strath terrace deposited on Galisteo Fm, typically 10 ft or less thick. The elevation above grade of the tread is between ss and ff feet. Qt_2 and its tributary terraces, Qtt_2, can be found along the entire stretch of Galisteo Creek. Some paired units occur on the north side of the creek. Qt_2 correlates well with Qt_2 found in the Madrid quad.

Qt1 – Fill-cut/strath(?) terrace. strath terrace deposit less than 20 ft thick. The tread of Qt_1 occurs roughly 200 ft above grade. Possibly middle Pleistocene.

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

Qttu– Tributary terrace deposit, undefined.

Qtt_– Tributary terrace that correlates with the axial terrace of Galisteo creek bearing the same number. where **_** is from 1 to 6, denotes a tributary terrace that correlates with the axial terrace of the Galisteo River bearing the same number.

Qtta_–Fill-cut terrace—(Early to Middle Pleistocene?) Terrace deposits underlain by Tutero and/or Ancha gravel. where **_** is from 1 to 6, denotes a tributary terrace that correlates with the axial terrace of the Galisteo River bearing the same number. Approximately 240 feet above grade in the Picture Rock quad. It is significantly higher in elevation than Qt1 of the Madrid quad. Because of this, I chose the new designation. This is the oldest terrace of the present-day fluvial system. It is the first remnant of the river valley we see today.

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 Picture Rock quadrangle, the Santa Fe Group is represented by the Tuerto Gravel (**QTt**) and the Ancha Formation (**QTa**), which cap well-defined erosion surfaces 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 and southwestern parts of the Picture Rock quadrangle, and partly flanks the Cerrillos Hills; the Ancha Formation caps mesas north of Galisteo Creek and east of the Cerrillos Hills. 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). Koning (2001, in prep).

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) – Pink to tan siltstone and sandstone capped by 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. The matrix of the gravel cap consists of 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). Thickness to 30 m (100 ft).

Igneous Rocks

Paleogene System

Oligocene Epoch

Igneous Rocks

Oligocene igneous rocks occurring in the Picture Rock quadrangle are part of the Ortiz Porphyry Belt, which extends from South Mountain to La Cienega. 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 in the southeastern part of the Cerrillos Hills. 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. Cretaceous, Paleocene and Eocene strata are inclined to vertical to overturned at the area known as Garden of the Gods, 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 and volcanic 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 Picture Rock quadrangle. The feldspar-porphyry latite **(Tl** stock in the in the northwestern part of the Cerrillos Hills, in the northeastern corner of the Picture Rock 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 Picture Rock.

Tam – Monzonite porphyry. Medium grained feldspar-porphyry stock that forms the unmineralized core of the small porphyry copper deposit in the southern part 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 Picture Rock quadrangle. Described as augite-biotite syenite-trachyte porphyry Disbrow and Stoll (1957).

Tlp– Andesine porphyry latite.

Ttl Latite and trachytic latite.

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. North-northwest-trending, to northeast-trending.

Te – Espinaso Volcanics of Stearns (1953a) Light grey to lavender grey, clast supported agglomerate (lahars?), volcaniclastic sandstone, and minor white volcanic tuff. Latite clasts are subrounded to subangular and range up to two meters (7 ft). Kautz and others (1981) report ages ranging from 25.1 Ma to 34.6 Ma for the Espinaso Volcanics, which regionally lie conformably upon the Galisteo Formation and are unconformably overlain by Santa Fe Group sediments. Disbrow and Stoll (1957) measured more than 610 m (2000 ft) of latitic tuff, tuff-breccia, and flows at Sweet's Ranch in sections 23 and 24, T14N, R8E. The volcanic sources for these deposits were the Ortiz and Cerrillos intrusive centers.

Tef– Espinaso Volcanics—Volcaniclastic sedimentary rocks and pyroclastic flows.

Ti– Intrusive rocks, undivided.

Sedimentary Rocks

Eocene Epoch

Tg – Galisteo Formation *(Sensu latto)* – Steeply to locally overturned beds of pebbly sandstone and red mudstone of the Galisteo Formation are well exposed on the east side of the Cerrillos Hills forming the picturesque outcrops in the area known as New Mexico's Garden of the Gods along NM-14. Red and whitish sandstone of the Galisteo Formation forms low ridges on the east side of NM-14. The unit is also exposed more or less continuously along Galisteo Creek from NM-14 to the quadrangle's southeast corner.
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.

Tgu – Upper Galisteo Formation -- Massively bedded, poorly consolidated, white to light tan sandstone. Locally contains petrified logs to one meter (three feet) diameter and up to eight meters (25 ft) long. Approximately 280 m (900 ft) thick.

Tgl – Lower Galisteo Formation – Red siltstone and mudstone with interbeds of tan to white, pebbly sandstone. The proportion of granitic pebbles relative to Paleozoic sedimentary clasts increases upward in the section. Cobbles and boulders of limestone and granite occur in an interval 200 to 300 feet above the base of the lower Galisteo Formation over a strike length of 7.3 km (4.6 mi) in the southwestern part of the Picture Rock quadrangle. The thickness of the unit is approximately 1200 m (3000 ft).

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. Well-sorted pebbles in conglomerate beds are composed of white and gray quartzite and chert.
In the southeastern part of the Cerrillos Hills strata of the Diamond Tail Formation, along with the subjacent Menefee Formation of the Mesa Verde

Group and the overlying Galisteo Formation are steeply inclined to locally overturned due to emplacement of the Cerrillos igneous complex. Regionally, the Diamond Tail Formation lies with angular unconformity across strata of progressively younger age to the southwest (including the Menefee Formation) as a result of Latest Cretaceous-Paleocene Laramide uplift of the Sangre de Cristo block. The Diamond Tail Formation was subdivided from the Galisteo Formation of Stearns (1943) and Lucas (1982) by Lucas and others (1997), citing a disconformity and faunal break. In field practice, however, the contact is drawn at the base of the first continuous red mudstone.

Lucas (1982) measured a thickness of 353 m (1,158 ft) for a lower sandstone unit of the Galisteo Formation that may be correlated with the Diamond Tail Formation in the southeastern part of the Cerrillos Hills. This thickness is considerably less than the 820 m (2700 ft) reported by Maynard and others (2001) about 2 km to the southwest in the Madrid quadrangle, or the 442 m (1459 ft) at its type locality in the Hagan Basin (Lucas and others (1997)). It is considerably greater than the 90 m (300 ft) reported by Lisenbee and Maynard (2001) east of the Ortiz Mountains.

MESOZOIC ERATHEM

CRETACEOUS

Upper Cretaceous

Mesa Verde Group – The Mesa Verde Group is exposed at the surface in the southeastern part of the Cerrillos Hills, where it is domed and intruded by andesite porphyry of the Cerrillos laccolith. The Mesa Verde Group was intersected in several petroleum exploration wells along the Galisteo Creek.

Kmf – Menefee Formation – 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 thickness varies from 0 m to 300 m (0-1000 ft) in the Cerrillos Hills and exploration wells.

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. Its lower contact with the upper Mancos shale is gradational. Thickness is 30m (100ft) in the Cerrillos Hills and varies from zero to 150 m (500 ft) in exporation wells as a result of Laramide erosion.

Mancos Shale

The Mancos Shale is intruded by the Cerrillos laccolith and subsequent stocks and dikes in the Cerrillos Hills area in the western part of the Picture Rock quadrangle. Exposures are thus discontinuous, faulted and altered. Although members of the Mancos Shale are not broken out in the Picture Rock quadrangle, it is believed that most of the Mancos Shale exposed can be correlated to the Niobrara Shale Member. A fetid, bioclastic shaley limestone in a faulted exposure along the western margin of the quadrangle is correlated with the Juana Lopez Member. Combined thickness of the Mancos Shale, as measured by Bachman (1971), along Galisteo Creek, is 643.5 m (2117 ft). In the oil test wells, in the southeastern part of the Picture Rock quadrangle, approximately 600 m (2000 ft) of Mancos Shale was intersected.

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

Kd– **Dakota Formation** – (cross sections only) – Thicknesses reported for the Dakota from petroleum tests range from 33 m (110 ft) to 125 m (385 ft) across short distances. As such extremes are not reported from outcrops within the region, this variance suggests selection of different contacts by different loggers.

JURASSIC

Jurassic (cross sections only) **–** includes the Morrison Formation, the Summerville Formation, the San Rafael Group (Todilto Fm), and Entrada Sandstone.

TRIASSIC

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

PALEOZOIC ERATHEM

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

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

Akright, R.L., 1979, Geology and mineralogy of the Cerrillos copper deposit, Santa Fe County, New Mexico: New Mexico Geological Society, Guidebook 30, pp. 257-260.

Bachman, G.O., 1975, Geologic map of the Picture Rock 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.

Bauer, P., and Giles, D.L., 1995, Turquoise: *minipaper in* Bauer, P.W., Maynard, S.R., Smith, G.A., Giles, D.L., Lucas, S.G., Barker, J.M., Smith, E.W., and Kottlowski, F.E., Third-day road log, from Santa Fe to the Cerrillos Hills, Cerrillos and the Ortiz Mountains: New Mexico Geological Society Guidebook, 46th Field Conference, Geology of the Santa Fe Region, pp 60-61.

Bauer, P.W., Maynard, S.R., Smith, G.A., Giles, D.L., Lucas, S.G., Barker, J.M., Smith, E.W., and Kottlowski, F.E., 1995, Third-day road log, from Santa Fe to the Cerrillos Hills, Cerrillos and the Ortiz Mountains: New Mexico Geological Society Guidebook, 46th Field Conference, Geology of the Santa Fe Region, pp 60-61.

Black, B.A., 1979b, Oil and gas exploration in the Santa Fe – Galisteo - Hagan area of New Mexico: New Mexico Geological Society, Guidebook 30, p. 275-279.

Coles, D.W., 1990, Alteration and mineralization of the Carache Canyon gold prospect, Santa Fe County, New Mexico [MS Thesis]: Fort Collins, Colorado State University, 183 p.

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.

Erskine, D.W., and Smith, G.A., 1993, Compositional characterization of volcanic products from a primarily sedimentary record: Geological Society of America Bulletin, v. 105, p. 1214-1222.

Giles, D.L., 1995, Cerrillos Mining District: *minipaper in* Bauer, P.W., Maynard, S.R., Smith, G.A., Giles, D.L., Lucas, S.G., Barker, J.M., Smith, E.W., and Kottlowski, F.E., Third-day road log, from Santa Fe to the Cerrillos Hills, Cerrillos and the Ortiz Mountains: New Mexico Geological Society Guidebook, 46th Field Conference, Geology of the Santa Fe Region, pp 61-62.

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.

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.

Kautz, P. F., Ingersoll, R. V., Baldridge, W. S., Damon, P. E., and Shafiqullah, M., 1981, Geology of the Espinaso Formation (Oligocene), north-central New Mexico: Summary: Geological Society of America Bulletin, v. 9, p. 980-983.

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., 2001, Preliminary geologic map of the Turquoise Hill 7.5-minute quandrangle, Santa Fe County, New Mexico: New Mexico Bureau of Mines and Mineral Resources, Open-file Geologic Map OF-GM 48 , scale 24,000.

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.

Lisenbee, A.L. and Maynard, S.R., 2001, Geology of the Captain Davis Mountain 7.5-min. quadrangle, Santa Fe County, New Mexico, New Mexico Bureau of Mines and Mineral Resources, Open-file Geologic Map OF-GM 48 , scale 1:12,000.

Lucas, S.G., 1982, Vertebrate paleontology, stratigraphy, and biostratigraphy of Eocene Galisteo Formation, north-central New Mexico: New Mexico Bureau of Mines and Mineral Resources, Circular 186, 34 pp.

Lucas, S.G., Cather, S.M., Abbott, J.C., and Williamson, T.E., 1997, Stratigraphy and tectonic implications of Paleogene strata in the Laramide Galisteo Basin, north-central New Mexico: New Mexico Geology, November, 1997.

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.

Marcou,

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.

Maynard, S.R., Woodward, L.A., and Giles, D.L., 1991, Tectonics, intrusive rocks, and mineralization of the San Pedro-Ortiz porphyry belt, north-central New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bulletin 137

Maynard, S., Rogers, J. and others, 2001, Geology of the Madrid 7.5-min. quadrangle, Santa Fe County, New Mexico, New Mexico Bureau of Mines and Mineral Resources, Open-file Geologic Map OF-GM 40, scale 1:12,000.

Mickey, V., 1986, Santa Fe County has first commercial oil: Western Oil World, p. 12-13.

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

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.

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.

Sauer, R. R., 1999, Petrochemistry and geochronology of plutons relative to tectonics in the San Pedro-Ortiz porphyry belt, New Mexico (unpublished Master's thesis): Boulder, University of Colorado, 115 p.

Sawyer, D.A., Shroba, R.R., Minor, S.A., and Thompson, R.A. 2002, Geologic map of the Tetilla Peak quadrangle, Santa Fe and Sandoval Counties, New Mexico: U.S.Geological Survey, Miscellaneous Field Studies Map MF-2352.

Smith, G.A., Larsen, D., Harlan, S.S., McIntosh, W.C., Erskine, D.W., and Taylor, S., 1991, A tale of two volcaniclastic aprons: Field guide to the sedimentology and physical volcanology of the Oligocene Espinaso Formation and Miocene Peralta Tuff, north-central New Mexico: New Mexico Bureau of Mines and Mineral Resources, Bulletin 137, p. 87-103.

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.

Wargo, J.G., 1964, Geology of a primary disseminated copper deposit near Cerrillos, New Mexico: Geological Society of America Special Paper 76, p.296.