GEOLOGIC MAP OF THE LA MESITA NEGRA SE QUADRANGLE, BERNALILLO COUNTY, NEW MEXICO

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DESCRIPTION OF MAP UNITS

[Sediments and lava flows in the map area record alluvial, eolian, colluvial, and volcanic processes of the past several million years. The surficial deposits (post-Santa Fe Group sediments) on the map are known or estimated to be at least 1 m thick; most deposits are poorly exposed. Thin (< 50 cm), discontinuous deposits of eolian sand and sheetwash (Qea, Qes, and Qsw) locally are present on gently sloping map units older than the alluvium in stream channels and low terraces (Qa). These thin eolian and sheetwash deposits are not mapped, but they are widespread on the gravel unit of the upper Santa Fe Group sediments (Tg) on the eastern flank of the Llano de Albuquerque, near the eastern boundary of the map area (quadrangle). Small deposits of artificial fill (af) less than about 25 m wide are not mapped. Fractional map symbols (for example, Qsw/Qby1) are used where thin deposits mantle lava flows and other deposits. These fractional units are not described here; instead refer to descriptions of individual units. Fractional units are not shown on the correlation of map units diagram.

The distribution of map units is based primarily on interpretation of 1:36,000-scale, color, aerial photographs taken on June 13, 1994, and August 5, 1996, and 1:40,000-scale, color infrared, aerial photographs taken on May 5, 1991. Most of the contacts on this map were transferred from the aerial photographs using a Kern PG–2 stereoplotter. The locations of the Westland Development No. 1–1J1E and Carpenter Atrisco Grant No. 1 wells were determined with the aid of aerial photographs using a Kern PG–2 stereoplotter. The location of the Westland Development No. 1–Y drill hole was determined by David A. Sawyer, of the U.S. Geological Survey, with the aid of a global positioning system (GPS) unit.

Age assignments for surficial deposits are based chiefly on the relative degree of modification of original surface morphology, relative heights above channels of modern intermittent streams, and degree of soil development. Soil-horizon designations are those of the Soil Survey Staff (1975), Guthrie and Witty (1982), and Birkeland (1999). Most of the surficial deposits are calcareous, and they contain both primary and secondary calcium carbonate. Stages of secondary calcium carbonate morphology (referred to as stages I through III Bk or K soil horizons in this report) are those of Gile and others (1966) and Machette (1985).

Grain or particle sizes of surficial deposits are field estimates, based on the modified Wentworth scale (American Geological Institute, 1982). In descriptions of surficial map units, the term "clasts" refers to particles larger than 2 mm in diameter, whereas the term "matrix" refers to particles smaller than 2 mm in diameter. The clasts in most of the surficial deposits in the map area were derived chiefly from the gravel unit of the upper Santa Fe Group sediments (Tg). Commonly they are subangular to rounded chert, red granite, gneiss, schist, quartzite, petrified wood, and sparse porphyritic volcanic rock, sandstone, siltstone, and basalt. They were derived primarily from sources west of the map area. Those in surficial deposits that overlie lava flows near the northeastern corner of the map area commonly are angular and subangular basalt fragments.

Dry matrix colors of the surficial deposits were determined by comparison with Munsell Soil Color Charts (Munsell Color, 1973). Colors of the surficial deposits generally are similar to those of the sediments and (or) bedrock from which they were derived. The colors of the surficial deposits commonly range from white (2.5Y 8/1) to light reddish brown (7.5YR 6/4). Colors of the lava flows and cinder deposits were determined by comparison with a Geological Society of America Rock-Color Chart (Rock-Color Chart Committee, 1995). Colors of the upper Santa Fe Group sediments are field terms and were not determined with color charts.

In this report, the terms "alluvium" and "alluvial" refer to surficial material transported by running water confined to channels (stream alluvium) as well as by running water not confined to channels (sheetwash). The terms "colluvium" and "colluvial" refer to surficial material transported on slopes chiefly by mass-wasting (gravity-driven) processes—such as creep, debris flow, and rock fall—aided by running water not confined to channels (sheetwash). Surficial map units that include debris-flow deposits probably also include hyperconcentrated flow deposits.

The gently rolling upland that covers about three-quarters of the map area in this report is referred to as the Llano de Albuquerque (Bryan and McCann, 1938). It also is referred to by some of the residents of Albuquerque as the West Mesa (Ceja Mesa of Kelley, l977). Some of the faults shown as concealed on the map are based chiefly on interpretation of high-resolution aeromagnetic data (Grauch, 1999). Concealed faults that are identified mainly on the basis of interpretation of aeromagnetic data are labeled "AM" on the map. The named fault on the map corresponds with that used by Personius and others (1999).

Sheet 2 shows the La Mesita Negra SE geologic map on a screened shaded relief base generated from data in the National Elevation Dataset. This data was collected on 30-m spacings. Sun illumination is from the northwest at 45 degrees above the horizon. The shading highlights fault scarps and other linear topographic features. Shaded relief was first used on geologic maps printed in the United States more than 140 years ago. The two geologic maps prepared by John S. Newberry that accompanied a report by Joseph C. Ives on the 1857–58 exploration of the lower Colorado River had shaded relief topography that was produced by ruled tints. This method of showing shaded relief was developed by the topographer and artist, Baron F.W. von Egloffstein (McKinney, 2002).

The geology was mapped in 1996–99. The primary mapping responsibilities were as follows. Shroba mapped the surficial deposits and the upper undivided unit of the Santa Fe Group sediments (Ts) in the eastern part of the map area. Schmidt and Maldonado mapped the upper Santa Fe Group sediments in the western part of the map area. Schmidt mapped north of Interstate 40, and Maldonado mapped south of Interstate 40. Thompson mapped the volcanic rocks in the northeastern part of the map area. Personius interpreted the aeromagnetic data and mapped the faults on the Llano de Albuquerque and along the eastern boundary of the map area. Brandt prepared the digital compilation of the geologic map and the shaded relief seen on one of the versions of this map. Metric units are used in this report, except for measurements in drill holes and core holes, which were recorded in feet. A conversion table is provided for those more familiar with English units (Table 1). Divisions of geologic time used in this report are provided in Table 2.]

Table 1. Factors for conversion of metric units to English units to two significant figures.

Multiply	By	To obtain
centimeters (cm)	0.39	inches (in.)
meters (m)	3.28	feet (ft)
kilometers (km)	0.62	miles (mi)

Table 2. Divisions of geologic time used in this report.

[Modified from Hansen (1991). Informal divisions of Pleistocene time are from Richmond and Fullerton (1986); 1.81 Ma is from Lourens and others (1996); 5.32 Ma is from Berggren and others (1995). Ages are expressed in ka for kilo-annum (thousand years) and Ma for mega-annum (million years)]

Period	Epoch		Age
Quaternary	Holocene		0 to 10 ka
	Pleistocene	late	10 to 132 ka
		middle	132 to 788 ka
		early	788 ka to 1.81 Ma
Tertiary	Pliocene		1.81 to 5.32 Ma
	Miocene		5.32 to 24 Ma
Cretaceous			66 to 138 Ma
Jurassic			138 to 205 Ma
Triassic			205 to ~240 Ma

SURFICIAL DEPOSITS

Artificial-Fill Deposits

af **Artificial fill (latest Holocene)—**Compacted fill material composed mainly of silt, sand, and rock fragments. Mapped chiefly beneath and near segments of Interstate 40, in an inactive Bernalillo County landfill (or dump) north of Interstate 40 near the eastern boundary of the map area, and in the active Cerro Colorado landfill near the southwestern corner of the map area. Both of the fills contain organic and inorganic trash. The configuration of the Cerro Colorado landfill is based on aerial photography flown in May 1991. The configuration changes, due to continued filling. Unit af locally includes small areas where the land surface was modified by earth-moving equipment—the original geologic material cannot be recognized and in places it is overlain by very thin, discontinuous deposits of artificial fill. Estimated thickness is 1 m to more than 10 m in landfills

Alluvial Deposits

Qa **Alluvium in stream channels and beneath treads of low terraces (Holocene)—**Poorly sorted sand to sandy pebble gravel; locally contains thin lenses of cobbly pebble gravel. Alluvium is in channels of intermittent streams and beneath treads of discontinuous terraces less than about 3 m higher than stream channels, chiefly near the eastern boundary of the map area. Unit Qa locally includes minor sheetwash deposits (Qsw) and is susceptible to stream flooding. Deposits composed of well-sorted silty sand are susceptible to gullying. Estimated thickness is 1–10 m

Qt **Terrace alluvium (Holocene and late Pleistocene)—**Poorly sorted pebbly sand to clast-supported sandy pebble gravel and locally thin lenses of cobbly pebble gravel beneath discontinuous terrace remnants 3–5 m higher than the channels of intermittent streams in the northeastern part of the map area. Thin, unmapped deposits of sheetwash and eolian sand (Qsw and Qea) locally mantle unit Qt. The base of unit Qt is not exposed. Estimated thickness is 1–10 m

Qsw **Sheetwash deposits (Holocene and late? Pleistocene)—**Slightly pebbly to pebbly and cobbly sand and silty sand. Thin, unmapped deposits locally mantle old alluvial-slope deposits (Qao) and locally mantle terrace alluvium (Qt) and young alluvial-slope deposits (Qay). Unit Qsw was deposited chiefly by non-channelized surface flow, and locally it includes small, unmapped deposits of stream alluvium (Qa). Low-lying areas of

Qsw are susceptible to sheet and stream flooding and to gullying. Disturbed areas of Qsw probably are susceptible to wind erosion and deposition. Estimated thickness is 1–5 m

Qsw/Qby2 **Sheetwash deposits over lava flow unit 2**

Qsw/Qby1 **Sheetwash deposits over lava flow unit 1**

Qg **Gravelly alluvium (middle Pleistocene)—**Poorly sorted, pebbly silty sand to moderately well sorted, clast-supported, slightly cobbly, pebble gravel that overlies and underlies basaltic lava flows (Qbo and Qby1, respectively) near the northeast corner of the map area. A thin (about 30 cm), sandy, pumice-bearing layer is present near the middle of the unit. The pumice fragments in this layer probably were reworked from older deposits. Much of unit Qg probably is reworked sand and gravel from the upper Santa Fe Group sediments (Ts). Thickness is approximately 3 m

QTa **Old alluvium and calcic soils of the Llano de Albuquerque (early? Pleistocene and Pliocene)—**Slightly pebbly sand reworked mainly from the gravel unit (Tg) of the upper Santa Fe Group sediments and deposited chiefly as sheetwash(?) and stream alluvium. The upper part of the unit contains calcium carbonate enriched soils that have Bk and K horizons with stage II to IV carbonate morphology. These soils are well exposed along the western escarpment and, locally, in outcrops along the eastern escarpment of the Llano de Albuquerque. Slightly (< 20 %) pebbly, very fine to very coarse sand beneath soil K horizons appears to be alluvial; however, some of the slightly pebbly, very fine to medium sand that is present locally beneath K horizons may be eolian. Deposits of slightly pebbly sand in the lower part of the unit locally contain one or more minor disconformities. The lower part of QTa locally fills channels, inset into Tg, that have as much as about 1.5 m of relief. The calcic soils at the top of the unit apparently were formed in slightly pebbly sand. Those soils have K horizons that are about 85–140 cm thick. The K horizons have strong stage III and stage IV morphology in the uppermost 5–40 cm. The uppermost part of the K horizon locally has platy structure, whereas the rest of the K horizon commonly is massive and grades downward to coalesced, carbonate-rich nodules. The latter part of the K horizon and the underlying Bk horizon are formed in slightly pebbly sand. These horizons locally are as much as 200 cm in total thickness, and they have stage II–III morphology characterized by carbonate-rich nodules, some as large as 12 cm in diameter. Deposits of eolian sand and sheetwash (Qea and Qes) mantle unit QTa in most of the quadrangle. It is well exposed along the western escarpment of the Llano de Albuquerque. Unit QTa locally contains multiple buried calcic soils that have stage II–III carbonate morphology. As many as eight buried calcic soils are exposed in an 8.7-m-high section on the east side of a down-to-the-east normal fault, near the northwestern corner of the map area. Exposed thickness generally is 1.5–3 m

Alluvial and Colluvial Deposits

Qay **Young alluvial-slope deposits (Holocene and late Pleistocene)—**Gently sloping deposits composed chiefly of pebbly sand, pebble gravel, and locally thin lenses of cobbly pebble gravel along the eastern and western escarpments of the Llano de Albuquerque. These sediments are derived in part from upper Santa Fe Group sediments (Tg, Tps, and Ts). Unit Qay is chiefly stream alluvium and minor alluvial-fan deposits (the fan deposits are stream alluvium and debris-flow deposits) that locally are overlain by thin unmapped sheetwash deposits (Qsw). Unit Qay commonly underlies gently sloping surfaces on the eastern and western flanks of the Llano de Albuquerque, and it locally mantles valley sides and hill slopes. It is topographically lower and younger than unit Qao, and it locally grades into and locally includes unmapped stream alluvium (Qa). Low-lying deposits adjacent to stream channels are susceptible to flooding. Gently sloping deposits are susceptible to sheet flooding. Deposits of slightly pebbly, very fine to medium sand are subject to gullying. Exposed thickness generally is 2–9 m; estimated total thickness is 1–15 m

Qac **Alluvium and colluvium, undivided (Holocene and late? Pleistocene)—**Undifferentiated sheetwash deposits, stream-channel deposits, and minor fan alluvium and debris-flow deposits in the eastern part of the quadrangle. Unit Qac commonly ranges from pebbly, very fine to medium sand to poorly sorted, clast- and matrix-supported, slightly cobbly, pebble gravel that has a sand matrix.

Low-lying deposits of unit Qac are susceptible to stream flooding and locally to debris-flow deposition and gullying. Estimated thickness is 1–5 m

Qao **Old alluvial-slope deposits (late? and middle? Pleistocene)—**Gently sloping deposits composed chiefly of pebbly sand, pebble gravel, and, locally, thin lenses of cobbly pebble gravel near the northeastern corner of the map area. Unit Qao is derived in part from upper Santa Fe Group sediments (Ts). Unit Qao is chiefly stream alluvium and minor alluvial-fan deposits (the alluvial-fan deposits are stream alluvium and minor debris-flow deposits) that locally are mantled by thin, unmapped sheetwash deposits (Qsw). Unit Qao commonly forms a broad alluvial surface, and it is topographically higher and older than unit Qay. Low-lying deposits adjacent to stream channels are susceptible to flooding. Gently sloping deposits are susceptible to sheet flooding. Deposits of slightly pebbly very fine to medium sand are subject to gullying. Estimated thickness is 1–15 m

Colluvial Deposits

Qc **Colluvial deposits, undivided (Holocene to middle? Pleistocene)—**Nonsorted and nonstratified, mostly matrix-supported, sandy sediment and basaltic rock debris characterized by hummocky topography. Deposits range from pebbly silty sand to bouldery rubble that has a sandy matrix. Unit Qc overlies upper Santa Fe Group sediments (Ts) and is topographically below basaltic lava flows in the northeastern part of the quadrangle. Unit Qc includes debris-slide, soil-creep, and block-stream deposits, and probably also debris-flow deposits, as defined by Varnes (1978). These deposits may be susceptible to continued movement or reactivation due to natural processes and human-induced processes. Some of the basaltic blocks are as large as 2 x 2 x 4 m. Some of the sand in unit Qc probably was deposited by sheetwash. Maximum thickness possibly 40 m

Alluvial and Eolian Deposits

Qss **Sheetwash deposits, eolian sand, calcic soils, and minor stream alluvium associated with fault scarps (late and middle? Pleistocene)—**Mostly sandy sheetwash deposits, eolian sand, intercalated calcic soils, and minor stream alluvium east of the County Dump fault (Machette, 1978a; McCalpin, 1997) and east of an unnamed fault near the eastern boundary of the map area. Deposits range from slightly pebbly silty sand to pebble gravel; many of the deposits thicken toward these faults. Trench studies by McCalpin (1997) along the County Dump fault north of Interstate 40 exposed a 16-m-thick section of faulted Quaternary deposits that contains 13 buried calcic soils. The buried soils commonly have stage I–III carbonate morphology (Machette, 1978a; Machette and others, 1997; McCalpin, 1997). During the past 500,000 to 1,000,000 years, individual vertical displacements on the County Dump fault have been 0.75–3.5 m (McCalpin, 1997). The last displacement on the County Dump fault was tens of cm about 30,000 years ago (McCalpin, 2001). Thin unmapped eolian sand and sheetwash deposits (units Qea and Qes) locally overlie unit Qss. Estimated thickness is 10–20 m

Eolian Deposits

Qea **Active eolian sand (Holocene)—**Quartz-rich, very slightly calcareous, very fine to medium sand that lacks soils and supports little to no vegetation. The sand-size fraction is mostly very fine to fine and includes a minor amount of medium sand. The surface of unit Qea commonly is characterized by small ripples produced by blowing sand. Cross stratification locally is exposed in blowouts. Unit Qea locally is present in a zone approximately 50 m to 1 km wide along the western escarpment of the Llano de Albuquerque, near the western boundary of the quadrangle. The unit in places includes small deposits of inactive eolian sand and sheetwash (Qes). There are a few small deposits of active eolian sand in the eastern part of the map area, where off-road driving and other human activities have destabilized inactive eolian sand and sheetwash deposits (Qes). Unit Qea is subject to erosion and deposition by wind. Maximum thickness is approximately 16 m in barchan dunes near the northwest corner of the map area

Eolian and Alluvial Deposits

Qe **Active and inactive eolian sand and sheetwash deposits, undivided (Holocene and late? Pleistocene)—**Active eolian sand (Qea, described above) and inactive eolian sand

and sheetwash deposits (Qes, described below), mapped as an undivided unit on the eastern escarpment of the Llano de Albuquerque. Estimated thickness is 1–10 m

Qes **Inactive eolian sand and sheetwash deposits, undivided (Holocene and late? Pleistocene)—**Quartz-rich, non-calcareous to calcareous, locally slightly pebbly and cobbly, very fine to medium sand that supports a sparse cover of grasses, shrubs, and annual plants. Unit Qes mantles old alluvium and calcic soils (QTa) over much of the Llano de Albuquerque, and it is the most extensive unit in the map area. Thin unmapped deposits of active eolian sand (Qea) locally overlie Qes near the western boundary of the map area. Scattered pebbles, cobbles, and K-horizon fragments in Qes probably were derived from the underlying calcic soil and sediments (QTa, Tg, and Ts) and were moved upward by burrowing animals. Some or much of the sand probably was deflated from upper Santa Fe Group sediments that are exposed along the western escarpment of the Llano de Albuquerque and was deposited by southwesterly or westerly winds. Some of the silt- and clay-size fraction in Qes may have been derived from more distant sources, such as the flood plain of the Rio Puerco in the adjacent La Mesita Negra quadrangle, west of the map area. Unit Qes forms sand sheets and widely spaced sand dunes that are about 1–5 m high. Some of these dunes resemble linear dunes (Lambert, 1974), but they probably are modified parabolic dunes (Madole, 1995; Wells and others, 1990). The other dunes are simple and compound parabolic dunes. Arms of the simple and modified parabolic dunes commonly are oriented N 70–75˚ E and open to the west-southwest. The shape and orientation of these dunes indicate that the dominant paleowinds that formed the dunes were from the west-southwest. Most of the dunes are in an east-northeast-trending belt that is about 5.5 km wide, approximately parallel to Interstate 40. The belt extends from about 1 km north of the Interstate to about 4.5 km south of the Interstate. Dunes and blowouts are most abundant in a 14-km^2 area (delineated by a line with tick marks) in the western part of that belt. Surface soils commonly have color (cambic, Bw) and weak argillic (Bt) horizons about 15–30 cm thick. The Bw or Bt horizons locally overlie Bk horizons about 10–45 cm thick that have stage I–II carbonate morphology. Buried soils in Qes are exposed along the western margin of the Llano de Albuquerque, about 3 km north of Interstate 40. They are cambic and weak argillic B horizons, about 40–70 cm thick. They overlie old alluvium and calcic soils (QTa) and they are overlain by active eolian sand (Qea). Unit Qes locally includes small, unmapped deposits of stream alluvium (Qa) and active eolian sand (Qea). Low-lying deposits of Qes are susceptible to stream and sheet flooding and gullying. Disturbed deposits of unit Qes are susceptible to erosion and deposition by the wind (Lambert, 1974). Wells and others (1990) identified three major episodes of sand deposition, at about 15–9 ka, 6–2 ka, and after 1.5 ka (ka, thousand years), in the Chaco dune field about 50 km northwest of the map area. Comparison of the degree of soil development suggests that sand bodies in unit Qes may have been deposited during one or more of those eolian episodes. Unit Qes is thickest along the western margin of the 5.5-km-wide, east-northeast-trending belt along Interstate 40, and it is thinnest north and south of that belt. Exposed thickness is 1–7.5 m; estimated total thickness is 1–10 m

Qes/QTa **Inactive eolian sand and sheetwash deposits over old alluvium and calcic soils of the Llano de Albuquerque**

LAVA FLOWS AND RELATED DEPOSITS OF ALBUQUERQUE VOLCANOES

The Albuquerque Volcanoes is a 10-km-long series of basalt vents and associated lava flows that erupted from fissures, resulting from magma intrusion along prominent north-south-trending faults in the Albuquerque Basin. The volcanoes overlie the Llano de Albuquerque in the northeast part of the quadrangle and the southeast and southwest parts of the adjacent The Volcanoes and Los Griegos 1:24,00-scale quadrangles. Kelley and Kudo (1978) identified five vent areas. However, satellite vents have formed along the entire length of the inferred fissure. Lava flows erupted from vents along the fissure and flowed predominantly eastward for distances as great as 5 km, toward the Rio Grande. These flows formed a prominent basalt plateau that covers approximately 25–30 km^2 of the constructional Llano de Albuquerque geomorphic surface. Basalt flows are exposed prominently along the escarpment on the eastern margin of the Llano de Albuquerque, 25–30 m above the modern Rio Grande flood plain. Volcanic map units are delineated on the basis of lithology, morphology, and stratigraphic position. Units composed primarily of lava flows typically represent single eruptive events; they are characterized by one or more flows that consist of multiple flow lobes. Locally, the volcanic map units include interbedded pyroclastic deposits. Near-vent pyroclastic deposits associated with lava flow eruptions are denoted by the letter "c" appended to unit descriptors (for example, Qby5 and Qby5c) to imply deposition during the same eruptive event. Contacts between units were determined photogrammetrically. Detailed descriptions of facies textures of pyroclastic deposits and lava flows are given in Kelley and Kudo (1978), Smith and others (1999), and Crumpler (1999).

A middle-to-late Pleistocene age assignment for the volcanic rocks is based on two independent dating techniques. A whole-rock K/Ar determination of 0.19±0.40 Ma was reported by Bachman and Mehnert (1978). More recently, Geissman and others (1990) reported a weighted mean K/Ar age of 0.155±0.047 Ma, based on determinations for three samples collected near the base of the volcanic section. A $^{238}U/^{230}Th$ isochron determination for whole-rock and magnetite separates from two lava flows yielded an age of 0.156±0.029 Ma (Peate and others, 1996). Intercalated middle Pleistocene gravel deposits (Qg) that lack obvious soils separate early cliff-forming basalt flows of unit Qbo and younger flows of unit Qby1 at the southernmost terminus of the volcanic field. Geissman and others (1990) reported paleomagnetic declinations and inclinations of near-vent deposits and proximal lava flows that are statistically indistinguishable from those determined for distal flows at the base of the volcanic section. The declinations and inclinations reported suggest a short duration of magmatic activity during one of the Bruhnes Chron polarity excursions.

Young lava flows and related deposits (middle Pleistocene)—Medium- to dark-gray tholeiitic lava flows (48–50 wt % SiO_2, 4 wt % Na_2O+K_2O, 1.5 wt % TiO_2) and near-vent pyroclastic deposits associated with Hawaiian-type fissure eruptions. Proximal deposits include cinder deposits, spatter deposits, spatter agglutinate, clastogenic lava flows, and locally, thin pahoehoe lava flows that typically are radially distributed around small cones and cone remnants. The lava flows vary in thickness from < 1 m to several meters. Both near-vent deposits and lava flows contain ubiquitous phenocrysts (< 1–2 mm) of olivine and plagioclase in a fine-grained intergranular matrix of plagioclase, Fe-Ti oxides, augite, and interstitial glass.

Qby5c **Cinder deposits on lava flow unit 5**—Near-vent pyroclastic deposits of cone J (Kelley and Kudo, 1978). Predominantly cinders and spatter agglutinate; minor flow material. Maximum thickness is 40 m

Qby5 **Lava flow unit 5**—Medium- to dark-gray vesicular lava flows exposed along the southern and southeastern flanks of vent areas of cone J (Qby5c) and Black Cone (Kelley and Kudo, 1978), north of the map area. Lava flows typically are thin (1–2 m thick), and locally are interbedded with near-vent deposits (scoria, cinders, and spatter associated with fire fountain eruptions from cone J and Black Cone). Locally, ramp structures, push-up features, and small lava tubes are common. Exposed thickness is 3–6 m in map area; base not exposed

Qby4 **Lava flow unit 4**—Discontinuous, rubbly, dark-gray, thin (1–2 m thick), vesicular lava flows near the northeast corner of the map area. Exposures in the quadrangle are distal margins of flows, likely associated with eruption of lavas from vents of Black Cone, approximately 1 km north of the map area. Thickness is 1–2 m

Qby3 **Lava flow unit 3**—Discontinuous, rubbly, thin (1–3 m thick) dark-gray vesicular lava flows 0.5 km southeast of Black Cone. Throughout the rest of the volcanic field, the map unit forms an indistinct low-relief apron around fissure vents above cliff-forming flows of unit Qbo. Push-up structures and rafted pyroclastic deposits are common. Exposed thickness in map area is 2 m; base not exposed

Qby2c **Cinder deposits on lava flow unit 2**—Near-vent pyroclastic deposits of unnamed vent areas approximately 1 km and 1.5 km south of the cone J summit (Kelley and Kudo, 1978). Predominantly cinder and spatter agglutinate; minor flow material. Largely buried by younger lava flows of Qby3. Thickness is unknown; base not exposed

Qby2 **Lava flow unit 2**—Medium-to dark-gray lava flows exposed along an unnamed wash on the southwest margin of the volcanic field and as discontinuous and partially covered flows southeast of their presumed vents (Qby2c). Lava flows typically exhibit transitional pahoehoe to aa surface forms. Thickness is 2–6 m

Qby1 **Lava flow unit 1**—Medium-to dark-gray lava flows overlying gravel (Qg) near southern limit of exposed basalt. Typically thin (1–2 m) lava flows characterized by transitional surface forms from pahoehoe to aa, parallel to low-relief flow lobes along flow direction. Thickness is 3–7 m

Qbo **Old lava flows (middle Pleistocene)**—Massive dark-gray tholeiitic lava flows (48–50 wt % SiO_2, 4 wt % Na_2O+K_2O, 1.5 wt % TiO_2) forming prominent basalt cliffs in northeast quadrant of map area. Two lava flows, each approximately 8 m thick, are ponded along the southeast limit of exposure. Typical lava flow thickness northeast of map area is 1–4 m. Each flow consists of multiple flow lobes, a thin, rubbly flow base, and a characteristically blocky flow top. Lava flows have dense interiors and highly vesicular flow tops (commonly containing horizontal and vertical vesicle segregations in the upper third of each flow), and they contain ubiquitous phenocrysts (< 1–2 mm) of olivine and plagioclase in a fine-grained intergranular matrix of plagioclase, Fe-Ti oxides, augite, and interstitial glass. Exposed thickness is 6–8 m; base not exposed

UPPER SANTA FE GROUP SEDIMENTS

Upper Santa Fe Group sediments are well exposed and mapped along the western escarpment of the Llano de Albuquerque in the western part of the map area. Lambert (1968) and Kelley (1977) measured stratigraphic sections consisting chiefly of interbedded gray gravel and sand in upper Santa Fe Group sediments at El Rincon near the northwest corner of the map area.

`Tg` **Gravel unit of the upper Santa Fe Group sediments (Pliocene)—**Gray, sandy, pebble and cobble gravel interbedded with gray, pebbly, medium- to -coarse sand and sparse coarse gravel that locally contains abundant cobbles and rare boulders as long as 1–1.5 m. Gravel is mostly clast supported. Clasts are subangular to subrounded resistant rock types, of which 20–30 percent are well-rounded, silica-rich, and reworked from lower Tertiary to upper Paleozoic conglomerate. Gravel and sand interbeds are moderately well sorted. Most of the deposits are poorly indurated; locally they contain carbonate cement, which is most abundant beneath the carbonate-enriched soil in the overlying unit (QTa). Pebbles and cobbles are composed of chert (including chert fragments from the Pedernal Chert Member of the Abiquiu Formation), red granite, gneiss, schist, foliated granite, quartzite, petrified wood, and sparse porphyritic volcanic rock, sandstone, siltstone, and altered basalt. Rare large boulders are mostly chert from the Pedernal Chert Member, sandstone, siltstone, and basaltic flow rock. A clast count by Lambert (1968, p. 83) at his El Rincon section indicated 34 percent Precambrian igneous and metamorphic clasts, 46 percent Mesozoic sedimentary clasts, and 20 percent Tertiary volcanic clasts. Clasts typically are subangular. The lower part of unit Tg is less well sorted than the upper part. The lower part includes light-gray sand and small-pebble gravel that at outcrop scale contains small fluvial channel fills that are less than 1 m deep and a few to several meters wide. The upper part is moderately well sorted. It contains medium-gray, commonly coarse gravel and sand that at outcrop scale fill very large channels that are tens of meters deep and hundreds of meters wide. The upper part locally fills channels that cut into underlying units. Sediment transport in unit `Tg` was to the south and south-southeast, as indicated by channel orientation, crossbeds, clast imbrication, and clast provenance. The upward coarsening and the presence of large channels in the upper part of unit Tg may be related to development of a graded fluvial system. The upper contact of unit Tg is well exposed and abrupt beneath unit QTa. Unit Tg may be laterally equivalent to the gravelly upper part of the Ceja Member of the Arroyo Ojito Formation of Connell and others (1999) as mapped by Tedford and Barghoorn (1999, fig. 2) north of the map area. Unit Tg is laterally equivalent in part to the upper sand and gravel unit (QTui) of Maldonado and Atencio (1998a), and may be equivalent in part to their silt, sand, and clay unit (Tssi) in the adjacent Wind Mesa quadrangle, south of the map area. The Pliocene age assignment for unit Tg is based in part on a Blancan age [1.8–4.5 Ma (Lindsay and others, 1984; Lundelius and others, 1987)] of vertebrate fossils in temporally correlative sediments south of the map area near Los Lunas (Tedford, 1981; Love and others, 1998; Morgan and Lucas, 1999; Tedford and Barghoorn, 1999). That age also is based in part on the presence of 3.1-Ma pumice clasts above the base of the silt, sand, and clay unit in the adjacent Wind Mesa quadrangle (Maldonado and Atencio, 1998a; and Maldonado and others, 1999). Unit Tg is less than 30 m thick in the map area; it is as thick as 40 m in the adjacent The Volcanoes quadrangle, north of the map area

`Tps` **Pebbly sand unit of the upper Santa Fe Group sediments (upper Miocene)—**Tan, medium- to -fine sand (60–80 percent of unit) interbedded with gray, pebbly, medium- to -coarse sand and gray, sandy pebble gravel (20–40 percent of unit). Unit Tps locally contains thin beds of tan silt and reddish-brown clay, especially in the lower part the unit. Gray sand and gravel layers commonly are 1–2 m thick and are weakly cemented by calcium carbonate. Interbeds of tan sand are more than 2 m thick and are relatively unconsolidated. The sediments commonly produce step-like topography: the gray sand and gravel forms low risers and the tan sand forms long treads or flats. Unit Tps is transitional between the underlying mud and sand unit (Tms) and the overlying gravel unit (Tg). The poor sorting in the layers of tan sand in unit Tps is similar to that of the underlying unit Tms, which consists mostly of tan sand. Clasts in layers of gray sand and gravel in unit Tps commonly are smaller than those in the overlying unit Tg. Tan sand is predominant in unit Tps; therefore, the overall appearance of Tps is similar to that of the underlying Tms. Unit Tps may be equivalent in part to either the coarse sand and gravel unit (Tcsi) of Maldonado and Atencio (1998a) in the adjacent Wind Mesa quadrangle or the lower sand and gravel unit (Tlsi) of Maldonado and Atencio (1998b) in the nearby Dalies Northwest quadrangle. The Miocene age assignment for unit Tps is based on correlation with sediments of similar lithology exposed in a badland escarpment of the Rio Puerco about 11 km north of the map area (Tedford and Barghoorn, 1999). Thickness of unit Tps is about 20–30 m

Tms **Mud and sand unit of the upper Santa Fe Group sediments (upper Miocene)—**Tan, fine- to -medium sand (70–90 percent of unit) and interbeds of pale-reddish-brown and yellowish- to dark-greenish-brown clay and silty clay (10–30 percent of unit). Layers of tan sand are poorly consolidated and are about 2–6 m thick. They commonly have poorly exposed fluvial bedding and locally have preserved cross-beds. The conspicuous clay and silt beds are moderately consolidated and are 0.5–3 m thick. They stand in slight relief compared to beds of easily eroded, tan sand. Transport direction and the clast provenance, composition, and size range are similar to those of the tan sand in the overlying units, with the exception that granules (2–4 mm) and pebbles are sparse to absent in unit Tms. The clay beds are interpreted to be the tops of non-gravelly, upward-fining, depositional sequences. The upper contact of unit Tms commonly is sharp, and it commonly was placed at the top of the highest, conspicuous, 1-m-thick clay bed. Where thinner clay beds are abundant above the highest 1-m-thick clay bed, the upper contact was placed at the top of a thinner, higher, clay bed in order to include most of the clay beds in unit Tms. The Miocene age assignment for unit Tms is based on correlation with sediments of similar lithology exposed in a badland escarpment of the Rio Puerco about 11 km north of the map area (Tedford and Barghoorn, 1999). Unit Tms is more than 20 m thick in the map area. Commonly, it is about 23 m thick in the adjacent The Volcanoes quadrangle, north of the map area

Ts **Upper Santa Fe Group sediments, undivided (Pliocene and upper Miocene)—**Poorly exposed, slightly cobbly, pebble gravel, pebbly sand, and sand. Much of the sand is very fine to very coarse. It contains thin (5–50 cm) lenses of pebbly sand and gravel and, locally, thin (5 cm) lenses of silty clay. Clasts are chiefly subangular to rounded granite, chert (including chert fragments from the Pedernal Chert Member of the Abiquiu Formation), sandstone, petrified wood, and basalt. Unit Ts includes the gravel unit (Tg), and locally it includes the pebbly sand unit (Tps). Unit Ts locally may include minor unmapped old alluvium and calcic soils of the Llano de Albuquerque (QTa) adjacent to the Llano de Albuquerque geomorphic surface. Unit Ts locally may include the mud and sand unit (Tms) in gently sloping areas near the eastern boundary of the map area. Unit Ts is laterally equivalent, at least in part, to the Ceja Member of the Arroyo Ojito Formation of Connell and others (1999) in the adjacent Albuquerque West quadrangle (Connell and others, 1998). Unit Ts is also laterally equivalent in part to the upper sand and gravel unit (QTui) of Maldonado and Atencio (1998a), and may be equivalent in part to their silt, sand, and clay unit (Tssi) in the adjacent Wind Mesa quadrangle. Estimated thickness of unit Ts is 120 m

STRATIGRAPHY OF DEEP DRILL AND CORE HOLES IN AND NEAR THE MAP AREA

There are eight deep drill holes and one deep core hole in and near the map area that penetrate Santa Fe Group sediments and volcanic rocks (Table 3). The three deepest holes were drilled for hydrocarbon exploration and penetrate pre-Santa Fe Group rocks and sediments. The other five drill holes are water wells.

Utex Oil drilled Westland Development No. 1–1J1E in 1984 to a total depth of 16,665 ft (5,079 m). The drill hole penetrated 8,180 ft (2,493 m) of Santa Fe Group, 8,293 ft (2,528 m) of unit of Isleta # 2 of Lozinsky (1988; 1994), and bottomed in non-marine Cretaceous sedimentary rocks. Black (1999) believed otherwise, that the drill hole ended in Tertiary rocks.

Burlington Resources drilled the Westland Development No. 1–Y in 1997 to a total depth of 7,778 ft (2,371 m). The hole penetrated 5,201 ft (1,585 m) of Tertiary section. This section also included more than 500 ft (152 m) of Tertiary igneous rocks that form sills and dikes. Cretaceous sedimentary rocks, 1,979 ft (603 m) thick, were encountered at depths of 5,201–7,492 ft (1,585–2,284 m). Jurassic sedimentary rocks, 517 ft (158 m) thick, were encountered at depths of 7180–7,697 ft (2,188–2,346 m). The lowest unit penetrated in the drill hole is the Triassic Chinle Formation (Black, 1999).

F. H. Carpenter drilled Carpenter Atrisco Grant No. 1 in 1948 to a total depth of 7,245 ft (2,208 m). The drill hole penetrated 3,300 ft (1,006 m) of Santa Fe Group sediments (Lozinsky, 1988). The upper 400 ft (122 m) of the Santa Fe Group sediments contains more coarse sand than the middle 2,261 ft (689 m). The basal 639 ft (195 m) of the Santa Fe Group is light-gray sand that contains intermediate volcanic clasts (Lozinsky, 1988). The basal part probably is equivalent to the Piedra Parada Member of the Zia Formation (Tedford and Barghoorn, 1999). The Santa Fe Group sediments overlie 3,352 ft (1,022 m) of unit of Isleta # 2. In

Table 3. Thickness of geologic materials penetrated in deep drill holes and core hole in and near the map area.

[. . ., not described or not applicable; >, greater than; all elevations and thicknesses are in feet; well locations are in Universal Transverse Mercator (UTM) coordinates (meters) (zone 13, North American Datum 1927); sources of information: B, (Black, 1999); BL, B. A. Black, Black Oil Company, oral communication, 1999; HC, J.W. Hawley and S.D. Connell, oral communication, 1999; L, Lozinsky (1988; 1994); SH, John Shomaker, John Shomaker and Associates, written communication, 1999; SS, B.D. Stone and D.A. Sawyer, written communication, 1999; ST, Stone and others (1998); WA, Nanis Wallace, Burlington Resources, written communication, 1999; WI, Wilkins (1987)]

Well name	Westland Development	Westland Development	Carpenter Atrisco Grant	Cerro Colorado PW	Don	98th Street core hole	Oncho Grande	SWAB	Cerro Colorado MW
Well number	1-1J1E	1-Y	1		1			1	2
Well location									
UTM Easting	337482	331450	332660	329577	339980	340678	339173	333590	329355
UTM Northing	3887494	3882689	3880960	3876963	3882140	3884408	3879472	3883272	3874967
Ground surface elevation	5,773	5,940	5,785	5,830	5,345	5,320	5,370	5,796	5,670
Total depth	16,665	7,778	7,245	1,771	1,650	1,560	1,304	1,204	890
	Thickness								
Surficial deposits	. . .	. . .	. . .	. . .	. . .	19	. . .	16	. . .
Santa Fe Group									
Gravelly sediment (Ceja?)	20	298	226	259	90	78	. . .	204	138
Medium to coarse sand	. . .	242	174	421	397	344	. . .	200	251
Silty sediment	. . .	306	450	359	315	346	257	400	215
Medium sand	. . .	558	1,811	491	848	773	535	360	286
Basalt?	. . .	. . .	. . .	. . .	. . .	. . .	48	24	. . .
Rhyolitic volcanics	. . .	. . .	. . .	241	. . .	. . .	. . .	. . .	. . .
Fine to medium sand	. . .	1,066	. . .	. . .	. . .	. . .	464	. . .	. . .
Zia Formation	. . .	313	639	. . .	. . .	. . .	. . .	. . .	. . .
Santa Fe Group, undivided	8,180	. . .	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Unit of Isleta # 2	8,293	2,028	3,352	. . .	. . .	. . .	. . .	. . .	. . .
Galisteo Formation	. . .	390	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Cretaceous rocks, undivided	172	1,979	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Jurassic rocks, undivided	. . .	517	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Chinle Formation	. . .	81	. . .	. . .	. . .	. . .	. . .	. . .	. . .
Total thickness of Santa Fe Group	8,180	2,783	3,300	> 1,771	> 1,650	> 1,541	> 1,304	> 1,188	> 890
Sources of information	SS HC B	WA BL SS	L SS	SS SH	SS	ST	SS	WI SS	SS SH

the Albuquerque basin this unit commonly consists of purplish-red to gray, well-indurated, poorly to moderately sorted fine- to coarse-grained sandstone that contains interbeds of claystone and silicic to intermediate volcanic flows and tuffs (Lozinsky, 1994). Unit of Isleta # 2 in Carpenter Atrisco Grant No. 1 well is mostly fine to medium sandstone that contains three zones that are rich in mafic volcanic detritus, at depths of about 3,350–3,450 ft (1,021–1,052 m), 4,910–4,940 ft (1,497–1,506 m), and 5,500–5,630 ft (1,676–1,716 m) (Lozinsky, 1988).

The U.S. Geological Survey drilled SWAB 1 in 1981 to a total depth of 1,204 ft (367 m). The driller's log and grain-size analyses on the cuttings indicate that the drill hole penetrated 16 ft (5 m) of surficial deposits, 1,164 ft (355 m) of Santa Fe Group sediments, and 24 ft (7 m) of basalt (Wilkins, 1987). The gamma-ray log of the Santa Fe Group sediments penetrated in the drill hole indicate that the sediments at depths of 420–820 ft (128–250 m) contain more silt and clay that the overlying and underlying sediments.

The other four water wells (Cerro Colorado PW, Don No. 1, Oncho Grande, and Cerro Colorado MW No. 2) were drilled to total depths of 890–1,771 ft (271–540 m) and penetrated Santa Fe Group sediments and locally some volcanic material. None of the wells penetrated pre-Santa Fe Group rocks.

The 98th Street core hole was drilled by the U.S. Geological Survey and the City of Albuquerque just north of Interstate 40 in the adjacent Albuquerque West 7.5-minute quadrangle. It is located about 190 m east of the western border and about 3,660 m south of the northern border of the Albuquerque West quadrangle (well symbol 98a in Connell and others, 1998). The core hole was completed in 1996 to a total depth of 1,560 ft (476 m). Sampling recovered 760.6 ft (231.8 m) of core. The core hole penetrated about 19 ft (6 m) of Quaternary eolian sand and alluvium; 78 ft (24 m) of the upper gravelly unit of the Santa Fe Group; and at least 1,463 ft (446 m) of the middle unit of the Santa Fe Group (Stone and Allen, 1998). The upper unit of the Santa Fe Group is chiefly sand, gravel, and lenses of pebbly sand, silt, and clay. The middle unit of the Santa Fe Group is mostly interbedded sand, silty sand, silty clay, and clay (Stone and Allen, 1998). The sandy and gravelly upper unit of the Santa Fe Group probably is laterally equivalent to the Ceja Member of the Santa Fe Formation of Kelley (1977) and has been correlated with the Sierra Ladrones Formation (Machette, 1978b; Stone and Allen, 1998; Stone and others, l998).

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REFERENCES CITED

American Geological Institute, 1982, Grain-size scales used by American geologists, modified Wentworth scale, in Data sheets (2nd ed.): Falls Church, Virginia, American Geological Institute, sheet 17.1.

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.

Berggren, W.A., Hilgren, F.J., Langereis, C.G., Kent, D.V., Obradovich, J.D., Raffi, Isabella, Raymo, M.E., and Shackleton, N.J., 1995, Late Neogene chronology—new perspectives in high-resolution stratigraphy: Geological Society of America Bulletin, v. 107, p. 1272-1287.

Birkeland, P.W., 1999, Soils and geomorphology: New York, Oxford University Press, 430 p.

Black, B.A., 1999, Recent oil and gas exploration in the Albuquerque basin, *in* Pazzaglia, F.J., and Lucas, S.G., eds., Albuquerque geology: New Mexico Geological Society Guidebook 50, p. 437-439.

Bryan, Kirk, and McCann, F.T., 1938, The Ceja del Rio Puerco—A border feature of the Basin and Range Province in New Mexico. Part II, geomorphology: Journal of Geology, v. 46, p. 1-16.

Connell, S.D., Allen, B.D., Hawley, J.W., and Shroba, Ralph, 1998, Geology of the Albuquerque West 7.5-minute quadrangle, Bernalillo County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Open-file Digital Geologic Map DM 17, scale 1:24,000 [last modified January 4, 2000].

Connell, S.D., Koning, D.J., and Cather, S.M., 1999, Revisions to the stratigraphic nomenclature of the Santa Fe Group, northwestern Albuquerque basin, New Mexico, *in* Pazzaglia, F.J., and Lucas, S.G., eds., Albuquerque geology [guidebook]: New Mexico Geological Society Guidebook 50, p. 337-353.

Crumpler, L.S., 1999, Ascent and eruption at the Albuquerque Volcanoes—A physical volcanology perspective: New Mexico Geological Society Guidebook 50, p. 221-233.

Geissman, J.W., Brown, L., Turrin, B.D., McFadden, L.D., and Harlan, S.S., 1990, Brunhes Chron excursion/polarity episode recorded during the late Pleistocene, Albuquerque Volcanoes, New Mexico, USA: Geophysical Journal International, v. 102, p. 73-88.

Gile, L.H., Peterson, F.F., and Grossman, R.B., 1966, Morphological and genetic sequences of carbonate accumulation in desert soils: Soil Science, v. 101, p. 347-360.

Grauch, V. J. S., 1999, Principal features of high-resolution aeromagnetic data collected near Albuquerque, New Mexico: New Mexico Geological Society Guidebook 50, p. 115-118.

Guthrie, R.L., and Witty, J.E., 1982, New designations for soil horizons and layers and the new Soil Survey Manual: Soil Science Society of America Journal, v. 46, p. 443-444.

Hansen, W.R., ed., 1991, Suggestions to authors of the reports of the United States Geological Survey, seventh edition, Washington, D.C., U.S. Government Printing Office, 289 p.

Kelley, V.C., 1977, Geology of the Albuquerque basin, New Mexico: New Mexico Bureau of Mines and Mineral Resources Memoir 33, 59 p.

Kelley, V.C., and Kudo, A.M., 1978, Volcanoes and related basalts of Albuquerque Basin, New Mexico: New Mexico Bureau of Mines and Mineral Resources Circular 156, 30 p.

Lambert, P.W., 1968, Quaternary stratigraphy of the Albuquerque area, New Mexico: Albuquerque, University of New Mexico, Ph.D. dissertation, 329 p.

Lambert, P.W., 1968, 1974, Map showing present and potential sources of blowing sand in the La Mesita Negra SE quadrangle, Bernalillo County, New Mexico: U.S. Geological Survey Miscellaneous Field Studies Map MF-600, scale 1:24,000.

Lindsay, E.H., Opdyke, N.D., and Johnson, N.M., 1984, Blancan-Hemphillian land mammal ages and late Cenozoic mammal dispersal events: Annual Review of Earth and Planetary Sciences, v. 12, p. 445-488.

Lourens, L.J., Hilgen, F.J., Raffi, I., and Vergnaud-Grazzini, C., 1996, Early Pleistocene chronology of the Vrica section [Calabria, Italy]: Paleoceanography, v. 11, p. 797-812.

Love, D. W., Maldonado, Florian, Hallett, B., Panter, K., Reynolds, C., McIntosh, W.C., and Dunbar, N., 1998, Geology of the Dalies 7.5-minute quadrangle, Valencia County, New Mexico: New Mexico Bureau of Mines and Mineral Resources Open-file Digital Geologic Map DM 21, scale 1:24,000.

Lozinsky, R.P., 1988, Stratigraphy, sedimentology, and sand petrology of the Santa Fe Group and pre-Santa Fe Tertiary deposits in the Albuquerque basin, central New Mexico: Socorro, New Mexico Institute of Mining and Technology, Ph.D. dissertation, 298 p.

Lozinsky, R.P., 1994, Cenozoic stratigraphy, sandstone petrology, and depositional history of the Albuquerque basin, central New Mexico *in* Keller G.R., and Cather, S.M., eds., Basins of the Rio Grande Rift—structure, stratigraphy, and tectonic setting: Geological Society of America Special Paper 291, p. 73-82.

Lundelius, E.L., Jr., Churcher, C.S., Downs, T., Harington, C.R., Lindsay, E.H., Schultz, G.E., Semken, H.A., Webb, S.D., and Zakrzewski, R.J., 1987, The North American Quaternary sequence, *in* Woodburne, M.O., ed., Cenozoic mammals of North America—Geochronology and biostratigraphy: Berkeley, University of California Press, p. 211-235.

Machette M.N., 1978a, Dating Quaternary faults in the southwestern United States using buried calcic paleosols: Journal of Research U.S. Geological Survey, v. 6, p. 369-381.

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

Machette M.N., 1985, Calcic soils of the southwestern United States, *in* Weide, D.L., ed., Soils and Quaternary geology of the southwestern United States: Geological Society of America Special Paper 203, p. 1-21.

Machette, M.N., Long, Thomas, and Bachman, G.O., 1997, Laboratory data for calcic soils in central New Mexico—Background information for mapping Quaternary deposits in the Albuquerque basin: U.S. Geological Survey Open-File Report 96-722, 60 p.

Madole, R.F., 1995, Spatial and temporal patterns of late Quaternary eolian deposition, eastern Colorado, U.S.A.: Quaternary Science Reviews, v. 14, p. 155-177.

Maldonado, Florian, and Atencio, Arthur, 1998a, Preliminary geologic map of the Wind Mesa quadrangle, Bernalillo County, New Mexico: U.S. Geological Survey Open-File Report 97-740, 7 p., scale 1:24,000.

Maldonado, Florian, and Atencio, Arthur, 1998b, Preliminary geologic map of the Dalies Northwest quadrangle, Bernalillo County, New Mexico: U.S. Geological Survey Open-File Report 97-741, 7 p., scale 1:24,000.

Maldonado, Florian, Connell, S.D., Love, D.W., Grauch, V.J.S., Slate, J. L, McIntosh, W.C., Jackson, P.B., and Byers, F.M., Jr., 1999, Neogene geology of the Isleta Reservation and vicinity, Albuquerque basin, central New Mexico: New Mexico Geological Society Guidebook 50, p. 175-188.

McCalpin, J.P., 1997, Paleoseismicity of Quaternary faults near Albuquerque, New Mexico: U.S. Geological Survey, National Earthquake Hazards Reduction Program, Final Technical Report, Contract 1434-HQ-96-GR-02751, 18 p.

McCalpin, J.P., 2001, Late Quaternary faulting surrounds Albuquerque, defines the East Heights seismic gap: Geological Society of America Abstracts with Programs, v. 33, no. 5, p. A49.

McKinney, K.C., ed., 2002, Digital archive—Report upon the Colorado River of the West explored in 1857 and 1858 by Lieutenant Joseph C. Ives, geologic report with maps by John S. Newberry: U.S. Geological Survey Open-File Report 02-25, version 1.0.

Morgan, G.S., and Lucas, S.G., 1999, Pliocene (Blacan) vertebrates from the Albuquerque Basin, north-central New Mexico: New Mexico Geological Society Guidebook 50, p. 363-370.

Munsell Color, 1973, Munsell soil color charts: Baltimore, Maryland., Kollmorgen Corporation, Macbeth Division.

Peate, D.W., Chen, J.H., Wasserburg, G.J., Papanastassiou, D.A., and Geissman, J.W., 1996, 238U-230Th dating of a geomagnetic excursion in Quaternary basalts of the Albuquerque Volcanoes field, New Mexico (USA): Geophysical Research Letters, v. 23, p. 2271-2274.

Personius, Stephen, F., Machette, Michael, N., and Kelson, Keith, I., 1999, Quaternary faults in the Albuquerque area—an update: New Mexico Geological Society Guidebook, 50, p. 189-200.

Richmond, G.M., and Fullerton, D.S., 1986, Introduction to Quaternary glaciations in the United States of America, *in* Richmond, G.M., and Fullerton, D.S., eds., Quaternary glaciations in the United States of America: Quaternary Science Reviews, v. 5, p. 3-10.

Rock-Color Chart Committee, 1995, Rock-Color Chart: Boulder, Colorado, Geological Society of America.

Smith, G.A., Florence, P.S., Castrounis, M.L., Moore, J.D., Throne, John, and Zelley, Karin, 1999, Basaltic near-vent facies of Vulcan Cone, Albuquerque Volcanoes, New Mexico: New Mexico Geological Society Guidebook 50, p. 211-219.

Soil Survey Staff, 1975, Soil taxonomy: U.S. Department of Agriculture Handbook 436, 754 p.

Stone, B.D., and Allen, B.D., 1998, The 98th Street core—Key to analysis of Santa Fe Group stratigraphy and hydrology in the central middle Rio Grande Basin: U.S. Geological Survey Middle Rio Grande Basin Study—Proceedings of the Second Annual Workshop, Albuquerque, New Mexico, February 10-11, 1998: U.S. Geological Survey Open-File Report 98-337, p. 41-46.

Stone, B.D., Allen, B.D., Mikolas, Marlo, Hawley, J.W., Haneberg, W.C., Johnson, P.S., Allred, Barry, and Thorn, C.R., 1998, Preliminary lithostratigraphy, interpreted geophysical logs, and hydrogeologic characteristics of the 98th Street core hole, Albuquerque, New Mexico: U.S. Geological Survey Open-File Report 98-210, 82 p.

Tedford, R.H., 1981, Mammalian biochronology of the late Cenozoic basins of New Mexico: Geological Society of America Bulletin, v. 92, p. 1008-1022.

Tedford, R.H., and Barghoorn, Steven, 1999, Santa Fe Group (Neogene), Ceja del Rio Puerco, northwestern Albuquerque Basin, Sandoval County, New Mexico: New Mexico Geological Society Guidebook 50, p. 327-335.

U. S. Geological Survey and SIAL, Ltd., 1997, Description of digital aeromagnetic data collected north and west of Albuquerque, New Mexico: U. S. Geological Survey Open-File Report 97-286, 45 p., digital data available on U. S. Geological Survey web site at URL http://geology.cr.usgs.gov/.

Varnes, D.J., 1978, Slope movement types and process, *in* Schuster, R.L., and Krizek, R.J., eds., Landslides—Analysis and control: National Academy of Sciences, Transportation Research Board Special Report 176, p. 11-33.

Wells, S.G., McFadden, L.D., and Schultz, J.D., 1990, Eolian landscape evolution and soil formation in the Chaco dune field, southern Colorado Plateau, New Mexico: Geomorphology, v. 3, p. 517-546.

Wilkins, D.W., 1987, Characteristics and properties of the basin-fill aquifer determined from three test wells west of Albuquerque, Bernalillo County, New Mexico: U.S. Geological Survey Water-Resources Investigations Report 86-4187, 78 p.