Geologic Map of the
Loma Creston Quadrangle,
Sandoval County, New Mexico

By

Chamberlin, R. M.; Pazzaglia, F. J.; Wegmann, K. W.; Smith, G. A.

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801 Leroy Place, Socorro, New Mexico, 87801-4796

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and
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COMMENTS TO MAP USERS

Mapping of this quadrangle was funded by a matching-funds grant from the 1998 STATEMAP program of the U.S. Geological Survey, National Cooperative Geologic Mapping Program, under USGS award number 1434-HQ-97-AG-01781, to the New Mexico Bureau of Mines and Mineral Resources (Dr. Charles E. Chapin, Director; Dr. Paul W. Bauer, P.I. and Geologic Mapping Program Manager).

This quadrangle map has been Open-Filed in order to make it available as soon as possible. The map has not been reviewed according to NMBMMR standards, and due to the ongoing nature of work in the area, revision of this map is likely. As such, dates of revision are listed in the upper right corner of the map and on the accompanying report. ***The contents of the report and map should not be considered final and complete until it is published by the NMBMMR.***

A geologic map graphically displays information on the distribution, nature, orientation, and age relationships of rock and surficial units and the occurrence of structural features such as faults and folds. Geologic contacts are irregular surfaces that form boundaries between different types or ages of units. Data depicted on this geologic map are based on field geologic mapping, compilation of published and unpublished work, and photogeologic interpretation. Locations of contacts are not surveyed, but are plotted by interpretation of the position of a given contact onto a topographic base map; therefore, the accuracy of contact locations depends on the scale of mapping and the interpretation of the geologist. Significant portions of the study area may have been mapped at scales smaller than the final map; therefore, the user should be aware of potentially significant variations in map detail. Site-specific conditions should be verified by detailed surface mapping or subsurface exploration. Topographic and cultural changes associated with recent development may not be shown everywhere.

Any enlargement of this map could cause misunderstanding in the detail of mapping and may result in erroneous interpretations. The information provided on this map cannot be substituted for site-specific geologic, hydrogeologic, or geotechnical investigations. The use of this map to precisely locate buildings relative to the geological substrate is not recommended without site-specific studies conducted by qualified earth-science professionals.

The cross-sections in this report are constructed based on surficial geology, and where available, subsurface and geophysical data. The cross sections are interpretive and should be used as an aid to understand the geologic framework and not used as the sole source of data in locating or designing wells, buildings, roads, or other structures.

The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government.

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Loma Creston Quadrangle,
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Explanation of map symbols: Loma Creston 7.5' quadrangle

contact, location closely constrained, well exposed at triangle (all solid contacts shown for alluvium are approximately located).

contact, long dashed where approximately located, short dashed where inferred or intraformational (e.g. lithofacies boundary)

gradational lithofacies boundary

ancient paleovalley wall (inset contact of late Tertiary age)

thin (<1m thick) pumiceous ash bed, mostly water laid, usually rhyolitic, less common biotite-rich rhyodacitic ash beds indicated by "d"

aeromagnetic anomaly, locally defines concealed margins of basaltic lavas and tephras on northern part of Santa Ana Mesa (from unpublished map of V. J. S. Grauch, USGS, 1999); pos = positive magnetic anomaly neg = negative magnetic anomaly (i.e. reverse polarity). Shown as heavy line where fault appears to be coincident with magnetic anomaly

strike and dip of stratification/bedding, apparent or calculated dip in parentheses

horizontal stratification/bedding

dip direction and inclination of large crossbeds in "Tzu" (paleocurrent direction)

general paleocurrent direction (±30°) from clast imbrication

attitude of flow banding in silicic lavas

vitric margin of rhyolitic lava flow

normal fault, solid where location is well constrained, long dashed where approximately located, short dashed where inferred, dotted where concealed, queried where hypothetical. Observed dip shown at tick mark. Bar and ball on downthrown side.

fault with slickenlines (solid arrow shows pitch), half arrows indicate lateral component of slip, sense of shear (d = dextral, s = sinistral, n = normal, r = reverse) in parentheses, dominant component listed first. Sense of shear from combination of stratigraphic offset and pitch of slickenlines, and/or from Reidel shears (RS).

approximate axis of monoclinal flexure, solid arrow indicates steeper limb

axis of synclinal fold

sense of displacement on concealed fault (u = upthrown, d = downthrown)

slump block (toreva-style landslide block), typically within colluvial mantled slopes

cliff-forming face of silicified normal fault, tick mark shows dip

ancient colluvial deposit, graded to or buried by Tglp or Tc

coarse conglomerate zone in middle Santa Fe Group (Tsf) or medial Cochiti Fm (Tct). Mostly cobble/boulder conglomerates

inferred approximate location of volcanic vent; minor secondary vent (sec.).

obsidian pebble(s) in outcrop of Cochiti Formation or younger gravels (leader to location); obsidian mostly altered (hydrated) to perlite (open symbol), partly altered to perlite (dotted symbol), slightly altered to perlite (e.g., gray frosted surface, black symbol). Decimal next to symbol indicates visually estimated fraction of perlite observed (e.g. 0.8 = 8/10 ± 2/10 perlite)

windmill (water well for livestock)

location of sample collected for Ar-Ar dating (table 1) or geochemical analysis (table 2).

Map Units: Loma Creston 7.5' quadrangle

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Richard Chamberlin[1], chief compiler

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af   *Artificial fill.* Compacted sand and gravel fills over culverts along Borrego Canyon road, includes cemented ramp in Borrego Canyon and concrete dam south of Loma Creston. Also includes earthen dam at large stock tank on Santa Ana Mesa near south edge of quadrangle.

Quaternary surficial deposits and associated ash beds

Qa   *Alluvium—Holocene and uppermost Pleistocene.* Gravel, sand, silt and minor clay in valley bottoms of major drainages. Includes low terraces (1–2 above active channel) and toe-of-slope colluvium along low-order drainages. Approximately 1 m of historic aggradation is documented by mostly buried fence posts about 1 km south of Mesita Cocida. Includes fine-grained fill of large stock tank on Santa Ana Mesa. Probably 0–5 m thick in most areas.

Qe   *Eolian sand—upper Pleistocene and Holocene.* Well-sorted, thick to massively bedded, fine-grained dune sand on interfluves predominantly east and southeast of drainages .Significant accumulation of eolian sand also occur in high-standing swales locally developed on the gravel of Lookout Peak. Large sand sheet occurs at west foot of Santa Ana Mesa; smaller discontinuous sand patches on "Tb" not mapped. 0–~10 m thick.

Qae   *Alluvium and eolian deposits undivided—upper Pleistocene and Holocene.* Poorly-sorted, interbedded alluvial gravel, sand, silt and minor clay and well-sorted eolian sand. Deposit occurs in wide valley bottoms and along valley margins and has been observed to locally be interbedded with El Cajete ash (Qec). Forms widespread mantle over basalts on NW part of Santa Ana Mesa and over "Tglp" or "Tbp" east of Mesita Cocida. 0–~5 m thick.

Qc   *Colluvium and related hillslope deposits—upper Pleistocene and Holocene.* Poorly sorted, poorly stratified, matrix and clast supported talus, colluvium, rock falls, debris flows(?) and shallow slumps (larger slumps mapped separately). Significant accumulations of talus and scree are draped around mesas and cuestas capped by mafic lavas (Tcb, Tpb, Tpba and Tb), high gravel-capped mesas (Tglp) and footwall ridges of silicified Santa Fe Group sandstones. Map patterns of colluvium are locally schematic and preferentially shown where important bedrock relationships (e.g. fault traces) are obscured. Numerous gravel mantled slopes within the Cochiti Formation undivided (Tc), represent unmapped colluvium obscuring poorly indurated tuffaceous sandstones and ash beds in the lower Cochiti Fm (Tct). 0–~10 m thick.

Qco   *Older colluvium—lower Pleistocene to upper Pliocene(?).* High level remnant of monolithic colluvial wedge on southwest flank of Loma Canovas. Consists entirely of angular debris derived from the microporphyritic basaltic andesite lava (Tpba) that forms cliffs and ledges directly upslope. Numerous clasts are coated with degraded carbonate rinds. Probably not much younger than the high level terrace (Tglp) that it overlaps. 0–6 m thick.

Qca   *Alluvium and colluvium undivided—upper Pleistocene and Holocene.* Colluvium interbedded with alluvium. Deposit is ubiquitous in low-order drainages and as an extensive hillslope mantle in the narrows of Borrego Canyon. Buried soils are locally preserved in this deposit which also contains a significant, but highly variable component of eolian material. May include older debris-flow deposits on flanks of Loma Canovas. 0–~5 m thick.

Qec   *Reworked El Cajete tephra—upper Pleistocene and Holocene*. Isolated patches and locally continuous valley fills. Composed mostly of fine pumice lapilli (<1 cm) and shards (1–5 mm); derived from eruption of the ~60 ka El Cajete Member of the Valles Rhyolite. Reworked by alluvial and eolian processes, locally caps Qtu and is interbedded in Qae. Usually 0–3 m thick.

Qt   *Terrace deposits—middle to upper Pleistocene*. Alluvial sandy cobble to boulder, predominantly volcanic provenance gravel that underlie distinct treads in the context of the larger modern drainages, particularly Borrego Canyon. Strath terrace deposits are relatively thin (<3 m) and overlie straths of low relief. Fill terrace deposits are relatively thick (>3 m) and overlie straths of variable relief. Terrace deopsits along middle and lower Borrego Canyon contain sparse clasts of silicified sandstone (jasperized Tsf) and inconspicuous rare pebbles of frosted obsidian. Fill terrace deposits are relatively thick (>3 m) and overlie straths of variable relief.

    Qt5   *Terrace deposits—upper Pleistocene*. Fill terraces with treads approximately 5 m above grade in the medial portions of large drainages. In a similar landscape position to Qt5 of Rio Jemez valley thought to be ~60 ka. Includes fill terrace with tread approximately 1–4 above grade, found east of Loma Canovas; this tread is partly mantled by an El Cajete pumice deposit.

    Qt4   *Terrace deposits—middle(?) to upper Pleistocene*. Fill terraces with treads approximately 18–20 m above grade in the medial portions of large drainages. Straths are locally well-exposed. In a similar landscape position to Rio Grande terraces with an estimated age of 95±15 ka (Dethier and McCoy, 1993) and Qt4 of the Rio Jemez valley thought to be ~150 ka (Formento-Trigilio and Pazzaglia, 1998).

    Qt3   *Terrace deposits—middle Pleistocene*. Fill terraces with treads approximately 30 m above grade in the medial portions of large drainages. Terraces are only locally preserved in Borrego Canyon south of Mesa Cocida, but are more continuous east of the quadrangle where they merge with terraces of the Rio Grande with an estimate age of 170±40 ka (Dethier and McCoy, 1993). In a similar landscape position of Qt3 of the Rio Jemez valley thought to be ~300 ka (Formento-Trigilio and Pazzaglia, 1998). Terrace 2 km south of Mesita Cocida is overlain by undated rhyolitic ash (Qvt?) locally exposed in roadcut where preserved by overlying colluvium.

    Qt2   *Terrace deposits—middle Pleistocene*. Fill terraces with treads approximately 35–50 m above grade in the medial portions of large drainages. In a similar landscape position to Qt2 of the Rio Jemez valley thought to be ~400 ka (Formento-Trigilio and Pazzaglia, 1998).

    Qt1   *Terrace deposits—middle Pleistocene*. Strath terraces with treads approximately 60–85 m above grade in the medial portions of large drainages. In a similar landscape position to Qt1 of the Rio Jemez valley determined to be 602 ka where Lava Creek B ash is found in the middle portion of fill terrace deposits (Rogers, 1996). Qt1 terrace treads in Borrego Canyon notably converge with the modern channel upstream. West end of terrace south of Mesita Cocida is truncated by an unaltered Quaternary fault in the hangingwall of a silicified Miocene fault.

Qvt   *Ash bed—middle Pleistocene(?)*. Probably correlative with a medial member of the Valles Rhyolite. Light gray semi-altered fine ash with sparse small phenocrysts. Locally overlies Qt3 and buried by Qc, 2 km south of Mesita Cocida. 0–1 m thick.

Qao   *Older alluvium—early(?) to middle(?) Pleistocene*. Stratified alluvial sand and gravel capping interfluves not in the context of modern, large drainages. Mostly in isolated basin west of Loma Creston.

Tertiary Volcanic Strata of the Jemez Field

Upper Tertiary volcanic strata of the Jemez Field (Smith et al., 1970) provide important stratigraphic marker beds of
moderate to minor lateral extent in the Loma Creston quadrangle. These reasonably distinctive basaltic lava
flows and less distinctive rhyolitic ash beds are interleaved with sedimentary facies of the Santa Fe Group.
The isotopically datable volcanic strata can provide a critical temporal (and structural) framework that
permits a confident reconstruction of Santa Fe Group facies within and across extensional fault blocks of
the Rio Grande rift.

Tb   *Basalts of the San Felipe field (peripheral subfield of Jemez field)—upper Pliocene.* Thin
subhorizontal olivine basalt flows and cogenetic basaltic tephra (t) that cap the northern end of
Santa Ana Mesa. An unpublished high-resolution shaded aeromagnetic relief map of Santa Ana
Mesa area (V. J. S. Grauch, USGS) indicates these lavas and tephras are expressed by both
positive (normal polarity) and negative (reverse polarity) magnetic anomalies. $^{40}Ar/^{39}Ar$ ages of
these basalts from northeastern Santa Ana Mesa range from 2.62±0.15 to 2.41±0.03 Ma (Smith
and Kuhle, 1998); thus this eruptive series *may* span the Gauss/Matuyama magnetochron
boundary (older normal/younger reverse) at about 2.5 Ma.

Tbn/Tbnt   Olivine basalt lava (Tbn) and associated hydromagmatic basaltic tephra (Tbnt) erupted from a
small isolated eruptive center on the northwest corner of Santa Ana Mesa. This 2x3 km eruptive
center is well defined on the unpublished aeromagnetic map of Grauch, 1999. Peripheral tephra
deposits are associated with positive magnetic anomalies; central lavas are associated with a
strong negative magnetic anomaly. This small eruptive center is mostly concealed by older
Quaternary alluvium and eolian sand in a shallow graben between the east-down Cocida–Oso fault
zone and the west-down Algodonnes fault. Basaltic lava outcrop west of Borrego Canyon road
(Tbn) consists of medium dark gray olivine basalt with rare (<0.5%) fine to medium grained (0.5–
2 mm) greenish olivine and traces of plagioclase in a finely vesicular aphanitic groundmass; this
flow appears to be about 6 m thick and has been tilted gently to the east. Basaltic tuff on south rim
of Borrego Canyon (southeast of "the Narrows") is a bedded brown to dark gray hydromagmatic
tuff with plane beds and sandwave crossbeds; grains are fine to coarse ash with scattered lapilli to
2 cm. Ash grains are a mixture of sideromelane glass and quartzo-feldspathic sand derived from a
relatively non-volcanic sediment underlying the vent. The primary vent for this small basaltic
center is inferred to be present in proximity to a younger axial fault and southwest of (upwind of)
the most prominent tephra ridge. Secondary vents may have been present further northward along
a hypothetical NNE-trending feeder dike, which would help explain the apparent horseshoe-like
distribution of basaltic tephra. Tephra deposits on SE rim may be as much as 18 m thick.

Tb/Tbt   Topographic expression and magnetic anomaly patterns across Santa Ana Mesa are consistent
with single to multiple flow events associated with small northerly aligned shield volcanoes and
small cinder cones. Isotopic dating (K–Ar and Ar–A) yields ages of about 2.5 Ma (Bachman and
Mehnert, 1978; Smith and Kuhle, 1998). Lavas on northeast quadrant of mesa (east of Algodonnes
fault) exhibit mostly positive magnetic anomalies surrounding small tongues(?) of what may be
negatively magnetized flows. Low shields and cinder cones likewise show both positive and
negative signatures. Singular lava flow along west margin of mesa (south margin of Loma Creston
quad) is expressed by a moderate intensity negative anomaly (positive signatures at margin, most
likely are an "edge effect"; V .J. S. Grauch, oral comm., 1999). Note that portions of Santa Ana
Mesa within the Santa Ana Pueblo were not accessed during this preliminary mapping project. See
Smith and Kuhle (1998) for descriptions of basalts on northeast side of mesa; descriptions of
western lavas will be available from Personius (in prep. 1999). Lavas from the eastern side of the
mesa appear to be more evolved (plagiclase phenocryst bearing) than olivine-bearing and
aphanitic lavas of the western side. Marginal flows are approximately 4–6 m thick; shield and
cinder cone accumulations may be as much; as 90 m thick.

Nota Bene: Tta does not exist; it will be deleted . Don't know why the Ar date is too young. It is the
downfaulted equivalent of Tpba.

Tta — *Unnamed trachyandesite lava flow in valley east of Loma Canovas—* upper Miocene. Medium gray to dark gray, fine-grained, aphyric, trachyandesite lava. Blocky exposure east of Loma Canovas is relatively dense and nonvesicular (looks diabasic). This flow was apparently inset against medial Santa Fe units (Tsf-v and Tsf-sv) that underlie Loma Canovas. It yields an ^{40}Ar/^{39}Ar plateau age of 6.08± 0.24 Ma (LC-98-18, Table 1), which makes it distinctly younger than the Bearhead Rhyolite. This unnamed flow was initally correlated with the trachyandesite lava capping Loma Canovas, but it is significantly younger and geochemically distinct (Fig. 2) from the 7.0 Ma flow unit (Tpba). This unit appears to represent the thin distal margin (4-6 m thick) of a minor volume flow that originated a few km south of Bear Springs Peak (cf. Smith et.al. 1970).

Tbp — *Peralta Tuff member of Bearhead Rhyolite. Bedded rhyolitic lapilli tuffs, tuffs and minor tuff breccias—upper Miocene.* Mostly very light gray to white, glassy to lithoidal pumiceous bedded tuffs locally displaying graded bedding and thin sandy reworked beds. Sparse mafic to rhyolitic xenoliths locally observed in "sandy" matrix of tuff breccias. Bedded tuffs occur in three fault-controlled outcrop belts within northeast quadrant of quadrangle. Belt 1 occurs in footwall of Yelo fault (northeasternmost belt), belt 2 is mostly hydrothermally altered (jasperized) and occurs in footwall of the Oso fault zone; and belt 3 is located southeast of Mesita Cocida where preserved in the hanging wall of the Cocida fault zone. Abundant pumice lapilli contain sparse to rare (<1–3%) fine- to medium-grained (1–2 mm) euhedral phenocrysts of sanidine, biotite, plagioclase and rarely traces of quartz. Altered pumice in belt 2 is largely replaced by vuggy silica, thus producing the appearance of a lower phenocryst content (only traces of unaltered sanidine remain). A thin zone of unsilicified tuff at the stratigraphic top of belt 2 (south end) contains the typical assemblage of sparse sanidine, biotite and plagioclase. Belt 1 extends north of quadrangle toward a probable source at Cerrito Yelo (Smith et al., 1970); in this area the tuff overlies andesite lavas of the Paliza Canyon Fm. Gently dipping tuffs of belt 2 appear to lie in angular unconformity above moderately tilted rhyolite and andesite-rich epiclastic conglomerates that also contain thin beds of laminated rhyolitic ash and minor sandstones comprised of volcanic litharenites (unit Tsf(v)). Tuffs of belt 3 are preserved on an east-tilted ramp in the Cocida fault zone where they lie conformably above a thin eolian sandstone (Tsf(e)) and microporphyritic basaltic andesite lava (Tpba), downfaulted from the horst at Mesita Cocida. Here a moderate angular relationship is evident within middle Santa Fe beds (Tsf) below the basaltic andesite. To the west of Mesita Cocida, thin fluvially reworked rhyolitic pumice beds most likely equivalent to the Peralta Tuff (as yet undated), occur at multiple horizons within epiclastic sandstones and conglomerates assigned to the lower tuffaceous member of the Cochiti Formation (Tct). These tuffaceous sandstones and pumiceous ash beds lie conformably on a volcanic derived basal conglomerate (Tcl) that appears to be *inset* against the microporphyritic basaltic andesite (Tbpa) and underlying middle Santa Fe quartzo-feldspathic sandstones [Tsf(s)] on the NW flank of Mesita Cocida. Available ^{40}Ar/^{39}Ar dates on the Peralta Tuff range from ~7.0 to 6.75 Ma; also a Peralta-like tuff interbedded in the lower Cochiti Fm near Tent Rocks has been dated at 6.16±0.07 Ma (Smith and Kuhle, 1998). Peralta Tuff beds were apparently deposited across fault block topography and incised drainages (ie. an ancestral Borrego Canyon, west of Mesita Cocida) that were similar to modern topography (probably less total relief in late Miocene time). Peralta Tuff is also interbedded in ancestral Rio Grande deposits of the Sierra Ladrones Fm about 12 km east of exposures in Loma Creston quadrangle (see Smith and Kuhle, 1998). Ash beds, lavas, and piedmont-facies units interbedded with the Sierra Ladrones Fm are *normally* assigned to the upper Santa Fe Group. In northeast Loma Creston, the Peralta Tuff probably ranges from 30–60 m thick; coeval tuffs (in Tct) are locally absent on a horst block east of Bodega Butte, but they are also locally preserved in the graben south–southeast of Bodega Butte.

Tpba — *Basaltic andesite member of Paliza Canyon Formation—upper Miocene.* Dark to medium gray, microvesicular to dense, massive (blocky) to platy, very phenocryst poor (rare fine-grained plagioclase, 1–1.5 mm), microporphyritic (10–15% plagioclase microphenocrysts, 0.1–0.5 mm) basaltic andesite lava. Trace amounts of olivine in magmatic reaction relationship with the matrix have been observed in a sample from Loma Canovas. Flow unit is locally reddish brown to greenish gray where weakly altered on east side of Mesita Cocida. Platy flow foliated basal zone is

dense (nonvesicular) and usually 6–9 m thick. Blocky upper zone is usually microvesicular (dyktitaxitic) and fractures readily with a hammer blow. As mapped, locally includes 2–5 m of yellowish brown finely scoriaceous basal flow breccias (or possibly debris flows). Basal breccias are well exposed below isolated knobs south and west of Mesita Cocida. This distinctive microporphyritic flow caps a narrow horst block defined by the crestlines of Loma Canovas and Mesita Cocida. The east and west margins of this approximately 2 km wide south(?)-trending flow (elevations appear to decrease slightly to south) are locally down faulted to the east and west of these prominent landmarks. Map patterns of Smith et al. (1970) suggest that this flow originated near the north end of Loma Canovas (about 2.8 km south–southwest of Bear Springs Peak). The southern end of Mesita Cocida probably lies near the original terminus of this moderately viscous flow. The erosional gap between Loma Canovas and Mesita Cocida may have been initiated by southerly downwarping adjacent to the fault zone at the south end of Loma Canovas. This unit is presently undated; it is probably about 7 to 7.5 Ma, only slightly older than the Peralta Tuff. Assignment to Paliza Canyon Fm. is tentative. Average thickness approximately 30 to 36 m.

Tpd   *Dacite member of Paliza Canyon Formation—upper Miocene*. Medium dark gray to light gray, moderately phenocryst-rich (8-10%) to sparsely porphyritic (2–3%), plagioclase-hornblende-biotite dacite. Medium to coarse graind tabular phenocrysts of plagioclase (1–5 mm long) are 2–3 times more abundant than long slender hornblende prisms (3–6 mm long) and biotite is rare (<1%). Unit caps and forms most of the steep flanks below the elliptical north-trending ridge known as Loma Creston. Outcrops toward the north end of Loma Creston tend to be lighter in color and contain less phenocrysts, which suggests the flow may be compositionally zoned. Unit is strongly flow banded and platy fractured at exposures near base of the steep marginal slopes, which typically merge downslope into colluvium. Banded basal zone grades upward to weakly flow banded and massive dacite; tabular plagioclase and biotites are commonly aligned parallel to flow foliation; some foliation surfaces display a weak lineation defined by irregular (vuggy) vesicles and rarely by subparallel "needles" of hornblende. Foliated base of thick flow is moderately well exposed at south end of Loma Creston; basal flow breccias or tephras are not evident here. Outcrop patterns at Loma Creston suggest this viscous flat-topped stubby flow (cake-like torta) piled up over its vent (near topographic crest) and was later truncated (cut in half) by the east-down North Creston fault. Published K–Ar ages of dacite and "latite" porphyries in the Plaiza Canyon Fm. range from 7.4–10.1 Ma and yield an average of 9.0±0.9 Ma (n=5). This average is considered to be a reasonable estimate for the age of the Loma Creston flow. Maximum thickness is approximately 78 m.

Tpa   *Andesite member of Paliza Canyon Formation—upper Miocene.* Medium- to medium-light gray, greenish gray and light brownish gray andesite porphyry lava. Contains moderately abundant (12–15%) fine to medium grained (seriate) tabular plagioclase phenocrysts ranging from 0.3 to 2 mm long, rare (<1%) coarse-grained platioclase (5–7 mm), and sparse (2–3%) fine- to medium-grained pyroxene. Mostly massive to crudely flow banded, locally moderately vesicular and brecciated. Pyroxene is commonly altered to greenish chlorite and epidote, but plagioclase is usually fresh even where unit is intensely brecciated and silicified (BM 7008). Red jasperoid veinlets are moderately abundant and occur widely across the flow unit. This andesite flow appears to conformably overlie an olivine-pyroxene basalt flow (Tpb) and rhyolitic tuff breccias (Tcct); its southern margin appears to be onlapped and erosionally truncated by epiclastic conglomerates of the middle Santa Fe Group, Tsf(v). Unit caps west-facing dip slope at north end of "Oso Ridge". Probably represents a relatively small tongue of lava erupted from a minor vent about 2 km north of the quadrangle boundary. K–Ar ages of Paliza Canyon andesites sampled to the northwest and northeast of Loma Creston range from 8.7 to 10.6 Ma and yield an average of 9.3±1.5 Ma (n=5; Gardner and Goff, 1984). Map patterns of Smith et al., 1970, indicate that "Tpa" flow units *tend* to be older than associated dacitic flows (Tpd). Thus 9.3 Ma is tentatively accepted as a reasonable estimate for the age of this andesite flow unit. Maximum thickness is approximately 30 m.

Tpb/Tpbt   *Olivine–pyroxene basalt member of Paliza Canyon Formation and associated basaltic tephra (Tpbt)—upper Miocene.* Thin flow unit, usually 12–18 m thick, of medium to medium-dark gray, massive to vesicular, sparsely to moderately porphyritic, olivine–pyroxene (augite?) basalt; locally

associated with porphyritic basaltic tephra at a vent north of Mesita Cocida (Tpbt). Widespread unit in southwestern Jemez Mountains as mapped by Smith et al., 1970. Probably represents multiple flow, multiple vent, late Miocene eruptive unit similar to the Pliocene basalts capping Santa Ana Mesa. Phenocrysts are fine to medium grained (0.5–3 mm) and comprise 3 to 8% of the dense lavas. Olivine is typically the dominant phenocryst (3–6%) and black (augitic?) pyroxene is sparse to rare (<0.5–2%). Fine-grained plagioclase is a minor component (<1%) of some moderately phenocryst-rich lavas (e.g. south of Mesita Cocida). Olivine is commonly altered to reddish brown iddingsite in proximity to silicified fault zones. Phenocryst poor to aphyric basal zones have been locally observed at "Arenoso ridge". Traces of xenocrystic(?) quartz are locally present near the quadrangle boundary on southeast Borrego Mesa.

Discontinuous faulted, tilted and eroded outcrops of this unit occur in two distinct belts within the quadrangle. Along the west margin of the Loma Creston quadrangle this unit locally caps mesas and tilted blocks. In the north-central portion of the quadrangle this unit is only exposed on structurally high blocks comprising the Loma Canovas horst and the west-tilted block at "Oso Ridge". In both belts the olivine–pyroxene lavas locally lie directly on Canovas Canyon rhyolite lavas (Tcc) or cogenetic tuffs (Tcct) near the north margin of the quadrangle. Further south they overlie quartzo–feldspathic sandstones and minor conglomeratic sandstones of the lower middle Santa Fe Group [Tsf(c)]. The scoriaceous and finely vesicular bedded and blocky basaltic tephra (Tpbt) north of Mesita Cocida is moderately to intensely silicified and altered. Moderately abundant FeMg phenocrysts (olivine and pyroxene) are locally altered to hematitic clays, which partly fill euhedral pockets (1–3 mm) in the grayish red tephra. Milky fine-grained altered plagioclase also appears to be a minor phenocrystic component (~1%). Chalcedonic and jasperoidal silica partially to completely fill vesicles. Partially altered moderately porphyritic lavas texturally similar to the tephra locally overlie the bedded unit north of the inferred vent. The moderately porphyritic propylitically altered (calcitic) lava well exposed in the floor of Borrego Canyon (south of Mesita Cocida) is relatively pyroxene rich (2–3%, 1–3 mm); it is also very similar to the tephra unit 2 km to the north. Olivine-pyroxene lavas exposed on "Oso Ridge" contain smaller sparse phenocrysts of olivine and rare pyroxene suggesting that it is not the same flow as present north and south of Mesita Cocida. The sparsely porphyritic flow at Oso Ridge appears to wedge out southward against rhyolitic tuff breccias (Tcct) adjacent to a local lava dome (Tcc?). Although the wedge-out relationship is masked by colluvium, the olivine-pyroxene lava is clearly absent on the southwest side of the dome (300 m south of BM 7008). Olivine-pyroxene lavas are notably absent at Loma Creston where hornblende dacite lava (Tpd) and quartzo–feldspathic conglomeratic sandstones [Tsf(c)] appear to occupy the same stratigraphic position (60–90 m above Tcb). If the main source area for the western olivine–pyroxene lavas was on Borrego Mesa, then southerly flow of these lavas many have been blocked by local topographic highs associated with rhyolite lava domes at and adjacent to Borrego Dome (cf. Smith et al., 1970). "Tpb" lavas may also be mostly absent east of Loma Creston (in down-faulted basin), but a similar "flow lobe" seems to reappear near the base of Mesita Cocida. Leudke and Smith (1978) published a K–Ar whole rock data of 8.8±0.3 Ma on a sample of "Tpb" collected north of Borrego Dome. Gardner and Goff (1984) report two significantly different analytical results of 11.5±08 and 14.9±2.7 Ma for a basalt stratigraphically equivalent to Tpb at Paliza Canyon. Using *only* the two relatively precise determinations yields an average age of 10.1±0.6 Ma; this appears to be a reasonable approximation compared to average K–Ar ages for adjacent strata. Thickness ranges from 0–18 m.

Tcc/Tcct   *Canovas Canyon Rhyolite; rhyolitic lavas and lava domes (Tcc), with associated bedded tuffs (Tcct)—upper Miocene.* Mostly light gray to pinkish gray, flow-banded rhyolite lavas associated with cogenetic bedded pumiceous tuffs and lithic-rich tuff breccias. Forms disjointed isolated exposures along northern quarter of quadrangle; these isolated outcrop areas probably represent 4 or 5 different eruptive centers. Canovas Canyon lavas and tephras lie stratigraphically below basaltic and intermediate lavas of the Paliza Canyon Formation (Tpb, Tpa and Tpd). Two end-member types of rhyolite are recognized: 1) a phenocryst-poor to very phenocryst-poor rhyolite with rare (0.1–~1%) fine grained (0.5–1.5 mm) phenocrysts of biotite and occasional traces of fine (<0.5 mm) sanidine, and 2) a sparsely porphyritic rhyolite with with 2–4% phenocrysts of fine to medium grained (0.5–2 mm) sanidine, plagioclase and biotite, with traces of fine grained (<0.5

mm) quartz. "Type 1" rhyolite is the most common;"type 2" only occurs as rhyolitic blocks in a heterolithic bedded tuff breccia unit (Tcct) at the eastern toe of "Oso Ridge", immediately south of the quadrangle boundary. Both types of rhyolite occur as clasts in this sandy heterolithic tuff breccia, which suggests these end members may be locally associated with a compositionally zoned eruptive center. The sandy heterolithic breccias also contain as much as 50% quartzo–feldspathic grains and granules presumably derived from underlying Santa Fe beds (probably Tzu equivalent). Sandwave crossbedding in the heterolithic tuff unit indicates a hydromagmatic surge origin and a southerly transport direction away from a "type 2" lava dome located about 1.5 km north of the quadrangle boundary at "Oso Ridge" (Smith et al., 1970). Borrego Dome, located about 1.5 km north of the quadrangle boundary, is also apparently a "type 2" lava dome (cf. Smith et al., 1970). A "type 1" 90–120 m thick lava flow at southeast Borrego Mesa is strongly flow banded and locally shows vitric zones along its southern margin. This flow locally overlies "basalt of Chamisa Mesa" and is capped by an onlapping tongue of Paliza Canyon basalt (Tpb). A small portion of the large exposure of cliff-forming rhyolites south of Borrego dome (Bear Springs Peak quadrangle) extends into the Loma Creston quadrangle at the northernmost part of Borrego Canyon. Very fresh black biotite phenocrysts are conspicuous (but rare, <1%) within the spherulitic vitrophyre that marks the south margin of this flow (east side of canyon). The flows at Borrego Canyon and southeast Borrego Mesa were probably erupted from a flow/dome complex at and adjacent to Borrego Dome. Faulted and eroded remnants of a "type 1" lava dome and proximal tuff breccia are locally well exposed on the south flank of Loma Creston. Here the glassy to lithoidal pumiceous tuff breccias can be observed to locally cut across the underlying basalt (Tcb) where they also underlie the brecciated glassy margin of the flow. These relationships locally define the northwest wall of the initial explosion crater later filled with tephra and lava. Bedded lapilli tuffs west of the vent contain moderately abundant small to large xenoliths of diabasic basalt (rarely >1 m) and quartzo–feldspathic granules. Bedded tuffs locally exposed about 1.5 km southwest and south of Loma Creston also contain sparse small xenoliths of diabasic basalt (<2 cm).

Correlation of the "type 1" rhyolitic lava dome at "Oso Ridge" (east of BM 7008) has been controversial. Smith et al. (1970) originally mapped this narrow outcrop of very phenocryst poor rhyolite as a Canovas Canyon lava dome (or shallow intrusion) truncated by a large fault on its east margin and depositionally overlain by Canovas Canyon tuffs and mafic lavas (Tpb) on its western flank. Kelly (1977) later reinterpreted this narrow outcrop of nearly aphyric rhyolite and adjacent tuffs as a large fault bounded sliver of Bearhead Peak rhyolite and Peralta Tuff downfaulted to the east with Canovas Canyon and Paliza Canyon Formations forming the footwall on the west. This "type 1" lava dome is clearly truncated on its eastern margin; a highly silicified fault breccia, as much as 2 m thick, which locally forms a cliff at this boundary. The light gray to pinkish gray flow-banded rhyolite west of this fault is strongly altered and cut by numerous small silica veinlets. Fine grained rare biotite phenocrysts (<1 mm, <0.1%) are completely replaced by hexagonal pseudomorphs of hematitic clay. Two lines of field observation argue against the presence of large fault located west of the flow-banded rhyolite outcrop (Kelley's interpretation): 1) bedded tuffs about 600 m NNW of the dome crest locally contain a thin (2–3 m) very well indurated ledge-forming quartzo–feldspathic sandstone, which appears to be essentially continuous across the inferred western fault, and 2) massive beds of lithic-rich tuff breccia that occur immediately west and 400 m NW of the dome crest contain abundant xenoliths of reddish brown very crystal-poor rhyolite with traces of unaltered phenocrystic biotite. The latter outcrop of lithologically equivalent tuff breccia lies west of the fault inferred by Kelley and about 12 m stratigraphically below Paliza Canyon basalt (Tpb). These observations indicate the faulted dome (east side only) is most likely correlative with the Canovas Canyon Rhyolite, as originally mapped by Smith et al. (1970).

Tcb   *"Basalt of Chamisa Mesa" of Smith et al., 1970—upper Miocene.* Thin flow unit, typically about 12 m thick, of grayish black to dark gray, vesicular to massive, diabasic basalt with very sparse (0.5–2%) fine-grained (<1 mm) phenocrysts of reddish brown olivine, and occasionally a trace of yellow-brown bronzy pyroxene. A hypothetical source area on Borrego Mesa (7 km northwest of Loma Creston) would be consistent with its mapped distribution (Smith et al., 1970) and the observed ESE paleocurrents (i.e. paleoslope) of the underlying upper Zia Fomation sandstones.

This flow unit appears to terminate within Santa Fe Group sandstones about 1.7 km south of Bodega Butte; suggesting the Arenoso ridge outcrops also lie near its southern terminus. Small isolated outcrops of diabasic basalt are locally exposed in arroyo walls approximately 0.5 km southwest of the southern end of Loma Creston. These outliers are comprised of dense nonvesicular basalt that locally display blocky jointing and spheroidal weathering. The isolated diabasic outcrops, surrounded by Quaternary alluvium appear to lie about 30 m stratigraphically below "Tcb" outcrops on the south end of Loma Creston. These exposures are tentatively interpreted as "basalt of Chamisa Mesa" equivalents locally downfaulted to the west relative to outcrops at Loma Creston. Alternatively the isolated diabase outcrops might represent a small sill within Tzu, but this relationship is not known elsewhere. Tcb is apparently absent near Loma Canovas, 3 km north of quadrangle boundary (Smith et al., 1970). Only one published K–Ar date is available for this unit, a single whole-rock analysis yielded an age of 10.4±0.5 Ma (Leudke and Smith, 1978). Gardner and others (1986) recommended abandoning the "Basalt of Chamisa Mesa" as a stratigraphic unit. However, in the Loma Creston quadrangle it appears to be a distinctive mappable unit, consistent with the description of Smith et al., 1970. Thickness 0–18 m.

Tertiary Sedimentary Strata of the Santa Fe Group

The Santa Fe Group comprises Neogene and lower Quaternary sedimentary fill of extensional fault block basins that collectively represent a north-trending regional zone of subsidence between the Colorado Plateau and Great Plains provinces. This zone of Neogene subsidence is generally known as the Rio Grande rift. Flanking uplifts and peripheral basins (e.g. Estancia Basin) are also part of the Rio Grande rift system. The Santa Fe Group in the Loma Creston quadrangle is divided into three major units representing upper, middle and lower Santa Fe Group deposits. Respectively, these are: 1) the volcanic-rich gravels, sands and reworked ash beds of the Cochiti Formation (Tc–, redefined here), 2) unnamed middle Santa Fe (Tsf–) conglomeratic sandstones and quartzo–feldspathic sandstones representing three major lithofacies of two depositional systems and 3) quartzo–feldspathic fluvial sandstones of the upper Zia Formation (Tzu). Conglomeratic sandstones and sandstones of the middle Santa Fe Group are most likely correlative with the upper Miocene Arroyo Ojito Formation of Connell et al. (in press); however, detailed correlation with Arroyo Ojito members recently defined by Connell et al. seems premature. A geomorphically defined upper Pliocene gravel unit, the "Gravel of Lookout Park" (Tglp) of Smith and Kuhle (1998) is compositionally similar to the upper Cochiti Formation. In the Loma Creston quadrangle "Tglp" locally appears to form the constructional top of the Cochiti Formation; thus it is tentatively given member status in the Cochiti Formation.

Tglp (o)(y)   *Gravel of Lookout Park, member of Cochiti Formation(?); locally subdivided into older (o) and younger (y) gravel beds where associated surfaces show inset relationships—upper Pliocene.* Stratified cobble to boulder gravel almost entirely derived from upper Miocene volcanic strata. Relative proportions of basalt, basaltic andesite, andesite, dacite and rhyolite clasts vary with the bedrock lithology of the local provenance. High gravels east of Bodega Butte contain relatively abundant diabasic and olivine basalt with minor dacite and rhyolite clasts. In contrast gravels southeast of Mesita Cocida contain abundant basaltic andesite, andesite, and rhyolite with only minor basalt. Gravels about 1 km east of Bodega Butte contain rare clasts of light gray silicified quartzo–feldspathic sandstone (probably Tzu); likewise younger gravels [Tglp(y)] northeast of "the Narrows" also contain rare clasts of red (jasperized) quartzo–feldspathic sandstone [Tsf(s)]. These rare nonvolcanic components reflect local erosional unconformities at the base of the gravel beds downstream from where they cut into older Santa Fe strata. Minor nonvolcanic detritus of similar origin is also locally recognized in the upper Cochiti Formation northeast of Santa Ana Mesa (Smith and Kuhle, 1998). As mapped here the Gravel of Lookout Park is both conformable and locally disconformable on the upper Cochiti Formation. "Tglp" gravels are generally recognized to underlie gently sloping high level geomorphic surfaces that typically descend in a southeasterly direction. Southwesterly slopes are also recognized on the east side of upper Borrego Canyon (near Loma Canovas). Numerous high-angle normal faults locally displace these upper Pliocene surfaces in the area southeast of Bodega Butte and north of Santa Ana Mesa. Exact correlation of these surfaces remains problematical because of these structural complexities. The high gravel about 2 km east of Bodega Butte (at BM 6593) is readily projected to the top of the

Cochiti capped hill 4 km to the north (BM 6742) by assuming a 1° SSE slope. Thus the high gravels east of Bodega Butte are reasonably interpreted as the constructional top of the Cochiti Formation (locally conformable on Cochiti).

Lookout Park gravels also locally display inset relationships on and near the footwall of the Cocido–Oso fault zone. Along the west side of Santa Ana Mesa (2 km south of Borrego Canyon Road) the Ranura fault appears to be locally concealed (truncated) by a younger inset high-level gravel bed [Tglp(y)]; further east this ledge-forming gravel appears to extend under a narrow salient of upper Pliocene lava (Tb) on the footwall of the Cocida–Oso fault zone. Younger (y) and older (o) Lookout Park gravels are also recognized east of the Cocida–Oso fault zone on the north side of Borrego Canyon (north of "the Narrows"). The older gravel bed [Tglp(o)] preserved about 1.5 km north of Borrego Canyon projects approximately 78 m above the modern drainage; whereas the younger gravel [Tglp(y)] immediately north and south of the canyon projects about 60 m above the canyon floor. Small remnants of younger(?) Lookout Park gravel are present in the wind gap about 2 km SSE of Mesita Codida. If this correlation is correct, then Borrego Canyon probably flowed through this gap at about 2.5 Ma. South of Borrego Canyon the younger gravels immediately overlie bedded basaltic tuffs (Tbnt) of upper Pliocene age (~2.5 Ma). In lower Borrego Canyon, approximately 12 km to the ESE of "the Narrows", Lookout Park gravels again overlie upper Pliocene basaltic tephra (Smith and Kuhle, 1998). Both units are interpreted as being slightly inset relative to mesa capping basalt (Tb2) on the south side of lower Borrego Canyon (Smith and Kuhle, 1998). Notably the Lookout Park gravels in lower Borrego Canyon project only 30 m above the modern drainage. Further east the Gravel of Lookout Park merges with (is conformable with) the upper Cochiti Formation. These relationships are consistent with an interpretation of syndepositional uplift of the Cocida–Oso footwall block contemporaneous with subsidence and aggradation in the Santo Domingo basin. The Gravel of Lookout Park, as mapped in the Loma Creston quadrangle, is both slightly older than and slightly younger than the upper Pliocene basalts (ca. 2.5 Ma) that cap Santa Ana Mesa. On structurally high blocks it is about 12–15 m thick; on subsiding blocks near the Rio Grande, coarse equivalents in the upper Cochiti Formation may be considerably thicker and younger. A recent hydrologic test well about 7 km northwest of Cochiti Dam, indicates as much as 39 m of coarse Lookout Park-type gravel locally underlies lower Bandelier Tuff on the downthrown side of the Pajarito fault (Chamberlin and others, 1999). Eolian sands (mostly unmapped) and complex polygenetic calcic soils (stage IV–IV) locally overlie the Lookout Park gravels in the Loma Creston quadrangle.

Tcl   *Cochiti Formation of upper Santa Fe Group—upper Miocene to upper Pliocene.* As mapped and
Tct   redefined here, the Cochiti Formation is locally complete and well exposed on the isolated hill
Tcu   about halfway between Loma Creston and Mesita Cocida (BM 6742). A key area on the northwest
Tcx   flank of this hill shows most of the important aspects of the formation. Here the basal volcanic-
Tc   rich cobble to boulder conglomerate (Tcl) is about 2–3 m thick and disconformably overlies both
Tcls   quartzo–feldspathic sandstones [Tsf(s)] and granite-bearing conglomeratic sandstones [Tsf(g)].
Tcls   The latter is locally preserved on the hangingwall of a small down-to-the-west fault
       (approximately 5 m displacement), which appears to be buried by the basal volcanic-rich
       conglomerate (Tcl). This cliff-capping (rim forming) basal conglomerate is well exposed across 2–
       3 km of the upper Borrego Canyon area. Because of its minor thickness and rim-forming nature it
       is shown only as a single line on the geologic map (Tcl). Clast lithologies and imbrications in the
       basal conglomerate indicate southeasterly paleocurrent directions. Sparse to rare clasts of granitic
       pebbles and small cobbles recycled from the underlying granitic conglomerate [Tsf(g)] are locally
       present to the south and southeast of these downfaulted outcrops. However, about 0.8 to 1.7 km
       northeast of BM 6742 the basal Cochiti conglomerate is completely lacking in granitic detritus. A
       6 cm thick bed of well indurated glassy water laid rhyolitic lapilli tuff lies about 1 m above the
       basal conglomerate at the key area and in several other locations as shown on the map. As yet
       undated, these glassy lapill tuffs appear to be lithologically similar to sparsely porphyritic to
       nearly aphyric Peralta Tuff beds that contain <2% phenocrysts of sanidine, quartz and rare biotite.
       Similar glassy pumice beds also occur about 15 and 42 m above the basal conglomerate. These
       younger pumice beds are intercalated with poor to moderately indurated light brownish gray sands
       or sandstones and light to medium gray volcanic-rich (andesite-dacite-rhyolite and basalt-bearing)
       gravels, gravelly sands, and conglomeratic sandstones. The total thickness of interbedded ashes,

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gravels and conglomeratic sandstones is about 57 m; this interval locally represents the lower tuffaceous member (Tct) of the Cochiti Formation as redefined here. The lower tuffaceous member (or Peralta Tuff member) of the Cochiti *grades* upward into poor to moderately indurated light brown conglomeratic sandstones and intercalated volcanic-rich gravels generally in lacking the pumice beds found below. Where well exposed these upper conglomeratic sandstones and gravels (Tcu) commonly contain sparse to rare small pebbles of black obsidian that are partially to almost completely replaced by light gray flaky perlite. Good exposures of obsidian-bearing conglomeratic sandstones occur west of BM 6742; here pebbles about 9 m below the hill crest consist of about 20% (2 parts in 10) perlite and those about 27 m below the crest consist of about 50% (5 parts in 10) perlite. Similar observations in roadcuts south of Bodega Butte indicate that progressive in-situ replacement of obsidian pebbles by perlite can be used as a crude clock to approximate the relative age and stratigraphic position of some well exposed upper Cochiti beds. Perlitic obsidians are quite fragile and good exposures relatively rare, so these delicate indicators are preferably photographed rather than manhandled. The basal conglomerate and lower conglomerates in the tuffaceous member apparently lack the presence of perlitic obsidian. The hill crest at the key area is capped by 2–3 m of volcanic-rich boulder-cobble gravel similar to remnants of Lookout Park gravel found 1–2 km east of Bodega Butte, where the Cochiti is as much as 60 m thick. On structurally high blocks east of Bodega Butte the total thickness of the Cochiti ranges from 12–30 m. Total thickness of the Cochiti Formation at the key area is approximately 102 m. Field observations further to the northeast and southwest of the key area indicate this *unconformity bound unit* is best explained as remnants of the fill of an ancestral Borrego Canyon, which was downcut between resistant lava capped highlands at Loma Creston and Mesita Cocida approximately 7 million years ago. This paleocanyon backfilled nearly to its rim by about 2.5 Ma. About 1 km southwest of the key area (BM 6742) poorly indurated pumice beds and light brown sands (Tct) appear to lie directly on a thick interval (>30 m) of relatively granite-rich conglomeratic sandstones ([Tsf(g)] of the middle Santa Fe Group. The basal volcanic-rich conglomerate (Tcl) is missing here. Similar stratigraphic relationships appear to define the base of the Cochiti Formation in the shallow graben 1.5 km east of Bodega Butte. The Cochiti Formation ranges from approximately 12 to 30 m in thickness (including "Tglp"). The Cochiti may thicken abruptly to several hundred meters on the downthrown eastern side of the Cocida–Oso fault zone, which generally forms the west margin of the Santo Domingo Basin.

A rare example of ancient colluvial deposits within the Cochiti Formation (Tcx) is found on a small knob 1.3 km WSW of BM 6472. Volcanic-rich conglomerates on the east side of this knob clearly overlie about 18 m of lower Cochiti Formation (Tct). At the same elevation on the west side of the knob, the same conglomerate is mantled by 4 or 5 large boulders (0.6–1 m long) of granite-rich cobble conglomerate that are distinctly out of place, at least 18–21 m above their potential source bed [Tsf(g)]. These erratic blocks within the Cochiti Formation are interpreted as remnants of an ancient colluvial deposit derived from the footwall of the north Creston fault zone located 100–200 m west of this knob.

The poorly indurated lower tuffaceous member of the Cochiti Formation (Tct) is commonly masked by colluvial gravels shed from the upper Cochiti beds (Tcu) and the Gravel of Lookout Park (Tglp). Where this appears to be the case, the gravel mantled slopes are generally mapped as Cochiti Formation undivided (Tc). The upper Cochiti (Tcu equivalent) located east of the Cocida–Oso fault is mostly poorly exposed and thus generally mapped as Tc, except where well exposed.

Approximately 12–30 m of moderate to slightly pumiceous conglomeratic sandstones that locally overlie the Peralta Tuff about 1–1.5 km south and southeast of Mesita Cocida are assigned here to the lower Cochiti Formation (Tcls). Where fluvially reworked pumice is moderately abundant, these sandstones can be mistaken for Peralta Tuff. Basal contact with Peralta Tuff is slightly erosional but otherwise looks conformable.

Our redefinition of the Cochiti Formation is generally consistent with observations of Smith and Kuhle (1998). They recognize that the Cochiti Formation locally contains nonvolcanic detritus recycled from older Santa Fe beds. They also demonstrated that Peralta Tuff beds are locally interbedded with quartzite-rich sands and gravels of the ancestral Rio Grande assigned to the Sierra Ladrones Formation. We suggest that entrenchment of ancestral Borrego Canyon just prior to eruption of the Peralta Tuff is a remote signal of the initial integration of the ancestral Rio

Grande into the northern Albuquerque Basin. In this sense, the Cochiti Formation as mapped here represents all of the local piedmont facies that is laterally equivalent to the Sierra Ladrones Formation, which essentially defines the upper Santa Fe Group in the northern Albuquerque Basin.

As defined here the basal Cochiti Formation is slightly older than the Peralta Tuff, which has a maximum age of about 6.7 to 7.0 Ma. Upper Cochiti beds, locally mapped as "Tglp" are slightly older and younger than 2.5 Ma basalts that cap Santa Ana Mesa. Maximum thickness of the Cochiti Formation east of the Cocida–Oso fault is probably 300–500 m. This redefinition of the Cochiti Formation has moved the previously defined gradational basal contact with Peralta Tuffs (Smith and Lavine, 1996) downward about 60 m to a sharp disconformity immediately overlain by Peralta Tuff.

Tsf(e)	*Unnamed eolian sandstone—upper Miocene*. This fine grained reddish brown quartzo–feldspathic sandstone, about 3–6 m thick, is locally well exposed southeast of Mesita Cocida. It appears to be conformably sandwiched between basaltic andesite lava (Tpba) and the overlying Peralta Tuff (Tbp). The massive sandstone is interpreted as a thin eolian deposit because it displays a uniform fine grain size and a highly irregular (jagged) basal contact with the subjacent mafic lava.

Tsf
Tsf(v)
Tsf(g)
Tsf(sg)
Tsf(s)
Tsf(sv)
Tsf(vd)

Unnamed sandstones, conglomeratic sandstones, conglomerates and minor mudstones of the Middle Santa Fe Group (mostly equivalent to Arroyo Ojito Formation of Connell et al. in press)— upper Miocene. Composite interval of sediment about 120 m thick comprised by four major lithofacies: 1) volcanic-rich conglomeratic alluvial apron deposits derived from growing (and/or eroding) Paliza Canyon volcanoes of mostly andesitic to dacitic composition [Tsf(v)], 2) granite and Pedernal chert-bearing fluvial fan conglomeratic sandstones [Tsf(g) and Tsf(sg)] and 3) quartzo–feldspathic sandstones and minor mudstones compositionally and laterally equivalent to facies 2 [Tsf(s)] and 4) quartzo–feldspathic sandstones (facies 3) strongly intercalated with volcanic-rich conglomeratic sandstones mostly eroded from volcanic highlands [Tsf(sv)]. Facies 2, 3, and 4 are volumetrically dominant. Facies 2 most likely represents fluvial fan deposits of an easterly flowing "ancestral Rio Guadalupe" which headed on the eastern flank of the Nacimiento Mountains (where there was little or no volcanism in upper Miocene time). Facies 3 probably represents a lower energy fluvial plain between the fluvial fan (facies 2) and alluvial fans from eroding volcanic highlands (facies 4). "Tsf" is stratigraphically bound by 6.7–7.0 Ma Peralta Tuff ash beds (Tbp and Tct) at the top and by ~9.5–10 Ma sparsely porphyritic basalts of the lower Paliza Canyon Formation (Tpd) at the base (in most areas). "Tsf" is only preserved east of the Creston fault zone (north and south segments). Sparse paleocurrent observations and cursory observation of clast size distributions suggest that the fluvial axis of lithofacies 2 entered the Creston hanging wall basin about halfway between Bodega Butte and Loma Creston. Boundaries between the major lithofacies are usually not readily mappable; In some areas they appear to intertongue intimately over significant stratigraphic intervals (>30 m). Moderately distinctive subhorizontal boundaries (short dashed contacts) have locally been mapped where one facies has prograded over another; however, numerous small faults and areas of poor exposure limit the consistent mappability of such boundaries. One strongly gradational (near vertical) boundary between facies 3, Tsf(s), and interleaved facies 1 and 3, Tsf(sv), has locally been mapped east of Loma Creston.

Tsf(v)

A good reference section for type 1 lithofacies, Tsf(v), is locally well exposed on the south end of Loma Creston where approximately 45 m of volcanic derived boulder–cobble conglomerates immediately overlie Paliza Canyon basalt (Tpb). These andesite–dacite–rhyolite rich gravels, which predate the Peralta Tuff, look remarkably similar to post-Peralta gravels in the lower and upper Cochiti Formation. Other reference outcrops include intensely silicified (jasperized) rhyolitic to andesitic conglomerates with minor tuffaceous sandstones and volcanic litharenites that are well exposed along the crest of "Oso Ridge". Similar jasperized volcanic conglomerates and conglomeratic sandstones occur on the southern flank of Mesita Cocida. Alteration patterns here reflect proximity to faults *and* initial variations in lateral permeability. Tsf(v) at Mesita Cocida appears to grade southward into Tsf(sv) and Tsf(s), consisting mostly of quartzo–feldspathic sandstones with minor volcanic and granitic components. Another minor local variant

of the volcanic lithofacies consists of about 9 m of dacitic pumiceous sandstones [Tsf(vd)] that conformably overlie "Tpb" south of Mesita Cocida. These moderately phenocryst-rich pumiceous sandstones with relatively abundant biotite are probably coeval with the onset of upper Paliza Canyon intermediate volcanism.

Tsf(g)   A good reference area for cobble- to boulder-bearing conglomeratic sandstones [Tsf(g)] in the uppermost 30 m of lithofacies 2 [Tsf(sg)] is found in the hanging wall of the Creston fault about 2.3 km NNE of Bodega Butte. Cobbles and small boulders of pinkish granite, variegated (black and white) Pedernal chert and greenish gray silty sandstones (Mesozoic?) can locally be observed here in poor to moderately good exposure on the south and north sides of the canyon. Although the contact is not well exposed, these coarse conglomeratic beds appear to be unconformably overlain (4° angular difference) by subhorizontal pumiceous sandstones and gravels of the lower Cochiti Formation (Tct and Tcu). Cobbles and boulders form a minor fraction (<5%) of the conglomeratic beds, and these units appear to fine fairly rapidly eastward and down section into more common pebbly sandstones

Tsf(sg)   A good reference section for granite and Pedernal chert-bearing pebbly conglomeratic sandstones with interbedded quartzo–feldspathic sandstones, Tsf(sg), is located on the isolated knob about 2 km south of Mesita Cocida. These pale red conglomeratic sandstones about 30 m thick locally contrast with the underlying light gray quartzo–feldspathic sandstones and minor moderately volcanic-rich conglomeratic sandstones [Tsf(sv)]. However, the underlying gray beds also contain rare granules of granite and chert, which implies they are essentially a finer-grained variant of the same system.

Tsf(s)   Excellent exposures of mostly planar bedded quartzo–feldspathic sandstones and mudstones of the type 3 lithofacies Tsf(s) are found in cliffs capped by Cochiti conglomerate (Tcl) about 1 km west of Mesita Cocida. These sandstones occupy the same stratigraphic interval as the granite-bearing conglomeratic sandstones, Tsf(g) observed 2–5 km further south. About 60 m of light brownish gray sandstone and minor thin beds of reddish brown mudstone are present in the cliffs west of Mesita Cocida. Sandstones are moderately indurated and locally contain minor granular to pebbly beds with sparse volcanic and cherty clasts. This unit locally coarsens down section. The Tsf(s) lithofacies extends eastward under Mesita Cocida. A red, locally silicified, cliff of this facies, which underlies the basaltic andesite (southwest side of Mesita Cocida), gives "cooked mesa" its name. About 200 m further east this poorly indurated quartzo–feldspathic sand facies is also locally exposed in a steep ravine.

Tsf(sv)   A good reference section of intimately interbedded lithofacies 1 and lithofacies 3 is well exposed in a narrow canyon about 2.4 km southwest of Loma Canovas. The north wall of the canyon shows about 60 m of rhythmically interbedded medium gray volcanic-rich conglomerates (1–2 m thick; mostly andesite and dacite) and light brown (buff) quartzo–feldspathic sandstones. The section coarsens upward from about 10% conglomerate to 30% conglomerate.

Tsf(c)   *Unnamed quartzo–feldspathic sandstones and minor conglomeratic sandstones of the lower middle Santa Fe Group—upper Miocene*. Consists predominantly of poorly to moderately well indurated, planar bedded, light gray to pale yellowish brown, quartzo–feldspathic sandstones. "Tsf(c)" is stratigraphically bound by the overlying porphyritic basalt member of the Paliza Canyon Formation and the underlying "basalt of Chamisa Mesa" of Smith et al., 1970. This map unit is about 60–72 m thick and partly coeval with the Canovas Canyon Rhyolite, which is the source of its preliminary designation (c). The poorly dated bracketing lavas are about 9.5 to 10.5 million years old. This unit is locally well exposed on Bodega Butte, on the south end of "Arenoso ridge" and in the large roadcut about 3.8 km south of Bodega Butte (footwall of Santa Ana fault zone). Planar-bedded sandstones and mudstones of the medial "Tsf(c)" are exposed in the Santa Ana footwall block. East of this minor silicified fault (<18 m displacement), uppermost Tsf(c) locally contains a 1–2 m thick cobbly conglomeratic sandstone. The sandy matrix of this volcanic-rich conglomerate is quartzo–feldspathic. The subrounded clasts are mostly intermediate porphyries that contain sparse to moderately abundant phenocrystic plagioclase. Rhyolitic clasts

are rare, some weakly foliated rhyolites contain moderately abundant (2–3%) phenocrysts of sanidine and biotite. Most of these volcanic clasts were probably recycled from the Abiquiu Formation; this bed clearly predates intermediate (andesitic) volcanism in the Jemez Mountains. A stratigraphically equivalent conglomerate bed about 1 km to the south also contains granitic detritus, which is consistent with a source to the northwest. These fluvial beds may represent a relatively low gradient precursor to the ancestral Rio Guadalupe system seen in the upper middle Santa Fe Group [Tsf(sg)]. Bedded rhyolitic tuffs and pumiceous sandstones associated with Canovas Canyon eruptive centers (Tcct) occur in the lower part of this unit near Loma Creston. Light gray rhyolitic pebbles, often altered to soft clay, are a rare but widely observed component in these fluvial sandstones. Rare phenocrysts of biotite (only) and the post-depositional clay alteration suggest these were originally vitric clasts of Canovas Canyon rhyolite. Where the underlying Tcb is absent, these sandstones will probably be mapped with the upper Zia Formation.

Tzu   *Upper member of the Zia Formation—middle to upper Miocene*. Dominantly crossbedded quartzo–feldspathic sandstone with minor conglomeratic sandstone, siltstone and mudstone. Underlies upper Miocene "Basalt of Chamisa Mesa". Maximum *exposed* thickness in area 3 km northwest of Bodega Butte is about 150 m. The base of Tzu is apparently not exposed in the Loma Creston quadrangle. Poor to moderately indurated sandstones below the mesa capping basalt are usually not well exposed. The upper 90 m of this unit is, however, locally well exposed in canyon walls about 1–3 km south of Loma Creston. Here this pre-Canovas Canyon unit is well cemented by hydrothermal chalcedony on the south side of a local Canovas Canyon vent (i.e. intrusion). A narrow canyon near the south end of this silicified outcrop (500 m south of windmill) locally displays large crossbeds as much as 10 m high and megaripples with wavelengths greater than 1 m. Some of the well sorted crossbedded sandstones contain coarse grained to granular laminations indicative of a fluvial environment. This unit also contains minor beds of pebbly conglomeratic sandstone near its top at other localities (at south end of Arenoso ridge and 0.6 km southwest of rhyolite vent at Loma Creston). Crossbed orientations indicate easterly paleoflow for this large meandering river system, which may also be a precursor to the ancestral Rio Guadalupe system. Maximum thickness west of the quadrangle is probably less than 300 m.

Tsf   *Santa Fe Group undifferentiated—middle to upper Miocene*. Includes faulted outcrops east of the Santa Ana fault zone in southwest corner of quadrangle. Access has yet to be made in this area. Exposures in hanging wall of Santa Ana fault zone probably include equivalents of Tsf(c) and Tsf(v) or Tsf(g). The base of the Cochiti Formation is not well defined here; it is assumed to be about 90–120 m thick here. Some map relationships have been projected northward from a "Preliminary Geologic Map of Part of the Santa Ana Pueblo Quadrangle, Sandoval County, New Mexico" by Stephen F. Personius, U.S. Geological Survey.

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