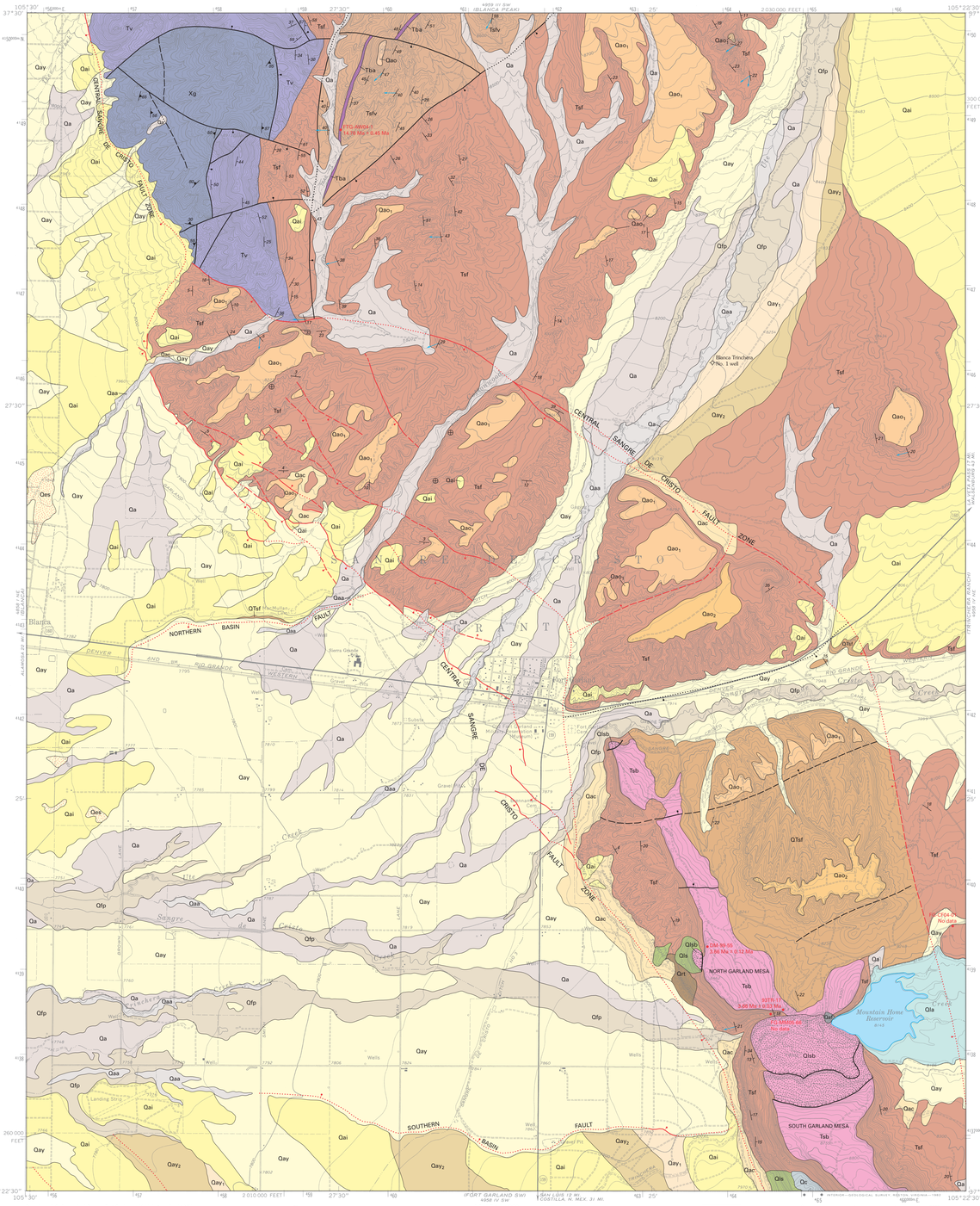


Base from U.S. Geological Survey, Fort Garland, 1965 (photorevised 1982)
Polyconic projection. 1927 North American Datum
10,000-foot grid based on Colorado coordinate system, south zone
1,000-meter Universal Transverse Mercator grid ticks, zone 13

APPROXIMATE MEAN DECLINATION, 2008

SCALE 1:24 000

CONTOUR INTERVAL 20 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929

MAP LOCATION

Geology mapped by A.R. Wallace and M.N. Machette in 2006 using aerial photographs and field reconnaissance. Geology compiled on a 1:24,000-scale topographic base map using a photogrammetric plotter (Kern PG-2) and digital orthophotographic maps

Digital data by T.R. Brandt

Editing and digital cartography by L.J. Binder
Denver Publishing Service Center

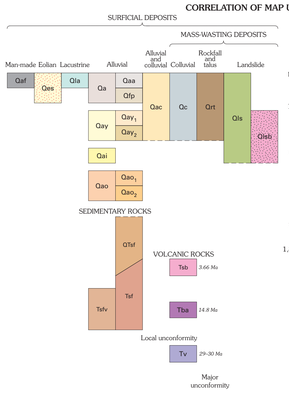
Manuscript approved for publication February 22, 2008

REVISED GEOLOGIC MAP OF THE FORT GARLAND QUADRANGLE, COSTILLA COUNTY, COLORADO

By
Alan R. Wallace and Michael N. Machette
2008

Printed on recycled paper

CORRELATION OF MAP UNITS



DESCRIPTION OF MAP UNITS

[This map is revised from Wallace (1997a) and includes new mapping of Quaternary units and faults in the Fort Garland 7.5-minute quadrangle. Map-unit names and stratigraphic revisions are based on ongoing mapping of the entire Alamosa 30′ × 60′ sheet. See Machette (1985) and Birkeland (1999) for soil horizon nomenclature and carbonate morphology. OIS; marine oxygen isotope stage]

SURFICIAL DEPOSITS

Qaf — **Man-made deposits (historic)**—Earth-fill embankment for Mountain Home Reservoir in the southeast part of map area and in areas of road fills (not mapped)

Qes — **Eolian deposits (Holocene)**—Fine- to medium-grained quartz-rich sand that has been transported by the wind. Forms small pronounced dunes as much as 3 m high and 30 m wide; more extensive to west of quadrangle. Some deposits are very young (active dunes) especially on downwind side of center-pivot irrigation circles, others contain weak buried soils (A horizons) indicating multiple episodes of landscape stability and redeposition of sand in the middle to late Holocene (that is, past 6,000 years; see Machette and others, 2007)

Qla — **Lacustrine deposits (upper Holocene)**—Lake sediment composed of organic-rich, fine-grained sand, silt, and clay in Mountain Home Reservoir, east of the mesas southwest of Fort Garland (informally known as the Garland mesas). Only exposed on margins of reservoir when water level is low. Thickness about 1–5 m; unit is thickest where streams enter the reservoir and along now-inundated former channel of Trinchera Creek

Alluvial deposits (Quaternary)—Unconsolidated, poorly sorted, silt- to boulder-size material along and adjacent to streams. Locally includes colluvium on slopes adjacent to major streams. Where colluvium is a significant component, the materials are mapped as unit Qac (alluvium and colluvium). Clasts along smaller drainages are mostly reworked from sediment of the Santa Fe Group; clasts along Ute and Sangre de Cristo Creeks were derived both from bedrock source areas to the north and east, and reworked from Santa Fe Group sediment exposed in adjacent slopes. The base of upper Pleistocene and Holocene alluvial deposits along Ute and Sangre de Cristo Creeks and basinward of the central Sangre de Cristo fault zone is buried, so thicknesses are unknown

Qa — **Recent stream alluvium, undivided (Holocene)**—Fine-grained, organic-rich silt and clay to medium-grained sand and gravel in stream channels and floodplains along modern drainage courses, but which are too small or discontinuous to map separately as units Qaa or Qfp. Grain size and lithology vary depending on source materials in drainage system. Gravel clasts are generally <15 cm in diameter, but become finer (< 5–10 cm) to the west along Ute and Sangre de Cristo Creeks in the western part of the mapped area and along Trinchera Creek downstream of Mountain Home Reservoir. Thickness at least 2–3 m; base of unit not exposed

Qaa — **Active stream alluvium (upper Holocene)**—Fluvial silt, sand, and gravel in modern to presently active stream channels that retain fresh geomorphic expression as seasonally flooded channels, oxbow loops, and abrupt terrace escarpments. Mapped primarily along major streams, such as Ute Creek and lower reach of Sangre de Cristo Creek, and west of the quadrangle. Thickness at least 2 m; base of unit not exposed

Qfp — **Floodplain alluvium (lower Holocene)**—Fine-grained, organic silt and clay to medium-grained sand and pebble gravel that form slightly elevated floodplains adjacent to active channels. Floodplains have muted depositional features, such as infilled oxbow loops or subtle terrace margins. Primarily mapped adjacent to active stream alluvium (Qaa) in wide valleys, such as Ute and Sangre de Cristo Creeks along the western margin of the quadrangle, upstream of where these streams and Trinchera Creek enter Smith Reservoir (fig. 1). Thickness at least 2–3 m; base of unit not exposed

Qay — **Younger stream alluvium (upper Pleistocene)**—Unconsolidated fluvial sand and gravel in alluvial fans or in former floodplains that are now terraces as a result of stream downcutting and (or) faulting. Gravel clasts are subrounded, unweathered, and derived from Early Proterozoic metamorphic rocks and Paleozoic limestone and sandstone that are exposed to the north and northeast of the quadrangle. The deposits commonly have weak soils with Bw and Bk horizons where the local water table has remained several meters below the surface. Unit Qay is preserved in terraces 3–10 m above modern streams or is inset against older alluvial deposits (Qai and Qao) and sediment of the Santa Fe Group (QTsf or Tsf) within the foothills of the Culebra Range (fig. 1). Unit forms a major composite terrace with two levels (subunits Qay_1 and Qay_2). West of the central Sangre de Cristo fault zone, Qay forms alluvial fans and piedmont slopes graded to local base levels in the western and southwestern part of the quadrangle. Qay is probably 10–50 ka (see dating of similar units by Crone and others, 2006). Thickness is 2–10 m; locally more common in alluvial fans at base of steep slopes

Qay_1 — **Younger stream alluvium, subunit 1 (upper Pleistocene)**—Lower, younger subunit of stream alluvium along major composite terrace on east side of Ute Creek and at the south edge of quadrangle (see also mapping by Kirkham and Heimsoth, 2002). Probably associated with Pinedale glaciation of OIS 2

Qay_2 — **Younger stream alluvium, subunit 2 (upper Pleistocene)**—Higher, older subunit of stream alluvium along major composite terrace on east side of Ute Creek and at the south edge of quadrangle (see also mapping by Kirkham and Heimsoth, 2002). Probably associated with OIS 2 or 3

Qai — **Intermediate stream alluvium (upper Pleistocene and upper middle Pleistocene)**—Unconsolidated, poorly exposed sand and pebble- to cobble-size gravel in former floodplains that are now terraces, in alluvial fans, or in piedmont slopes that cut across Santa Fe Group sedimentary rocks. Unit contains moderately weathered, slightly fractured, subrounded clasts derived from Early Proterozoic metamorphic rocks and Paleozoic limestone and sandstone exposed to the north and northeast of the quadrangle. The relict surface of unit has moderately developed soils (Bt and stage I-II Bk horizons) and, in places, is covered by thin deposits (<1 m thick) of eolian sand and silt (loess). Unit has multiple subunits (undivided herein) that have been moderately deformed by strands of the central Sangre de Cristo fault zone, and thus are preserved at a range of elevations relative to modern stream level. Where the unit forms broad terraces, it is about 27–32 m above the modern channels of Ute and Sangre de Cristo Creeks. However, these elevations vary because of deformation across the central Sangre de Cristo fault zone. The piedmont facies forms broad surfaces cut across sediment of the Santa Fe Group (mainly Tsf) 25–32 m above modern stream level, but is rarely preserved at the surface west of the central Sangre de Cristo fault zone because of burial on the footwall (western) side of the fault. However, away from the fault zone the piedmont slope formed by this unit is locally preserved as islands 2–5 m above modern stream level, or is buried by younger alluvium along the western margin of the quadrangle, east of Smith Reservoir (fig. 1). Most of unit is probably associated with Bull Lake age (OIS 4) glacial outwash in the Blanca Peak quadrangle to the north (A.R. Wallace, USGS, unpub. mapping, 1995), although unit may include younger (undivided) materials deposited during OIS 4–5. Thus, most of Qai is probably 50–150 ka. Deposits mapped as Qai on this map were previously designated as lower deposits of older alluvium (mapped as unit Qoal by Wallace, 1997a). Thickness is 2–5 m and 5–15 m beneath piedmont slopes and terraces (respectively); commonly >10 m thick in alluvial fans

Qao — **Older alluvium (middle Pleistocene)**—Moderately consolidated, poorly exposed sand and pebble- to cobble-size gravel in high terraces, alluvial fans, or piedmont slopes that cut across Santa Fe Group sedimentary rocks. Gravel clasts are subrounded, fractured and (or) weathered, and are derived from Early Proterozoic metamorphic rocks and Paleozoic limestone and sandstone exposed to the north and northeast of the quadrangle. The relict surface of unit has strongly developed calcic soils (thick Bt and (or) stage III Bk horizons) and, in places, is covered by thin (1–2 m thick) deposits of eolian sand and silt (loess); basal 2–3 m of unit has ground-water oxidized, reddish-brown matrix. The alluvium has two map subunits (Qao_1 and Qao_2) that are strongly deformed by strands of the central Sangre de Cristo fault zone (fig. 2) and preserved at a wide range of elevations relative to modern stream level. Mapped as undivided Qao where subunits could not be recognized or reliably correlated. Forms broad terraces and piedmont slopes preserved as high, isolated remnants of formerly broad surfaces that cut across sediment of the Santa Fe Group (mainly Tsf). Alluvial fans comprised of Qao are not preserved west of the central Sangre de Cristo fault zone owing to burial on the footwall (southwest) side of the fault. Qao is probably 150–450 ka. Deposits mapped as older alluvium on this map were also designated as older alluvium (Qoal and Qoau) by Wallace (1997a). Qao and its subunits are 2–10 m thick beneath terraces and piedmont slopes, and commonly >10 m thick in alluvial fans

Qao_1 — **Older stream alluvium, subunit 1 (middle Pleistocene)**—Lower, younger subunit of stream alluvium. Adjacent to Ute Creek, two remnants of subunit Qao_1 are preserved about 75–87 m above present stream channel. Within the central Sangre de Cristo fault zone (fig. 2), the surface of Qao_1 is 46–58 m above larger stream channels. Subunit Qao_1 is probably associated with Bull Lake age (OIS 6) glacial outwash in Blanca Peak quadrangle to the north (A.R. Wallace, USGS, unpub. mapping, 1995)

Qao_2 — **Older stream alluvium, subunit 2 (middle Pleistocene)**—Higher, older subunit of stream alluvium. Within the central Sangre de Cristo fault zone (fig. 2), the surfaces of Qao_2 are deformed and lie 112–150 m above larger stream channels. Subunit Qao_2 is probably associated with pre-Bull Lake age (OIS 8 and older) glacial outwash in Blanca Peak quadrangle to the north (A.R. Wallace, USGS, unpub. mapping, 1995)

Qac — **Alluvial and colluvial deposits, undivided (Holocene to upper Pleistocene)**—Fine- to coarse-grained alluvium and colluvium that form gentle to moderately sloping surfaces adjacent to steep hillslopes. Unit consists of pebbly to cobbly silty sand to pebbly sand. Most of the silt and sand was probably eolian, but it has been reworked by alluvial and colluvial processes (slopewash). Contains weak to moderately developed zonal soils with A, Bw, and (or) Bk horizons. Surface of deposits typically is not dissected. Thickness at least 2–3 m; base of unit not exposed

MASS-WASTING DEPOSITS

[Locally derived deposits of colluvium, landslides, rockfalls, and talus exposed around the margins of the Garland mesas where Servilleta Basalt (Tsb) is underlain by the Santa Fe Group (QTsf or Tsf). Typically includes some eolian sand and locally debris-flow deposits, stream deposits, and ponded alluvium that cover areas too small to map separately. Thickness variable, but commonly 5–20 m at base of steep slopes]

Qc — **Colluvium, undivided (Holocene and upper Pleistocene)**—Poorly sorted, nonstratified, sandy to gravelly deposits; typically on moderate to steep slopes adjacent to resistant rocks such as Tsb. Only mapped in southeast corner of quadrangle where unit continues south into the Fort Garland SW quadrangle (see Kirkham and Heimsoth, 2002). Commonly includes some eolian deposits and locally derived alluvium. Thickness 2–5 m; base of unit not exposed

Qrt — **Rockfall and talus deposits, undivided (Holocene to upper Pleistocene)**—Poorly sorted, nonstratified, gravelly to bouldery deposits of broken rock; typically on moderate to steep slopes adjacent to resistant rocks such as Tsb. Only mapped in southeast corner of quadrangle below the southwest side of North Garland mesa. Commonly associated with landslide headscarps and steep cliffs. Thickness at least 2–10 m; base of unit not exposed

Qls — **Landslide deposits (Holocene to middle Pleistocene)**—Chaotic to locally coherent deposits composed of poorly sorted, nonstratified, cobbly to bouldery fragments of Servilleta Basalt and remobilized sediment of the Santa Fe Group (QTsf and Tsf); commonly on moderate to steep slopes beneath steep cliffs or mesas. Younger deposits have a hummocky surface with sediment-filled closed depressions, whereas older deposits have hilly, but smoothed surface with thick accumulations of eolian sand, alluvium, and ponded deposits between masses of broken basalt. Only mapped in southeast corner of quadrangle below the west side of the Garland mesas and in the valley of Trinchera Creek where it bisects the mesas. Thicknesses commonly 2–20 m

Qlsb — **Landslide blocks (upper and middle Pleistocene)**—Large slabs of relatively coherent Servilleta Basalt (Tsb) within landslide masses (Qls); common on moderate to steep slopes beneath steep cliffs or on basalt-covered mesas. Only mapped in southeast corner of quadrangle on and below the west side of the Garland mesas and in the valley of Trinchera Creek where it bisects the mesas. Thickness commonly >20 m to 50 m reflecting thickness of adjacent Servilleta Basalt (Tsb)

SEDIMENTARY ROCKS

Santa Fe Group (middle Pleistocene to upper Oligocene)—Weakly to strongly consolidated, poorly to locally well-exposed sandstone and pebble-to-boulder conglomerate; poorly to moderately well sorted and bedded. This regionally extensive basin-fill unit contains subrounded clasts of Early Proterozoic felsic and mafic metamorphic and igneous rocks, Paleozoic limestone and sandstone, and Tertiary volcanic rocks, all derived from rocks exposed as far as 35 km to the northeast of the mapped area. Clast lithology generally reflects inverted bedrock stratigraphy; that is, lower parts of the section are rich in Tertiary volcanic rocks and upper parts of the section are rich in Proterozoic rocks. Clast imbrications indicate generally westward to southwestward stream transport. Clasts derived from rocks with distinctive lithology on Blanca Peak to the north (fig. 1) are conspicuously absent in most of the group, indicating late Tertiary uplift of Blanca Peak (see Wallace, 2004). The predominant facies is light-brown to reddish silt and sand with a prevalence of reddish Proterozoic felsic gneiss matrix and clasts but less than 30 percent volcanic clasts. Bedforms are sheeted, with broad to locally deeply incised channels, cross-bedding, and graded bedding. Mostly preserved in the subsurface, but locally exposed beneath the Garland mesas, in landslide scars around the mesas, and well exposed in the foothills east of the mesas and north and west of Fort Garland

QTsf — **Upper part (lower middle Pleistocene to Pliocene)**— Where basin-fill sediment lies on or above the Servilleta Basalt (Tsb), it is mapped as an informal upper member (QTsf) of the Santa Fe Group. These sediments are generally less deformed, are less oxidized, and contain fewer basin-center (playa-like) deposits than in the lower part of the Santa Fe Group (Tsf). More than 60 m of unit is exposed north of Mountain Home Reservoir in the Garland mesas block (fig. 2). Total thickness unknown due to faulting

Tsf — **Lower part (lower Pliocene to upper Oligocene)**— Where basin-fill sediment lies below the Servilleta Basalt and north or east of the central Sangre de Cristo fault zone (uplifted block), it is mapped as an informal lower member (Tsf) that comprises the majority of the Santa Fe Group. This sediment is generally more deformed, more oxidized, and contains more basin-center (playa-like) deposits than in the upper part of the Santa Fe Group (QTsf). Total thickness unknown due to faulting; about 1,100 m of basin-fill sediment (Santa Fe Group, undivided) was penetrated in the Blanca Trinchera No. 1 well drilled in 1952 by the Sunny Valley Oil Co. The precise location of this well is unknown, but it is about 5 km NNE of Fort Garland. In the Trinchera Ranch quadrangle to the east, Wallace (1996) reported that the lower Santa Fe Group might be more than 3,800 m thick

Tsfv — **Volcanic-rich facies (Miocene to upper Oligocene)**— This informal member of the Santa Fe Group is much like Tsf except that it contains abundant clasts (>60 percent of total clasts) of Tertiary volcanic rock. The unit is light gray due to an abundance of volcanic-rich clasts and matrix, but it also contains clasts of Paleozoic limestone and arkose and subordinate Proterozoic metamorphic rocks. Exposed in northwestern quarter of quadrangle in the Ikes Creek block (fig. 2). In the Trinchera Ranch quadrangle to the east (Wallace, 1996), the volcanic-rich facies typifies the lower part of the Santa Fe Group, but in the Ojito Peak quadrangle to the southeast, it is enclosed by the predominantly volcanic-poor facies (Wallace and Soulliere, 1996). Thickness unknown, but as much as 1,100 m of sediment is exposed in northern part of mapped area

VOLCANIC ROCKS

Tsb — **Servilleta Basalt (Pliocene)**—Vesicular to massive, thin flows of dark-gray to black tholeiitic basalt characterized by small olivine phenocrysts; flows locally have columnar joints. Lower Santa Fe Group sediment (Tsf) beneath flows contains a 1-m-thick reddish baked zone at the contact. Basalt is composed of millimeter-size plagioclase and olivine phenocrysts in a microcrystalline groundmass containing abundant plagioclase laths and triangular void spaces (that is, diktytaxitic texture). Two $^{40}Ar/^{39}Ar$ whole-rock dates of 3.66 Ma were obtained from (1) basalt west of Mountain Home Reservoir dam (sample locality 93TR-17; Wallace, 1997a) and (2) basalt on west side of the North Garland mesa (sample locality DM-99-55; Miggins, 2002). These flows are the youngest part of an extensive volcanic sequence of the Taos Plateau that is as old as 4.75 Ma (Miggins, 2002). Unit preserved in southeastern quarter of quadrangle in the Garland mesas block (fig. 2). Likely erupted from now-buried vents within the Culebra graben (fig. 1), between the Garland mesas and the Basaltic Hills to the southwest. Thickness 20–30 m

Tba — **Basaltic andesite (Miocene)**—Dark-brown, black, and locally reddish vesicular to massive basaltic andesite flow and agglutinate. Well to poorly exposed in northwestern quarter of quadrangle in the Ikes Creek block (fig. 2); where poorly exposed, it forms a dark-colored rubble within Santa Fe Group strata. Contains 1–2 mm plagioclase and pyroxene phenocrysts in a microscopic groundmass of plagioclase and pyroxene. A new $^{40}Ar/^{39}Ar$ plateau date of 14.76±0.45 Ma (D.P. Miggins, USGS, written commun., 2007) was obtained from basaltic andesite interbedded in the lower Santa Fe Group (Tsfv) in the northern part of the mapped area (locality FTG-AW04-1). This flow would probably lie in the medial part of the Hinsdale Formation of Lipman and Mehnert (1975). Thickness 10–20 m

Tv — **Older volcanic rocks (Oligocene)**—Andesite and dacite flows, poorly welded tuff, laharic breccia, and volcaniclastic rocks exposed in northwestern quarter of quadrangle in the Ikes Creek block (fig. 2). Flows are dark brown, black, or red; massive, with some agglutinate. Andesite contains plagioclase and pyroxene phenocrysts; dacite also includes phenocrysts of amphibole, biotite, sanidine, and rare quartz. Tuff is light to dark brown and forms coarse platy talus; phenocrysts include biotite, hornblende, plagioclase, sanidine, and locally quartz and pumice. Similar to, and perhaps identical to, tuff in Trinchera Ranch quadrangle to east dated at 29.6±0.1 Ma by $^{40}Ar/^{39}Ar$ geochronology (Wallace, 1996). Breccia is brown with angular, subrounded boulder-size clasts and variable amounts of interstitial matrix. Volcaniclastic rocks are light brown to gray interbedded with massive to thinly laminated, poorly to well-sorted sediment; laterally continuous volcaniclastic unit near middle of volcanic section contains abundant pumice and lithic clasts and forms massive, subrounded to thinly bedded outcrops. Lower part of volcanic section is juxtaposed against Early Proterozoic granite (Xg) by a west-dipping fault; upper contact with Santa Fe Group strata is an erosional unconformity. Unit may be partly equivalent to 29–30 Ma volcanic rocks of the Conejos Formation in the San Luis Hills, 15–20 km to southwest (Thompson and Machette, 1989), and to similar volcanic rocks in adjacent quadrangles (see quadrangle index map). Thick basal lahar sequence found in the Trinchera Ranch (Wallace, 1996) and Ojito Peak (Wallace and Soulliere, 1996) quadrangles may have been eliminated by faulting at the base of the section in Fort Garland quadrangle. Thickness 425–600 m where faulted, may be thicker along north boundary of quadrangle

Xg — **Granite, undivided (Early Proterozoic)**—Pinkish-tan to reddish, equigranular, medium-grained granite exposed in northwestern quarter of quadrangle in the Ikes Creek block (fig. 2). Foliated to massive but deeply weathered; forms grusy massive to subdued outcrops, and float consists of orange grus. Granite has phenocrysts of microcline, biotite, quartz, and subordinate plagioclase, but does not resemble any Proterozoic rocks exposed to the north and northeast in the Blanca Peak (fig. 1) and upper Ute Creek areas (A.R. Wallace, USGS, unpub. mapping, 1995). Thickness unknown; base of unit not exposed

LATE TERTIARY AND QUATERNARY STRUCTURAL GEOLOGY

All of the faults in the Fort Garland, Colo., quadrangle formed during extension related to the development of the Neogene Rio Grande rift (Wallace, 1995, 2004). Rifting began in the late Oligocene about 26 Ma, and the Quaternary faults (shown in red) reflect ongoing extension in the mapped area. The Neogene faults reflect uplift of two rift-related mountain ranges: the Culebra Range to the east and Blanca Peak to the north (fig. 1). Structural evidence in the Russell Colo., quadrangle to the northeast (see quadrangle index map; Wallace, 1997b), coupled with sedimentological evidence from the Santa Fe Group in this quadrangle and along the southern and western base of Blanca Peak (A.R. Wallace, USGS unpub. data, 1995), indicate that Blanca Peak rose slightly later than the Culebra Range (fig. 1). With time, uplift-related faulting along the Culebra Range and the southern side of Blanca Peak migrated west and south through the Ute Creek basin and into the San Luis Basin (fig. 1), thus creating an intermediate-level structural block (Ikes Creek block, fig. 2) cored by Proterozoic (Xg) and Tertiary volcanic (Tv) rocks. This relation is clearly evident in the Fort Garland quadrangle, where faults with known Quaternary movement are outboard from the range fronts. These faults displace Quaternary alluvium (Qai) and (Qao), and, locally, younger alluvium (Qay). Fault scarps that are 1.5–2 m high on unit Qay (upper Pleistocene) within the town of Fort Garland attest to recent movement on this part of the fault zone. No Quaternary movement has been found on other normal faults in the map area. However, Quaternary movement has been documented to the north along the base of Blanca Peak (Colman and others, 1985) and to the south along the Culebra Range front into northernmost New Mexico (Kirkham and Rogers, 1981; Colman and others, 1985; Thompson and others, 2007) on the central Sangre de Cristo fault zone (see Ruleman and Machette, 2007). McCalpin (1982) estimated a recurrence interval of 25–30 k.y. for large earthquakes along the range-bounding northern Sangre de Cristo fault zone, which appears to terminate on the south face of Blanca Peak. From there south to the New Mexico State line (near Amalia, New Mex.), the central Sangre de Cristo fault zone deforms late Pleistocene age and older alluvial units. At Rito Seco Creek, northeast of San Luis, Colo., Crone and Machette (2005) have documented early Holocene (9±2 k.y.) movement and three earlier faulting events over the past 48 k.y. on the central Sangre de Cristo fault zone.

In addition to the central Sangre de Cristo fault zone, we mapped two east-striking faults that are herein named the "northern basin fault" and the "southern basin fault"; they bound the Fort Garland basin (fig. 2) portion of the Culebra graben. These features are marked by escarpments that trend east-west; they have greater apparent displacements on their east ends than on their west ends, and the northern fault appears to have about 2 to 3 times the surface offset of the southern fault. At first glance, these escarpments appear to be fluvial because they trend subparallel to local drainages. However, both escarpments terminate at the western bounding fault of the central Sangre de Cristo fault zone, diminish in displacement west of the fault zone, and have greater scarp heights on older deposits (progressive growth with time). In addition, the surface of unit Qai is tilted northward on the footwall (northern block) of the northern basin fault (for example, near the MacMullan Cemetery, northwest of the Sierra Grande School). As such, these faults form a trap-door-like half-graben that has its maximum displacement adjacent to the central Sangre de Cristo fault zone.

Trinchera Creek, in the southeastern part of the quadrangle, was an antecedent stream that incised itself into the Servilleta Basalt and Santa Fe Group strata as the Garland mesa block (fig. 2) began to tilt northeastward sometime after about 3.7 Ma. Large blocks of the Servilleta Basalt, possibly triggered by Quaternary seismic activity, slid along a failure plane into the developing canyon and dammed Trinchera Creek. The dam created a lake that extended east along Trinchera Creek, depositing sediment that forms fertile soil along that valley (Wallace, 1996). This lake may have overflowed slightly through a small gap into the lower Ojito Creek drainage to the south, but Trinchera Creek ultimately overflowed and cut through the dam to resume its westerly course. The dam for Mountain Home Reservoir (Qaf) was constructed at the toe of the landslide and within the central Sangre de Cristo fault zone.

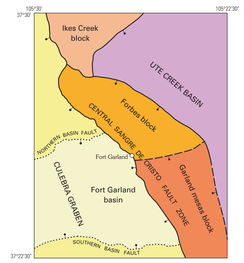


Figure 2. Major structural elements in the Fort Garland quadrangle, Colo. Faults shown as black lines; dashed where approximately located or inferred; dotted where concealed. Bar and ball on downthrown side.

REFERENCES CITED

Birkeland, P.W., 1999, Soils and Geomorphology (3rd ed.): New York, Oxford University Press, 430 p.

Colman, S.M., McCalpin, J.P., Ostenaa, D.A., and Kirkham, R.M., 1985, Map showing upper Cenozoic rocks and deposits and Quaternary faults, Rio Grande rift, south-central Colorado: U.S. Geological Survey Miscellaneous Investigations Series Map I–1594, 2 sheets, scale 1:125,000.

Crone, A.J., and Machette, M.N., 2005, Paleoseismic activity on the Sangre de Cristo fault near San Luis, Colorado [abs.]: Geological Society of America Abstracts with Program, v. 37, no. 7, p. 558, Abstract 256–2.

Crone, A.J., Machette, M.N., Bradley, L.-A., and Mahan, S.A., 2006, Data related to late Quaternary surface faulting on the Sangre de Cristo fault, Rito Seco site, Costilla County, Colorado: U.S. Geological Survey Scientific Investigations Map 2955, 1 sheet, various scales.

Johnson, B.R., and Bruce, R.M., 1991, Reconnaissance geologic map of parts of the Twin Peaks and Blanca Peak quadrangles, Alamosa, Costilla, and Huerfano Counties, Colorado: U.S. Geological Survey Miscellaneous Field Studies Map MF–2169, 1 sheet, scale 1:24,000.

Kirkham, R.M., and Heimsoth, C.M., 2002, Geologic map of the Fort Garland Southwest quadrangle, Costilla County, Colorado: Colorado Geological Survey Open-File Map 02–6, 1 sheet, scale 1:24,000.

Kirkham, R.M., and Rogers, W.P., 1981, Earthquake potential in Colorado: Colorado Geological Survey Bulletin 43, 171 p.

Lipman, P.W., and Mehnert, H.H., 1975, Late Cenozoic basaltic volcanism and development of the Rio Grande depression in the southern Rocky Mountains, *in* Curtis, B.F., ed., Cenozoic history of the Southern Rocky Mountains: Geological Society of America Memoir 144, p. 119–154.

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., Coates, M.M., and Johnson, M.L., eds, 2007 Rocky Mountain Section Friends of the Pleistocene Field Trip—Quaternary Geology of the San Luis Basin of Colorado and New Mexico, September 7–9, 2007: U.S. Geological Survey Open-File Report 2007–1193, 210 p. (available at http://pubs.usgs.gov/of/2007/1193)

McCalpin, J.P., 1982, Quaternary geology and neotectonics of the west flank of the northern Sangre de Cristo Mountains, south-central Colorado: Colorado School of Mines Quarterly, v. 77, no. 3, 97 p.

Miggins, D.P., 2002, Chronologic, geochemical, and isotopic framework of igneous rocks within the Raton basin and adjacent Rio Grande rift, south-central Colorado and northern New Mexico: Boulder, University of Colorado, M.S. thesis, 417 p.

Ruleman, C.A., and Machette, M.N., 2007, Chapter J—An overview of the Sangre de Cristo fault system and new insights to interactions between Quaternary faults in the Northern Rio Grande Rift, *in* Machette, M.N., Coates, M.M., and Johnson, M.J., eds., 2007 Rocky Mountain section friends of the Pleistocene field trip—Quaternary geology of the San Luis Basin of Colorado and New Mexico September 7–9, 2007: U.S. Geological Survey Open-File Report 2007–1193, p. 187–197. (available at http://pubs.usgs.gov/of/2007/1193)

Thompson, R.A., and Machette, M.N., 1989, Geologic map of the San Luis Hills area, Conejos and Costilla Counties, Colorado: U.S. Geological Survey Miscellaneous Investigations Series Map I–1906, 1 sheet, scale 1:50,000.

Thompson, R.A., Machette, M.N., and Drenth, B.J., 2007, Preliminary geologic map of the Sanchez Reservoir Quadrangle and eastern part of the Garcia Quadrangle, Costilla County, Colorado: U.S. Geological Survey Open-File Report 2007–1074, 1 sheet, scale 1:24,000.

Wallace, A.R., 1995, Cenozoic rift-related sedimentation and faulting, northern Culebra Range, southern Colorado, *in* Bauer, P.W, Kues, B.S., Dunbar, N.W., Karlstrom, K.E., and Harrison, Bruce, eds., Geology of the Santa Fe Region: New Mexico Geological Society 1995 Guidebook, 46th Field Conference, p. 147–153.

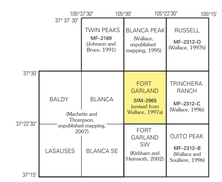
Wallace, A.R., 1996, Geologic map of the Trinchera Ranch Quadrangle, Costilla County, Colorado: U.S. Geological Survey Miscellaneous Field Studies Map MF–2312–C, 1 sheet, scale 1:24,000.

Wallace, A.R., 1997a, Geologic map of the Fort Garland Quadrangle, Costilla County, Colorado: U.S. Geological Survey Miscellaneous Field Studies Map MF–2312–E, 1 sheet, scale 1:24,000.

Wallace, A.R., 1997b, Geologic map of the Russell Quadrangle, Costilla County, Colorado: U.S. Geological Survey Miscellaneous Field Studies Map MF–2312–D, 1 sheet, scale 1:24,000.

Wallace, A.R., 2004, Evolution of the southeastern San Luis Basin margin and the Culebra embayment, Rio Grande rift, southern Colorado, *in* Brister, B.S., Bauer, P.W., Read, A.S., and Lueth, V.W., eds., Geology of the Taos Region: New Mexico Geological Society 2004 Guidebook, 55th Field Conference, p. 181–192.

Wallace, A.R., and Soulliere, S.J., 1996, Geologic map of the Ojito Peak quadrangle, Costilla County, Colorado: U.S. Geological Survey Miscellaneous Field Map MF–2312–B, 1 sheet, scale 1:24,000.



Index map showing Fort Garland quadrangle and adjacent 7.5-minute quadrangles. For U.S Geological Survey publications, number, if available, author, and date of publication are shown for quadrangle; for non-U.S. Geological Survey publications, author and year of publication are shown.

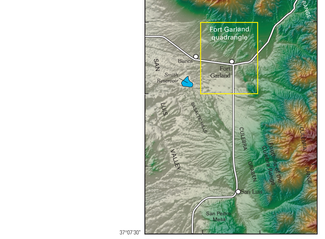


Figure 1. Place names and features mentioned in the text. The Fort Garland quadrangle is indicated by the yellow box.

Contact

Quaternary fault—Bar and ball on downdropped side; solid where well located; dashed where approximately located or inferred; dotted where concealed

Fault—Bar and ball on downdropped side; solid where well located; dashed where approximately located or inferred, dotted where concealed

Head scarp—Hachures on downdropped side. Solid where well located, dashed where approximately located or inferred. Headwall failure due to landsliding

Strike and dip of horizontal bedding

Strike and dip of inclined bedding

Strike and dip of inclined foliation

Paleocurrent direction—Based upon orientation of imbricate clasts in Santa Fe Group sedimentary rocks. Symbol combined with strike and dip of bedding symbols

DM-99-55 Sample locality for $^{40}Ar/^{39}Ar$ age determination

Approximate location of the Blanca Trinchera No. 1 well (SW¼ sec. 2, T. 30 S., R. 72 W.)

Suggested Citation:
Wallace, A.R., and Machette, M.N., 2008, Revised geologic map of the Fort Garland quadrangle, Costilla County, Colorado: U.S. Geological Survey Scientific Investigations Map 2965, scale 1: 24,000.

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ISBN 978-1-4113-2127-4