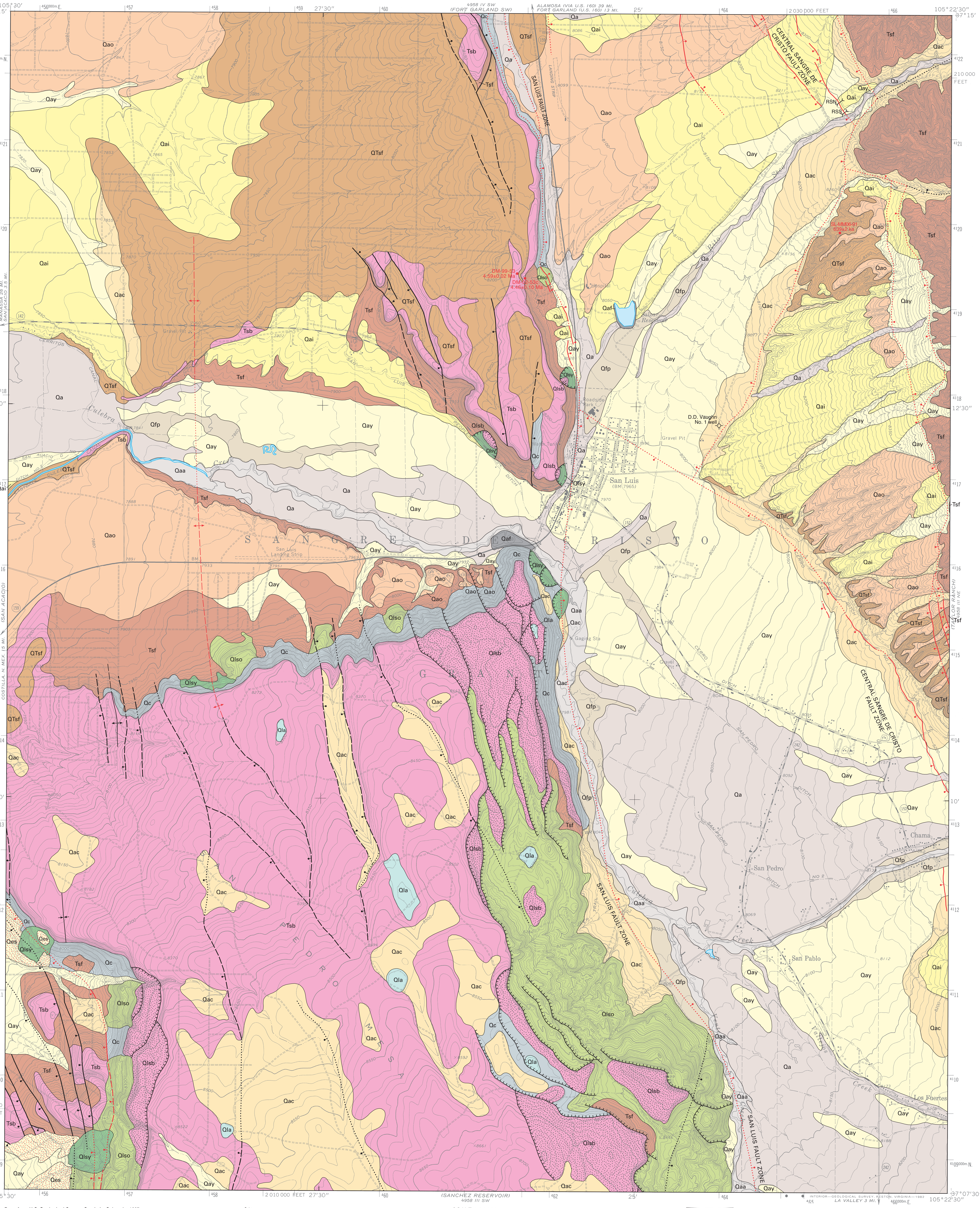

Base from U.S. Geological Survey, San Luis, Colorado, 1967.
Polyconic projection. 1927 North American datum
10,000-foot grid based on Colorado coordinate system, south zone
1,000-meter Universal Transverse Mercator grid ticks, zone 13

APPROXIMATE MEAN DECLINATION, 2008

SCALE 1:24 000

CONTOUR INTERVAL 10 FEET
DATUM IS MEAN SEA LEVEL

MAP LOCATION

Geology mapped in 2006 using aerial photographs, aeromagnetic and gravity data (Bankey and others, 2006), and field reconnaissance. Geology compiled on 1:24,000-scale topographic base map using a photogrammetric plotter (Kern PG-2) and orthophotographic maps

Digital data prepared by Ted Brandt

Editing and digital cartography by Lisa Ramirez Rukstales

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GEOLOGIC MAP OF THE SAN LUIS QUADRANGLE, COSTILLA COUNTY, COLORADO

By

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2008

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Printed on recycled paper

DESCRIPTION OF MAP UNITS

Map-unit names and stratigraphic associations are based on mapping of the entire Alamosa 30' x 60' sheet, which contains many more units. See Birkeland (1999) and Machette (1985) for soil horizon nomenclature and carbonate morphology. OIS indicates marine oxygen isotope stage

SURFICIAL DEPOSITS

Man-made Deposits

Qaf **Artificial fill (historic)**—Mainly material in small earth-fill dams for reservoirs and sewage treatment plant

Eolian Deposits

Qes **Eolian sand (Holocene)**—Forms small pronounced dunes as much as 3 m high and 5- to 10-m-thick ramps against the western base of San Pedro mesa. Some deposits are very young (active dunes); others contain weak buried soils (A horizons) indicating multiple episodes of landscape stability and redeposition of sand

Lacustrine Deposits

Qla **Lake sediment (Holocene)**—Comprised of organic-rich, fine-grained sand, silt, and clay in small natural depressions on San Pedro mesa

Alluvial Deposits

Qa **Undifferentiated stream alluvium (Holocene)**—Fine-grained, organic-rich silt and clay to medium-grained sand and gravel that form active stream channels and floodplains along most drainage courses, some of which are too small to map separately as either unit Qaa or Qfp. Grain size and lithology vary depending on source material in stream headwaters. Gravel clasts are generally <10 cm in diameter and fine to the west along Culebra Creek; slightly coarser (10–15 cm) along streams draining the Culebra Range to the east of San Luis

Qaa **Active stream alluvium (upper Holocene)**—Fluvial sand and gravel in modern to recently active stream channels that retain fresh geomorphic expression (that is, oxbow loops or abrupt terrace escarpments). Gravel clasts are generally <10 cm in diameter and fine to the west along Culebra Creek; slightly coarser (10–15 cm) along streams draining the Culebra Range to the east of San Luis

Qfp **Floodplain alluvium (lower Holocene)**—Fine-grained, organic-rich silt and clay to medium-grained sand and pebble gravel that form floodplains adjacent to active channels. Floodplains commonly have muted depositional morphology (that is, infilled oxbow loops, subtle terrace margins). Gravel clasts are generally <10 cm in diameter along streams draining the Culebra Range to the east of San Luis and fine to the west along Culebra Creek

Qay **Younger stream alluvium (upper Pleistocene)**—Fluvial sand and gravel in former floodplains that are now terraces 1–2 m above modern stream level or as alluvial fans and piedmont slopes along the foothills of the Culebra Range. Commonly has weak soil with Bw and (or) Bk horizons. Qay is probably 10–50 ka (see dating of similar units by Crone and others, 2006) and associated with OIS 2 or 3

Qai **Intermediate stream alluvium (upper and middle Pleistocene)**—Fluvial sand and gravel at elevations about 2–5 m above modern stream level in terraces, alluvial fans, and piedmont slopes along the foothills of the Culebra Range. Forms major intermediate-level (13–15 m high) terraces along Culebra Creek, west of San Pedro mesa. The relict surface of the intermediate stream alluvium has moderately developed soil (Bt and stage II–III Bk horizons). Locally, thin deposits of unit Qay overlie unit Qai or Qao. Most of unit is probably associated with Bull Lake age (OIS 4) glacial outwash from the Culebra Range, although unit may include younger (undivided) materials deposited during OIS 4–5. Thus, most of unit Qai is probably 50–150 ka

Qao **Older stream alluvium (middle Pleistocene)**—Fluvial sand and gravel about 5–15 m above modern streams as terraces or as alluvial fans and piedmont slopes along the foothills of the Culebra Range. Elevations of the alluvium surfaces vary and commonly converge downstream because of fault activity. Forms major high-level (25–30 m high) terrace and composite alluvial fan south of Culebra Creek, west of San Pedro mesa. The relict surface of the old stream alluvium commonly has strongly developed calcic soil (thick Bt and/or stage III Bk horizons). East of San Luis, old stream alluvium lies unconformably on sediment of the Santa Fe Group (QTsf) that contains 639±2 ka Lava Creek B ash. Most of unit is probably 150–450 ka, and associated with Bull Lake age (OIS 6) or pre-Bull Lake age (OIS 8 or 12) glacial outwash from the Culebra Range

Alluvial and Colluvial Deposits

Qac **Alluvium and colluvium, undivided (Holocene and upper Pleistocene)**—Fine- to coarse-grained alluvium and colluvium that forms gentle to moderately sloping surfaces adjacent to and on bedrock-cored hills, such as San Pedro mesa. Material is typically pebbly-to-cobbly, silty sand to pebbly sand. Most of the silt and sand is probably eolian, but 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 is typically not dissected

Colluvial Deposits

Qc **Colluvium, undivided (Holocene and upper Pleistocene)**—Poorly sorted, nonstratified, sandy to gravelly deposits; common on moderate to steep slopes adjacent to resistant bedrock. Typically includes minor eolian deposits and locally derived alluvium. Thickness probably 2–10 m

Landslide Deposits

Qlsy **Young landslides (Holocene and upper Pleistocene)**—Remobilized sediment of the Santa Fe Group (QTsf) with poorly sorted, nonstratified, cobbly-to-bouldery fragments of Servilleta Basalt (Tsb); typically on moderate to steep slopes beneath steep cliffs. Young deposits commonly have a hummocky surface with sediment-filled closed depressions. They also appear to have some characteristics of flowage, perhaps having formed during moist climates

Qlso **Old landslides (upper and middle Pleistocene)**—Remobilized sediment of the Santa Fe Group (QTsf) with poorly sorted, nonstratified, cobbly-to-bouldery fragments of Servilleta Basalt (Tsb); typically on moderate to steep slopes beneath steep cliffs. Old deposits commonly have hilly, but smoothed surface with thick accumulations of eolian sand, alluvium, and ponded deposits between masses of broken basalt. These deposits have abrupt bases, suggesting that they are displaced by the southern Sangre de Cristo fault zone. Commonly the fault has not displaced adjacent young deposits (Qa, Qay, and Qes) and therefore is rarely visible in these deposits, which is evidence of late Pleistocene but not Holocene fault movement in this area. Large slabs and blocks of Servilleta Basalt (Tsb) are mapped separately in large old landslides

Qlsb **Landslide blocks (upper and middle Pleistocene)**—Large slabs of relatively coherent Servilleta Basalt (Tsb) within landslide masses (Qlsy and Qlso); common on moderate to steep slopes beneath steep cliffs or on basalt-covered mesas. Mapped chiefly in the south-central part of quadrangle where the Rio Culebra has trimmed the eastern margin of San Pedro mesa, which has been uplifted along the San Luis fault zone. Thickness commonly >20 m to 50 m reflecting thickness of adjacent Servilleta Basalt (Tsb)

Sedimentary Rocks

Santa Fe Group (lower middle Pleistocene to upper Oligocene)—Weakly to strongly consolidated, poorly to locally well-exposed siltstone, sandstone, and pebble-to-cobble 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 in the Culebra Range to the northeast and east 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. Bedforms are sheeted, with locally to widespread, deeply incised channels, crossbedding, and graded bedding. Mostly preserved in the subsurface, but locally exposed beneath the San Luis and San Pedro mesas, and in the foothills east of San Luis. Where these sediments are interbedded with the Servilleta Basalt (Tsb), the group is subdivided into upper and lower parts above and below the basalt, respectively

QTsf **Upper part (lower middle Pleistocene to Pliocene)**—Slightly oxidized, poorly consolidated, friable sandstone, siltstone, and pebble-to-cobble conglomerate that lie above Servilleta Basalt (Tsb). Mostly preserved in the subsurface, but locally exposed beneath the mesas west and southwest of San Luis, in landslide scars around the mesas, and in the foothills east of San Luis. In the uppermost part of the section, sediment locally contains white, silty, fine-sand-size volcanic ash (Lava Creek B) that was erupted from the Yellowstone caldera in northwestern Wyoming at 639±2 ka. Exposed thickness of upper part of Santa Fe Group is probably 100–200 m but is about 350 m thick in Energy Operating Co. Williamson No. 1 drill hole (Kirkham and others, 2005), which is located south of Sanchez Reservoir quadrangle to the south (Thompson and others, 2007)

Tsf **Lower part (Pliocene to upper Oligocene)**—Moderately oxidized, moderately consolidated sandstone, siltstone, and pebble-to-cobble conglomerate that lie beneath the Servilleta Basalt (Tsb). Also contains clayey mudstones deposited in ancient playas. Deposits in most exposures are relatively fine grained considering proximity to their source area in the Culebra Range, suggesting that the coarse-grained component may have been confined to the Culebra graben (the modern valley occupied by the town of San Luis). Primarily in subsurface, but locally exposed beneath basalt-covered mesas, and east of the central Sangre de Cristo fault zone. Exposed thickness of lower part of Santa Fe Group is probably 100–200 m but is about 1,500 m thick in Energy Operating Co. Williamson No. 1 drill hole (Kirkham and others, 2005), which is located south of Sanchez Reservoir in the quadrangle to the south (Thompson and others, 2007). In addition, unit Tsf must have been found in the D.D. Vaughn No. 1 well in the Culebra graben east of San Luis, but the lithologic log is not available to the authors

Volcanic Rocks

Tsb **Servilleta Basalt (Pliocene)**—Thin, dark-gray flows of tholeiitic basalt containing small olivine phenocrysts, diktytaxitic texture, and local vesicle pipes and segregation veins. As many as six flows are exposed on western rim of San Pedro mesa south of the quadrangle (Thompson and others, 2007). Likely erupted from vents to the south and west of the map area. $^{40}Ar/^{39}Ar$ age determinations of 4.46±0.10 Ma (DM-02-53c) and 4.59±0.02 Ma (DM-99-53) were reported by Miggins (2002) from flows on San Luis mesa (informally named mesa west of San Luis, see sample locations on this map), whereas dates of 4.8–3.7 Ma have been obtained on other samples of Servilleta Basalt in the region. Maximum exposed thickness is about 30 m; as much as 143 m thick in the Energy Operating Co. Williamson No. 1 drill hole (Kirkham and others, 2005), which is located south of Sanchez Reservoir in the quadrangle to the south (Thompson and others, 2007)

Contact

Fault—Bar and ball on downdropped side; shown in red where fault has Quaternary movement. Solid where certain; dashed where approximately located or inferred; dotted where concealed

Landslide escarpment—Topographic headwall or escarpment associated with landslides chiefly along margins of San Pedro mesa where Servilleta Basalt (Tsb) is underlain by sediment of the lower Santa Fe Group (Tsf). Large slide blocks of basalt mapped separately as unit Qlsb. Only prominent or continuous escarpments are shown. Hachure on downdropped side

Fold—Solid where accurately located; dashed where approximately located or inferred; dotted where concealed.

Anticline—Surface trace of gentle anticline (Quaternary movement shown in red) expressed on terrace surface of old alluvium (Qao) and in sediment of lower Santa Fe Group (Tsf) south of Culebra Creek and in Servilleta Basalt (Tsb) on the northwest part of San Pedro mesa

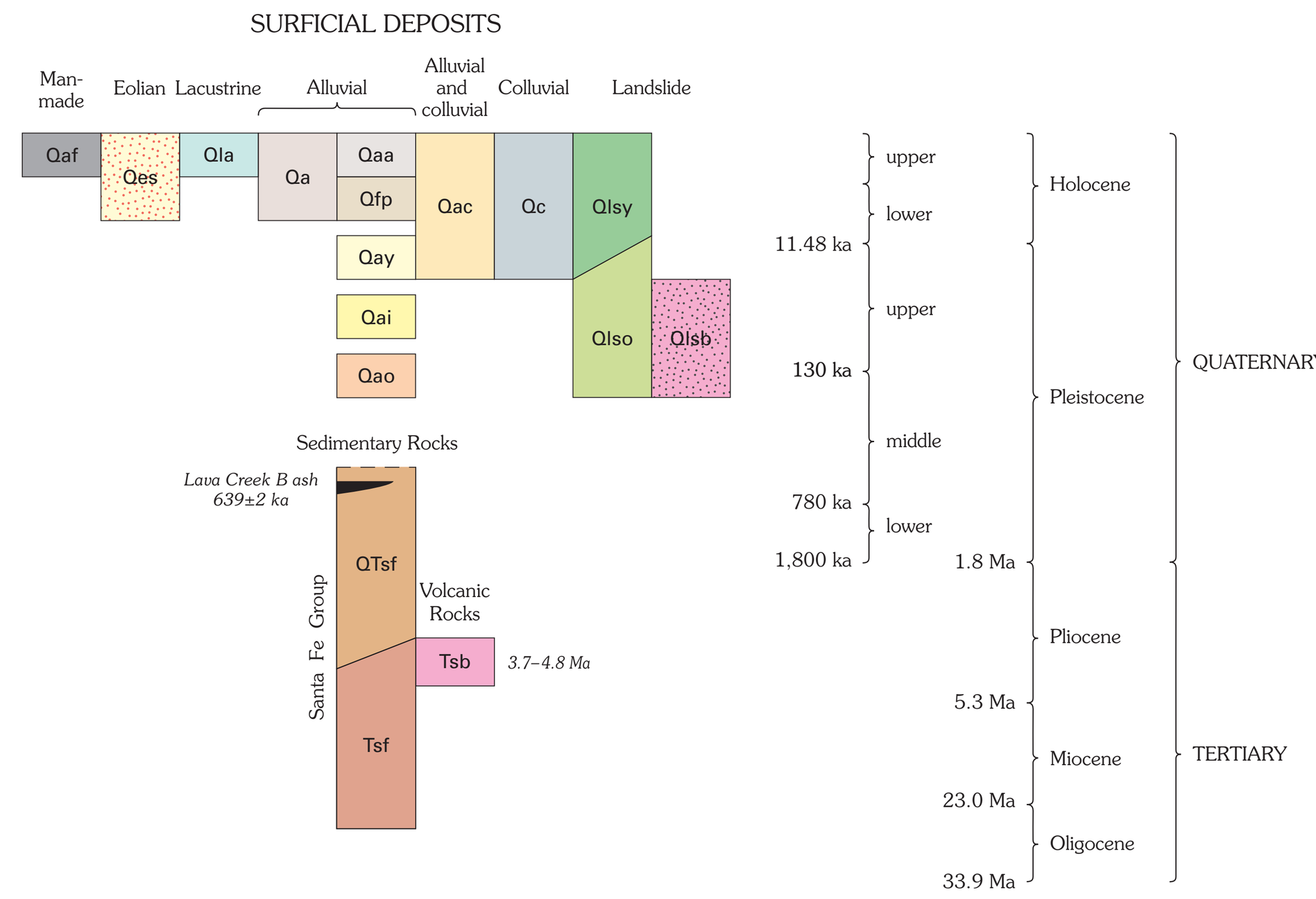
Syncline—Surface trace of gentle north-trending syncline in Servilleta Basalt (Tsb) on the northwest part of San Pedro mesa

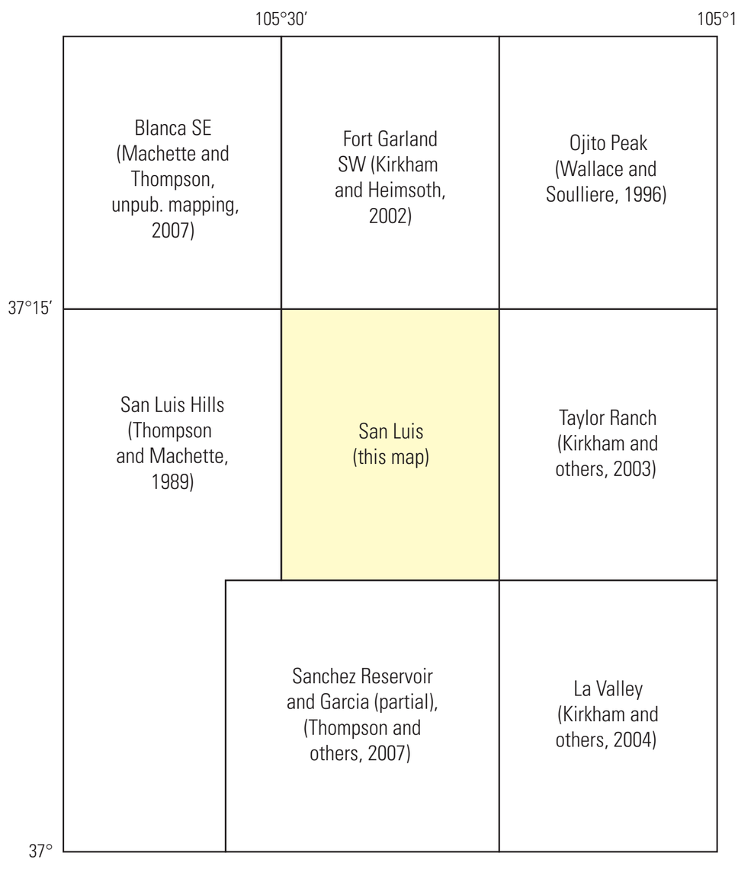
DM-99-53 **Location and age of dated rock or sediment**—Samples of unit Tsb were dated using $^{40}Ar/^{39}Ar$ methods by Miggins (2002). Sample of volcanic ash (tephra) from upper part of unit QTsf is chemically correlated to 639±2 ka Lava Creek B ash (Lanphere and others, 2002) from the Yellowstone caldera, Wyoming (Elmira Wan, USGS-Menlo Park, Calif., written commun., 2007)

Approximate location of the D.D. Vaughn No. 1 well (NW1/4 SW1/4 Sec. 24, T.3N., R.72W.)—This well was drilled in 1962 about 1.6 km east of San Luis. An electric log by Welex (Tusas Minerals, Inc.) reported a total logged depth of 3,273 ft (about 1,000 m), but no lithologies were noted

RSN **Location of trenches across central Sangre de Cristo fault zone**—Results described by Crone and others (2006). RSN—Rito Seco North, RSS—Rito Seco South

CORRELATION OF MAP UNITS





INDEX MAP SHOWING SOURCES OF GEOLOGIC DATA

BASIC STRUCTURE AND BRIEF DESCRIPTION OF GEOLOGIC HISTORY

San Luis, the oldest town in Colorado, is located in a broad valley that is the direct result of tectonism, volcanism, and alluviation. West and south of town are two mesas (the informally named San Luis mesa west of San Luis, and San Pedro mesa south of the Rio Culebra) that form a north-trending horst, whereas the valley to the east of the mesas is a north-northwest-trending graben (Culebra graben, restricted sense). The foothills to the east of town, define the western margin of the uplifted Culebra Range, which is part of the Sangre de Cristo Mountains. The faults that bound the horst and graben show evidence of Quaternary movement because they offset surficial deposits as well as juxtapose older units, such as the Servilleta Basalt (Tsb) against sediment of the Santa Fe Group (QTsf and Tsf).

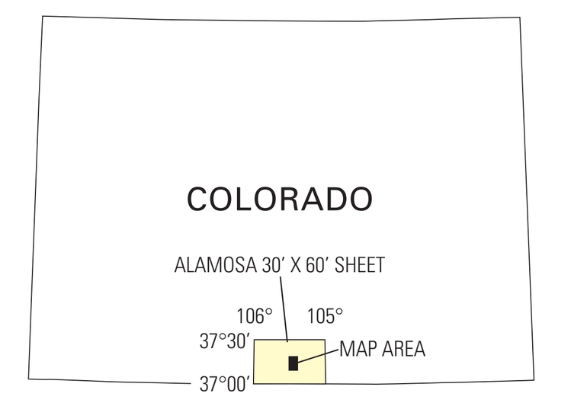
The mesas are bounded by the San Luis fault zone on the east and the southern Sangre de Cristo fault zone on the west. The Culebra graben is bounded on the east by the central Sangre de Cristo fault zone, which has Holocene (<10 ka) movement. Such recent movement indicates that the fault zone is active and thus poses a hazard to the town of San Luis and surrounding region. The general trace of the central Sangre de Cristo fault zone forms a consistent pattern of right steps, from Sanchez Reservoir on the south (Thompson and others, 2007) toward Fort Garland on the north (see Kirkham and others, 2002; Wallace and Machette, 2008). The central Sangre de Cristo is one of three fault zones (northern, central, and southern) that comprise the 250-km-long Sangre de Cristo fault system, which extends from Poncha Pass, Colo., on the north to Taos, N. Mex., on the south (see Ruleman and Machette, 2007, for a discussion of fault nomenclature in this region). However, the individual strands in the central Sangre de Cristo fault zone are not simple linear structures; they are complex, curvilinear, overlap, and form en echelon stepovers. At Rito Seco Creek in the northeastern corner of the map, Crone and others (2006) found evidence that four surface-faulting earthquakes occurred on the central Sangre de Cristo fault zone in about the past 48 k.y., and the most recent event occurred about 9,000±2,000 years ago (Crone and Machette, 2005). No other paleoseismic data exist for the central Sangre de Cristo fault zone, the southern Sangre de Cristo fault zone (to the west), or the San Luis fault zone. However, our mapping suggests that late Quaternary movement (<130 ka) has probably occurred on all these fault zones. In addition to faulting hazards, many slopes below the mesa rims are covered with landslide deposits, colluvium, and (or) unmapped rockfall debris. These unstable slopes are caused by hard, competent basalt (Tsb) lying on soft, incompetent sediment of the Santa Fe Group (chiefly Tsf).

The oldest map units exposed in the quadrangle are sedimentary rocks of the upper Oligocene to lower middle Pleistocene Santa Fe Group (QTsf and Tsf). As mapped, unit Tsf is upper Oligocene to Pliocene in age and generally underlies the Servilleta Basalt (Tsb), or is present on the uplifted, eastern side of the central Sangre de Cristo fault zone (see Kirkham and others, 2003). The Servilleta Basalt was erupted from numerous vents on the Taos Plateau to the southwest, and perhaps locally from unmapped or buried vents in the southern San Luis Valley. The Pliocene Servilleta Basalt typically ranges in age from 4.8–3.7 Ma in southern Colorado, although $^{40}Ar/^{39}Ar$ dates on these rocks in the San Luis quadrangle range from 4.59 to 4.46 Ma (see description of Tsb). These basalt flows lapped against the ancient sedimentary foothills of the Culebra Range and, thus, are only preserved east of the central Sangre de Cristo fault zone in a few localities. In the Culebra graben, multiple flows of the Servilleta Basalt are reported to be about 143 m thick in the Energy Operating Co. Williamson No. 1 drill hole (Kirkham and others, 2005; R.M. Kirkham, written commun., 2005), south of Sanchez Reservoir. On San Pedro mesa to the west, the Servilleta Basalt is typically 30–40 m thick (Thompson and others, 2007), but thins to the northwest to several meters thickness.

The upper part of the Santa Fe Group (QTsf, Pliocene to lower middle Pleistocene) is exposed mainly west of the central Sangre de Cristo fault zone, having been either eroded or sparsely deposited on the uplifted, eastern side of the fault. Aeromagnetic data, which is sensitive to the depth of strongly magnetic rocks such as basalt (fig. 1), suggests that the Servilleta Basalt (Tsb) is buried to depths of 200 m or more in parts of the Culebra graben southeast of San Luis (Bankey and others, 2006; Thompson and others, 2007). The Servilleta Basalt appears to be rather shallow at several locations in the graben and on San Luis mesa.

The upper part of the Santa Fe Group contains tephra (Lava Creek B ash) from the 639±2 ka eruption of the Yellowstone caldera in northwestern Wyoming. This tephra is interbedded in fine-grained sediment (QTsf) that dips about 3° to the north and is capped by 3–5 m of coarse gravel (Qao). Thus, in the Culebra graben, the uppermost (and youngest) part of the Santa Fe Group is younger than about 640 ka (early middle Pleistocene). The older stream alluvium, which forms a complex alluvial fan on the Costilla Plains (southwest of the quadrangle, see Thompson and Machette, 1989), is everywhere coarser than and unconformable on sediments of the Santa Fe Group. We suspect that the older alluvium may be as old as 0.6–0.5 Ma on the basis of the thickness and morphology (advanced stage III) of calcic soils developed on the fan surface.

Uplift of the San Pedro mesa horst and subsidence of the adjacent Culebra graben to the east was mostly accomplished by movement on the bounding faults, as mentioned previously. Although Culebra Creek has probably been superposed across the horst since deposition of the Servilleta Basalt, it managed to keep pace with up-to-the-west-uplift on the San Luis fault zone. Old stream alluvium (Qao) is preserved along the banks of the creek in the horst and west of it; conversely, in the graben, old and intermediate stream alluvium (units Qao and Qai, respectively) are faulted and downdropped. Deposition of alluvium from the Culebra Range has kept pace with ongoing graben formation such that Culebra Creek flows across the sill formed by San Pedro mesa. However, the creek labors to maintain westward flow; both east and west of the San Luis fault zone, Culebra Creek has a meandering course whereas the course is more linear across the fault zone. Most of the topographically low part of the graben, which is covered by upper Pleistocene to Holocene alluvium, has a high water table, typically within 5 m of the surface. Outside of the graben, the ground-water table is tens to hundreds of meters deep, especially beneath the mesas and in the foothills of the Culebra Range.



MAP LOCATION

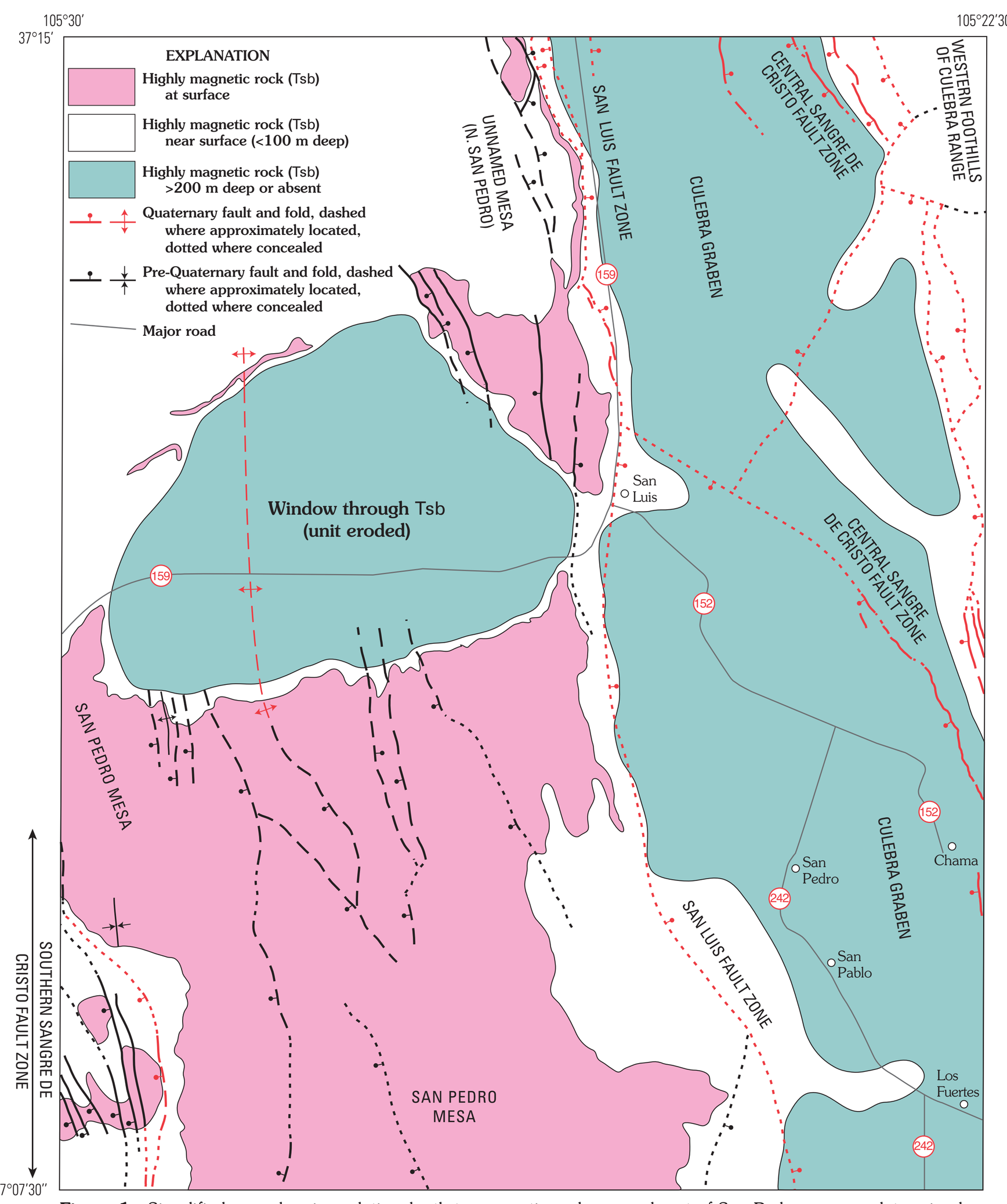


Figure 1. Simplified map showing relative depth to magnetic rocks on and east of San Pedro mesa as determined from high-resolution aeromagnetic data of Bankey and others (2006). Area west of San Luis is relatively deep to magnetic rocks owing to erosion of the Pliocene Servilleta Basalt (unit Tsb). These same depths probably extend to the north and south beneath the basalt-covered mesas, although Proterozoic rocks that are possibly rooted are present on San Pedro mesa, about 4.5 km south of the San Luis quadrangle (see Thompson and others, 2007).

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