APPENDIX 1. DESCRIPTIONS OF THE GEOLOGIC UNITS FOR THE QUESTA-AREA CROSS SECTIONS AND GEOLOGIC MAP, TAOS COUNTY, NEW MEXICO

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Descriptions of Geologic Units

Tailings ponds (modern-historic) – Areas of artificially deposited fill and debris; delineated where aerially extensive; consists predominantly of mining-related mill tailings and tailings dams west of Questa; the geologic map shows the pre-tailings geology, based on interpretation of aerial photos

Qal Alluvium (Holocene) – Poorly to moderately sorted sand, pebbles, and boulders in stream channels, valley floors, and active floodplains; weak to no soil development; clasts along the Red River are principally granitic rock types, quartzite, and basaltic; clasts along tributaries draining the western side of the Rio Grande are principally volcanic rock types; up to 7 m estimated thickness

Qt8rr Stream terrace deposits of the Red River (middle to late Holocene) – Poorly sorted silt, sand, pebbles, cobbles, and boulders; clasts primarily of quartzite, schist, granite, and volcanic rock types; deposits have negligible soil development; typically present as thin (< 5 m) alluvial deposit beneath high-stage floodplain or adjacent to active alluvial channels; equivalent to Qt8 of Kelson (1986) and Pazzaglia (1989)

Qt7rr Stream terrace deposits of the Red River (early to middle Holocene) – Poorly sorted silt, sand, pebbles, cobbles, and boulders; clasts primarily of quartzite, schist, granite, and volcanic rock types; associated soils have stage I calcium carbonate development; typically present as thin (< 5 m) alluvial deposit on strath surface cut on volcanic bedrock; equivalent to Qt7 of Kelson (1986) and Pazzaglia (1989)

Qfy Qty Young alluvial-fan and stream terrace deposits (latest Pleistocene to Holocene) – Poorly sorted silt, sand, pebbles, cobbles, and boulders; clasts primarily of quartzite, schist, granite, and volcanic rock types; associated soils have stage I calcium carbonate development; includes units Qf6 along the mountain front (Arroyo Seco quadrangle), Qt6 (Los Cordovas quadrangle) and Qt8 (Arroyo Hondo and Arroyo Seco quadrangles) of Kelson (1986)
**Qfyv**  
*Young alluvial-fan deposits from volcanic terrane* (latest Pleistocene to Holocene) – Poorly sorted silt, sand, pebbles, cobbles, and boulders; clasts primarily of volcanic rock types; associated soils have stage I calcium carbonate development; source areas primarily volcanic terrane on west side of Rio Grande and drainages on Guadalupe Mountain

**Qsw**  
*Sheetwash alluvium* (late Pleistocene to Holocene?) – Alluvial aprons composed mostly of pebbly to silty sand that accumulated on gentle slopes, such as those on Servilleta Basalt (Tsb); some of the silt- to fine sand-size fraction in these deposits may be of eolian origin (Shroba and Thompson, 1998); deposits of unit Qsw along the shores of intermittent ponds or small lakes on Servilleta Basalt (Tsb); low-lying areas of unit Qsw are susceptible to sheet flooding due to unconfined overland flow, and locally to stream flooding and gullyng; recently disturbed surface of unit Qsw may be susceptible to minor wind erosion; estimated thickness is 1 to 5 m, but possibly as much as 10 m (Thompson et al., 2014)

**Qe**  
*Eolian deposits* (late Pleistocene to Holocene) – Poorly to well-sorted sand and silt occurring primarily as a mantle or blanket; rare gravel lag; poorly exposed except in local road cuts; located predominantly on western side of the Rio Grande; weak to moderate soil development; predominant wind direction from southwest

**Qt6rr**  
*Stream terrace deposits of the Red River* (latest Pleistocene) – Poorly sorted silt, sand, pebbles, cobbles, and boulders; clasts primarily of quartzite, schist, granite, and volcanic rock types; associated soils have stage I to II calcium carbonate development; typically present as thin (< 5 m) alluvial deposit on strath surface cut on volcanic bedrock or unit QT1; associated with the Q6 surface of Kelson (1986)

**Qt5rr**  
*Stream terrace deposits of the Red River* (late Pleistocene) – Poorly sorted silt, sand, pebbles, cobbles, and boulders; clasts primarily of quartzite, schist, granite, and volcanic rock types; associated soils have stage II to III calcium carbonate development; typically present as thin (< 5 m) alluvial deposit on strath surface cut on volcanic bedrock or unit QT1; associated with the Q5 surface of Kelson (1986)

**Qls**  
*Landslides in Rio Grande gorge and tributaries* (late Pleistocene to Holocene) – Poorly sorted sand to boulders, includes rotational slide blocks (toreva blocks) within the Rio Grande and Rio Pueblo de Taos gorges involving detached blocks of Servilleta Basalt (Tsb); may also include areas underlain by Holocene colluvium in Rio Grande and Red River gorges

**Qmt**  
*Moraine and till* (Pleistocene) – Terminal and lateral moraines, and thick valley-bottom till; poorly sorted and generally unstratified clay, silt, and sand containing erratic boulders; characterized by hummocky or ridged topography; some till is mapped with colluvium (Lipman and Read, 1989)
**Qs**  
Talus and scree (Pleistocene to Holocene) – Angular rock fragments as much as 1 m in diameter forming talus cones, talus aprons and scree slopes; locally well sorted; grades into colluvium as sand and silt content increases; shown only in the Sangre de Cristo Mountains by Lipman and Read (1989)

**Qc**  
Colluvium (middle Pleistocene to Holocene) – Mostly locally derived, poorly to moderately sorted, angular to well-rounded sand, pebbles, and boulders; mapped on hill slopes and valley margins only where it obscures underlying relations; mantles slopes in Red River gorge and northeastern side of Red River fault zone in eastern part of Guadalupe Mountain quadrangle; prevalent along bases of mountain-front facets; north of Rio Pueblo de Taos dominated by quartzite and granitic rock types; south of Rio Pueblo de Taos dominated by sandstone and pebble conglomerate with minor limestone clasts; in northwestern part of Arroyo Hondo quadrangle (west of Rio Grande), consists of thin mantle overlying volcanic bedrock; estimated at generally less than 5 m thick

**Qt4rr**  
Stream terrace deposits of the Red River (middle? to late Pleistocene) – Poorly sorted silt, sand, pebbles, cobbles, and boulders; clasts primarily of quartzite, schist, granite, and volcanic rock types; associated soils have stage III calcium carbonate development, argillic Bt soil horizons and 10YR to 7.5YR hues in Bt horizons; typically present as thin (< 5 m) alluvial deposit on strath surface cut on volcanic bedrock or unit QT1; associated with the Q4 surface of Kelson (1986)

**Qt3rr**  
Stream terrace deposits of the Red River (middle? to late Pleistocene) – Poorly sorted silt, sand, pebbles, cobbles, and boulders; clasts primarily of quartzite, schist, granite, and volcanic rock types; associated soils have stage III calcium carbonate development; typically present as thin (< 5 m) alluvial deposit on strath surface cut on volcanic bedrock or unit QT1; equivalent to Qt3 of Kelson (1986) and Pazzaglia (1989)

**Qao3**  
Older alluvium (middle? Pleistocene) – Poorly sorted silt, sand, and pebbles; clasts primarily of granitic, metamorphic, basaltic, and intermediate volcanic rocks; distinctly smaller clast sizes than units Qt2rr, Qt1rr, and Qt0rr; upper soil horizons locally affected by surface erosion; may be mantled locally by unit Qe; typically present as thin (< 5 m) alluvial deposit on strath surface cut on volcanic bedrock near rim of Rio Grande gorge; located only upstream of the Red River fault zone; correlative with unit Qao3 in Sunshine quadrangle (Ruleman et al., 2007)

**Qt2rr**  
Stream terrace deposits of the Red River (middle? Pleistocene) – Poorly sorted silt, sand, pebbles, cobbles, and boulders; clasts primarily of quartzite, schist, granite, and volcanic rock types; associated soils have stage III to IV calcium carbonate development; typically present as thin (< 5 m) alluvial deposit on strath surface cut on volcanic bedrock or unit QT1; includes correlative terrace deposit flanking southwestern side of Lama
Canyon on the Questa and Guadalupe Mountain quadrangles; equivalent to Qt2 of Kelson (1986) and Pazzaglia (1989)

**Qfo**  
**Alluvial fan deposits, undivided** (middle to late Pleistocene) – Poorly sorted silt, sand, pebbles, and cobbles; in Guadalupe Mountain quadrangle, composed primarily of intermediate and basaltic volcanic clasts; probably overlaps with units Qf2, Qf3, and Qf4, and with alluvial units Qt2 through Qt6, but not assigned to other fan units because of lack of well-defined age control, clear stratigraphic position, and distinct lithologic characteristics

**Qt1rr**  
**Stream terrace deposits of the Red River** (middle Pleistocene) – Poorly sorted silt, sand, pebbles, and boulders; clasts of basalt, quartzite, metamorphic rock types, and volcanic rock types; soil development not documented but upper soil horizons probably affected by surface erosion; present only locally along rim of Red River gorge, where it is inset into Qt0rr gravel deposits and Tertiary volcanic rocks

**Qf1**  
**Alluvial-fan deposits** (middle Pleistocene) – Poorly sorted silt, sand, pebbles, and boulders; stage III to IV calcium carbonate development, although soil horizons are commonly affected by surface erosion; Qf1 is differentiated from QT_L by larger clast size (Kelson, 1986), less oxidation, poor sorting, absence of abundant manganese oxide staining, and clasts that are less weathered; tephra within Qf1 deposits on Ranchos de Taos quadrangle near Stakeout Road was dated at 1.27±0.02 Ma (40Ar-39Ar method, W. McIntosh, personal commun., 1996); unit is more than 5 m thick in northeastern part of the Questa quadrangle, and thins from northeast to southwest

**Qtu**  
**Stream terrace deposits, undivided** (middle to late Pleistocene) – Poorly sorted silt, sand, pebbles, and boulders; clasts primarily of quartzite, schist, granite, and volcanic rock types; associated soils have stage II to III calcium carbonate development; typically present as thin (< 5 m) alluvial deposit on strath surface cut on volcanic bedrock or unit QT_L; probably correlative with Qt1 through Qt4

**Qt0rg**  
**Stream gravel deposited by ancestral Rio Grande** (early? to middle? Pleistocene) – Poorly sorted sand, pebbles, and cobbles; clasts of basalt, quartzite, slate, schist, other metamorphic rock types, and volcanic rock types; very rare Amalia Tuff clasts; associated with broad, highest terrace west of Rio Grande; upper soil horizons commonly affected by surface erosion; locally mantled by eolian sand

**Qt0rr**  
**Old stream terrace deposits flanking the Red River and tributaries** (early? to middle? Pleistocene) – Poorly sorted sand, pebbles, and cobbles; clasts of basalt, quartzite, and many volcanic and metamorphic rock types; upper part commonly affected by surface erosion; present upstream and downstream of Red River Fish Hatchery and in the confluence area between the Rio Grande and Red River; merges with unit Qt0rg in southern-most part of Guadalupe Mountain quadrangle and in Arroyo Hondo quadrangle
**Lama formation** (Pliocene to early? Pleistocene) – Poorly sorted sand, pebbles, and cobbles; clasts of basalt, quartzite, other metamorphic rock types, and other volcanic rock types; locally high percentage of angular to subangular quartzite pebbles and cobbles; commonly cross-bedded, and stained with black manganese oxide and yellowish-orange iron oxide coatings; oxidized; clasts are typically weathered or grussified; contains distinct discontinuous sandy interbeds; commonly crudely imbricated; imbrication suggests westerly flow direction in area north of Taos Municipal Airport, and southerly flow direction in areas north and west of Rio Pueblo de Taos, with northwesterly flow direction in area southeast of Rio Pueblo de Taos; well drillers records in the Questa area show clay layers (labeled “clay” on cross sections) in the shallow subsurface that are interpreted as lacustrine deposits; the unit is present between the Sangre de Cristo Mountains range front and the Rio Grande gorge over most of the map area; correlative with Lambert’s (1966) two informal facies of the “Servilleta Formation” (the “sandy gravel facies” found south of the Rio Hondo, and the “gravelly silt facies” found between the Rio Hondo and the Red River); correlative with Kelson’s (1986) informal “Basin Fill deposit”; correlative with the unit previously informally called “Blueberry Hill formation” in the Taos area; also correlative with Pazzaglia’s (1989) late Neogene-Quaternary rift fill sequence (unit Q1) which he informally named the Lama formation; herein the Lama formation is defined as the uppermost, pre-incision, sedimentary rift fill, and where extant represents the uppermost member of the Santa Fe Group; the unit therefore includes all of the basin fill between the oldest Servilleta Basalt (ca. 5.2 Ma) and the oldest Rio Grande (and tributary) terrace gravels (e.g., Qt0rg, Qt0rr); the Lama formation and the underlying Chamita Formation are texturally and compositionally similar and may be indistinguishable in boreholes, although Koning et al. (2015) noted a coarsening of sediment (south of this map area) that roughly coincides with the Chamita/Lama contact in this map area; the top of the Lama formation is typically marked by a sharp unconformity and color/textural contrasts with overlying gravels; the unit contains several laterally variable components of sedimentary fill that are associated with various provenance areas related to east- or west-flowing tributary watersheds that have been fairly persistent in the late Cenozoic; locally contains tephra layers; reworked tephra in a road cut near the Red River Fish Hatchery (elevation ca. 7160 ft) was probably derived from nearby ca. 5 Ma volcanic units (R. Thompson, personal comm., 2015); a tephra in the uppermost Lama formation yielded a date of ~1.6 Ma based on a chemical correlation with the 1.61 Ma Guaje Pumice eruption in the Jemez Mountains (elevation ca. 7660 ft, M. Machette, USGS, written comm., 2008); thickness ranges from zero to an exposed thickness of about 25 m at the southwestern end of Blueberry Hill, but may be considerably thicker in other parts of the map area.

**Santa Fe Group, undivided** (Miocene) – In cross section only. Basin-fill clay, silt, sand, pebbles, cobbles, and boulders of the Rio Grande rift; principally of the Chama-El Rito and Ojo Caliente Sandstone members of the Tesuque Formation; thickness unknown
**Tsb**  
**Servilleta Basalt** (Pliocene) – Tsb can locally be subdivided into lower Servilleta Basalt (TsbL), middle Servilleta Basalt (TsbM), and upper Servilleta Basalt (TsbU), although this map shows only TsbL and TsbU; flows of dark-gray tholeiitic basalt characterized by small olivine and tabular plagioclase phenocrysts, diktytaxitic texture, and local vesicle pipes and segregation veins; forms thin, fluid, widespread pahoehoe basalt flows of the Taos Plateau volcanic field erupted principally from large shield volcanoes in the central part of the Taos Plateau (Lipman and Mehnert, 1979) but also from several small shields and vents to the northwest of the map area near the Colorado border (Thompson and Machette, 1989; K. Turner, personal comm., 2014); additional buried vents west of the Rio Grande are likely; flows typically form columnar-jointed cliffs where exposed, with a maximum thickness of approximately 50 m in the Rio Grande gorge approximately 16 km northwest of Taos; separated by sedimentary intervals as much as 70 m thick in the southern part of the map area (Leininger, 1982); $^{40}$Ar-$^{39}$Ar ages from basalts exposed in the Rio Grande gorge (Cosca et al., 2014) range in age from $4.78 \pm 0.03$ Ma for the lowest basalt near the Gorge Bridge, to $3.59 \pm 0.08$ Ma for the highest basalt flow at the Gorge Bridge, broadly consistent with previous results by Appelt (1998); the base of the upper Servilleta Basalt lava flow section at La Junta Point yielded an $^{40}$Ar-$^{39}$Ar age of $3.78 \pm 0.08$ Ma (sample 10RG05 - M. Cosca, personal comm., 2014), whereas a lava flow at the base of the section south of Cerro Chiflo yielded an $^{40}$Ar-$^{39}$Ar age of $3.78 \pm 0.08$ Ma (sample RT08GM02 - M. Cosca, personal comm., 2014). The base of the Servilleta Basalt (TbsL) at La Junta Point yielded an $^{40}$Ar-$^{39}$Ar age of $5.22 \pm 0.11$ Ma (M. Cosca, personal comm., 2014).

**Tc**  
**Chamita Formation, Santa Fe Group** (Miocene? and Pliocene) – In cross section only. Sedimentary deposits between the lowest Servilleta Basalt and the Tesuque Formation; typically rounded to subrounded pebble- to cobble-size clasts in a sand to silt matrix; thick sections to the south reflect Proterozoic clast provenance and are dominated by schist, quartzite, and amphibolite with lesser volcanic clasts derived from the Latir volcanic field; locally, thin interbeds are typically dominated by pebble-size clasts in a fine sand to silt matrix and commonly includes the rock types above in addition to subangular and subrounded volcanic clasts derived locally from adjacent volcanic highlands of the Taos Plateau volcanic field.

**Tdmc**  
**Dacite of Unnamed Cerrito East of Montoso (UCEM) near-vent deposits** (Pliocene) – Near-vent deposits associated with lava flows of map unit Tdm; predominantly cinder, spatter agglutinate and volcanic bombs locally.

**Tdm**  
**Dacite of Unnamed Cerrito East of Montoso (UCEM)** (Pliocene) – Dark gray, sparsely phryic, low-silica, calc-alkaline dacite (64 wt% SiO2, 6 wt% Na2O+K2O) lava flows erupted from two vent areas east of Cerro Montoso; contains rare skeletal pyroxene phenocrysts and resorbed, subhedral olivine and quartz xenocrysts in a microcrystalline to glassy groundmass; locally includes small volume, aerially restricted andesite flows (McMillan and Dungan, 1986); $^{40}$Ar-$^{39}$Ar age determinations of $4.08 \pm 0.04$ Ma (sample
11RG42) and 4.6 ± 0.02 Ma (sample 11RG27) from north and south UCEM areas respectively (M. Cosca, personal comm., 2014); Appelt (1998) reported a similar 40Ar-39Ar age determinations of 4.16 ± 0.13 Ma from the northern part of mapped UCEM deposits; caps west rim of Rio Grande gorge, forming thin veneer, rarely more than single flow thickness on underlying flows of Servilleta Basalt (unit Tsbu) and local interbedded sedimentary deposits (Leininger, 1982; Peterson, 1981); neither relations are shown at the scale of this map due to extensive distribution of landslide deposits (unit Qls) in the southern part of the Rio Grande gorge in map area; scoria and spatter agglutinate common near poorly defined vent areas

**Tvr**

**Volcanic deposits of Red River volcano** (Pliocene) – Dacite lava flow and near vent pyroclastic deposits of moderate relief on the south side of Guadalupe Mountain and in canyon exposures in the middle and upper reaches of the Red River where dacite lava flows cap the gorge sequence on both sides of the drainage; lava flow exposed on both side of the Red River were fed locally by dikes exposed on both sides of the canyon; McMillan and Dungan (1986) reported chemical compositions for the underlying basaltic andesite (unit Tvhc) to dacite suite ranging from 52-61 wt% SiO2 and 4.2-7.4 wt% Na2O +K2O; medium grey dacite lavas are porphyritic, containing 5-15% phenocrysts of augite and bronzite with common olivine xenocrysts in a fine-grained to glassy groundmass of plagioclase, glass, pyroxenes, and titanomagnetite (McMillan and Dungan, 1986); dacite lavas are typically thick, up to tens of meters locally, and are characteristically discontinuous and aerially restricted; deposits of the Red River volcano overlie andesitic lava flows of the Hatchery volcano (unit Tvh) and locally deposits of south Guadalupe Mountain (unit Tdgs); 40Ar-39Ar age determination of 4.67 ± 0.06 Ma (sample RT08G-M12 - M. Cosca, personal comm., 2014) was obtained from a sample collected near the northeastern limit of exposed deposits

**Tvhc**

**Volcanic deposits of Hatchery volcano, near vent** (Pliocene) – Near-vent deposits associated with lava flows of map unit Tvh, predominantly cinder, spatter and agglutinate exposed in the Red River drainage approximately 1.25 kilometers northwest of the New Mexico State Fish Hatchery; near-vent spatter, agglutinate, and volcanic bombs are common near hill 7590’ on the south side of the Red River

**Tvh**

**Volcanic deposits of Hatchery volcano** (Pliocene) – Includes a sequence of lava flow, intercalated volcanic breccia, and near vent pyroclastic deposits in canyon exposures in the middle and upper reaches of the Red River drainage and as low relief hills adjacent to the Red River; lava flows include a series of predominantly basaltic andesite and andesite lava flows; McMillan and Dungan (1986) reported chemical compositions for the basaltic andesite to overlying dacite (unit Tvr) ranging from 52-61 wt% SiO2 and 4.2-7.4 wt% Na2O+K2O; dark gray basaltic andesite and andesite lava flows typically contain 5-10% phenocrysts of olivine and plagioclase; olivine phenocrysts can be large (up to 6mm) exhibiting well-developed skeletal overgrowths (McMillan and Dungan, 1986); andesite lava flows with aa flow tops and well exposed basal flow breccias tend to be thin, a few meters to 10 m thick, and are laterally continuous based on exposures in the Red River
canyon; deposits of the Hatchery volcano overlie dacite lava flows of Guadalupe Mountain, and locally overly two lava flows of Servilleta Basalt at the base of the Red River gorge near the New Mexico State Fish Hatchery (not differentiated at the map scale); $^{40}$Ar/$^{39}$Ar age determination of 4.82 ± 0.07 Ma (sample 11RG42 - M. Cosca, personal comm., 2014) was obtained from a sample at the base of the section approximately 0.6 km southwest of the New Mexico State Fish Hatchery

Tao **Andesite of Cerro de la Olla** (Pliocene) – Dark gray to black, porphyritic olivine andesite (58.5 wt% SiO2, 6.9 wt% Na20+K20) lava flows erupted from vents near summit of Cerro de la Olla, one of the largest, petrologically uniform, shield volcanoes of the Taos Plateau volcanic field (Lipman and Mehnert, 1979); contains 2-3% phenocrysts of olivine in a microcrystalline groundmass of plagioclase, olivine, augite, Fe-Ti oxides; the lower slopes of Cerro de la Olla in the northwestern part of the map area are commonly mantled in colluvium and rarely preserve well-developed flow morphology; instead outcrops typically exhibit blocky flow tops and remnants of numerous discontinuous and aerially restricted flow lobes; Appelt (1998) reported $^{40}$Ar-$^{39}$Ar ages of 5.03 ± 0.06 Ma for a groundmass separate from the west side of Cerro de la Olla

Tdgn **Dacite of Guadalupe Mountain, north** (Pliocene) – Predominantly trachydacite lava flows (62 wt% SiO2, 6.3 wt% Na20+K20) and associated near-vent pyroclastic deposits; contains sparse, small phenocrysts of plagioclase, hypersthene, and augite in a pilotaxitic glassy groundmass; proximal lava flows, lava dome remnants and near-vent pyroclastic deposits consisting mostly of spatter and agglutinate of the geographic north peaks of Guadalupe Mountain; spatter and cinder deposits are found locally in association with flank lavas and may represent remobilized central vent deposits or mark the location of satellite vents on the flanks of north Guadalupe Mountain; distinguished from lava flows of south Guadalupe Mountain on the basis of reversed magnetic polarity based on paleomagnetic and aeromagnetic determinations (M. Hudson and V.J.S. Grauch respectively, personal comm., 2014); $^{40}$Ar/$^{39}$Ar age determination of 5.04 ± 0.04 Ma (sample 10RG06 - M. Cosca, personal comm., 2014)

Tdgs **Dacite of Guadalupe Mountain, south** (Pliocene) – Predominantly trachydacite lava flows (62 wt% SiO2, 6.3 wt% Na20+K20) and associated near-vent pyroclastic deposits; contains sparse, small phenocrysts of plagioclase, hypersthene, and augite in a pilotaxitic glassy groundmass; proximal lava flows, lava dome remnants and near-vent pyroclastic deposits consisting mostly of spatter and agglutinate of the geographic south peaks of Guadalupe Mountain; distinguished from lava flows of north Guadalupe Mountain on the basis of reversed magnetic polarity based on paleomagnetic and aeromagnetic determinations (M. Hudson and V.J.S. Grauch respectively, personal comm., 2014); $^{40}$Ar/$^{39}$Ar age determination of 5.00 ± 0.04 Ma (sample 10RG07 - M. Cosca, personal comm., 2014); stratigraphic position relative to unit Tdgn is based on geophysical modeling of aeromagnetic data (B. Drenth, V.J.S. Grauch, personal comm., 2014) and age constraints relative to geomagnetic time scale; Appelt (1998) reported $^{40}$Ar/$^{39}$Ar ages of 5.17 ± 0.08 and 5.41 ± 0.06 Ma for groundmass separates from the south side of Guadalupe Mountain
Tdg  **Dacite of Guadalupe Mountain, undifferentiated** (Pliocene) – Predominantly trachydacite lava flows (62 wt% SiO$_2$, 6.3 wt% Na$_2$O+K$_2$O); contains sparse, small phenocrysts of plagioclase, hypersthene, and augite in a pilotaxitic glassy groundmass; distal lava flows exposed in the Rio Grande gorge and the Red River gorge are highly elongate and individual flows are laterally restricted, typically forming overlapping finger-like lobes characterized by radial cooling fractures and concentric brecciated carapaces where exposed in cross section; flows exposed in the Rio Grande gorge range considerably in thickness from a few meters to several tens of meters; lava flow directions exposed in the Rio Grande gorge appear to be predominantly from east to west, suggesting a primary source area at Guadalupe Mountain; dacite lava flows overlie both Cerro Chiflo dome deposits and lower Servilleta Basalt lava flows in the Rio Grande gorge; $^{40}$Ar/$^{39}$Ar age determination of 5.27 ± 0.05 Ma (sample 11RG08 - M. Cosca, personal comm., 2014)

Tam  **Andesite of Cerro Montoso** (Miocene) – Dark gray to black, porphyritic olivine andesite (57.6 wt% SiO$_2$, 8 wt% Na$_2$O+K$_2$O) lava flows erupted from vents on Cerro Montoso, one of the largest, petrologically uniform, shield volcanoes of the Taos Plateau volcanic field (Lipman and Mehnert, 1979); contains 2-3% phenocrysts of olivine in a microcrystalline groundmass of plagioclase, olivine, augite, Fe-Ti oxides; the lower slopes of Cerro Montoso in the western side of the map area are often mantled in colluvium and rarely preserve well-developed flow morphology; instead outcrops typically exhibit blocky flow tops and remnants of numerous discontinuous and aerially restricted flow lobes; Appelt (1998) reported an $^{40}$Ar-$^{39}$Ar age of 5.95 ± 0.18 Ma for a groundmass separate from the west side of Cerro Montoso

Tvc  **Trachyandesite of Cerro Chiflo** (Miocene) – Eroded remnants of large lava dome of porphyritic trachyandesite (63 wt% SiO$_2$, 7.7 wt% Na$_2$O+K$_2$O; rock designation based on IUGS classification (Le Bas and others, 1986); formerly described by Lipman and Mehnert (1979) as quartz latite; forms prominent cliff outcrops along Rio Grande gorge in northern part of map area; light brown to gray, weakly to strongly flow laminated, with phenocrysts of plagioclase, hornblende, and sparse biotite in a devitrified groundmass; xenoliths of Proterozoic schist, gneiss, and granite are common; flow breccias preserved around margins of dome and ramp structures common throughout the exposed interior; Appelt (1998) reported $^{40}$Ar-$^{39}$Ar ages of 5.38 ± 0.31 and 5.39 ± 0.08 Ma for groundmass separates from the west and east sides of the dome, respectively; more recent, preliminary $^{40}$Ar-$^{39}$Ar total fusion age determinations of approximately 10.65 Ma and approximately 9.86 Ma on biotite and hornblende separates respectively (sample 11RG43 - M. Cosca, personal comm., 2014) are more consistent with previously determined Miocene potassium-argon ages reported by Lipman and Mehnert (1979)

Tvb  **Volcanic deposits of Brushy Mountain** (Oligocene) – Volcanic rocks and deposits consisting primarily of andesite to dacite lava flows and flow breccias and rhyolite block-and-ash flows and ash-flow tuff with volumetrically minor air-fall deposits (Thompson et
al., 1986; Thompson and Schilling, 1988). Light tan, poorly welded, lithic-rich, rhyolite ash-flow tuff forms base of section near low saddle of Brushy Mountain; lower rhyolite contains phenocrysts of plagioclase and altered biotite, light brown altered pumice and angular to subangular vitrophyric inclusions (<0.5 cm to several cm) containing plagioclase phenocrysts and reddish-brown dacite inclusions (2 cm to several cm); locally overlain by thin outflow deposits of Amalia Tuff; post-Amalia Tuff deposits include light-grey to white rhyolite dome deposits including locally, block-and-ash flows, ash-flow tuffs, and air-fall deposits; all deposits are mineralogically similar containing sanidine, quartz, and minor biotite phenocrysts in a devitrified glass matrix; exposed in quarry on south side of Brushy Mountain and north side of Cerro Montoso; thin (< 2-3 m) andesite lava flows locally overlie rhyolite dome deposits and consist of medium- to dark-brown, porphyritic flows and flow remnants containing olivine, clinopyroxene, and plagioclase phenocrysts, plagioclase glomerocrysts, and minor orthopyroxene microphenocrysts in a fine- to medium-grained trachytic groundmass composed predominantly of plagioclase, clinopyroxene, and Fe-Ti oxides; the upper part of the section consists of light- to dark-gray, aphyric to porphyritic, dacite lava flows and flow breccias containing variable amounts of hornblende, plagioclase, clinopyroxene, Fe-Ti oxides, and minor orthopyroxene, sanidine, sphene, and zircon in a fine-grained to microcrystalline groundmass; lava flows are locally variable in thickness, discontinuous and commonly delineated on the basis of blocky rubble deposits and float; in the Rio Grande gorge, deposits are dominantly andesite to dacite breccias and reworked pyroclastic deposits overlying biotite and hornblende-bearing dacite lava flows; Zimmerer and McIntosh (2012) reported 40Ar/39Ar age determination on sanidine from a basal rhyolite of the Brushy Mountain section of 25.49 ± 0.04 Ma and 22.98 ± 0.08 from groundmass concentrates from an andesite lava flow in the upper part of the section.

**Volcanic deposits of Timber Mountain** (Oligocene) – Volcanic rocks and deposits consisting primarily of andesite to dacite lava flows and flow breccias and lesser rhyolite flows and ash-flow tuff (Thompson et al., 1986; Thompson and Schilling, 1988); light-brown, lithic-poor, densely welded, rhyolite ash-flow tuff forms base of section and contains moderately to highly flattened pumices, phenocrysts of plagioclase, sanidine, quartz, and biotite with subordinate amounts of Fe-Ti oxides, clinopyroxene, and orthopyroxene in a glassy to partially devitrified matrix; rhyolite ash-flow tuff is overlain by a lower sequence of moderately porphyritic lava flows and pyroclastic deposits containing variable amounts of plagioclase, clinopyroxene, Fe-Ti oxides, hornblende, plus or minus biotite, and sanidine xenocrystals; locally contains abundant quenched micropillow inclusions of basaltic lava and dacite xenoliths as much as 10 cm in diameter; lower dacite sequence is separated from an upper dacite sequence locally by medium- to dark-brown, porphyritic lava flow remnants containing olivine, clinopyroxene, and plagioclase phenocrysts, plagioclase glomerocrysts, and minor orthopyroxene microphenocrysts in a fine- to medium-grained trachytic groundmass composed of plagioclase, clinopyroxene, and Fe-Ti oxides; upper dacite sequence contains medium- to light-gray porphyritic, glassy lava flows and lava dome remnants containing phenocrysts of hornblende, biotite, plagioclase, clinopyroxene, and Fe-Ti oxides in variable proportion; a whole rock 40Ar/39Ar age of 24.22 ± 10
0.12 Ma (M. Cosca, personal comm., 2014) was obtained from a basal dacite vitrophyre southwest of the map area

**Tat**

**Amalia Tuff** (Oligocene) – Light gray to light brown moderately welded porphyritic, peralkaline, rhyolite ash-flow tuff erupted from the Questa caldera just east of the Village of Questa (Lipman and Reed, 1989); consists primarily of quartz and sanidine phenocrysts in a devitrified matrix; Fe-Ti oxides, titanite, and alkali amphibole phenocrysts are minor, lithic fragments are common; forms low erosional hills of outflow near Brushy Mountain in the Guadalupe Mountain quadrangle; Zimmerer and Mcintosh (2012) reported a mean age of 25.39 ± 0.04 Ma based on 1340Ar-39Ar laser fusion analyses of Amalia Tuff

**Tu**

**Tertiary igneous rocks, undivided** (Oligocene and Miocene) – Undivided plutonic and volcanic rocks of the Questa caldera and Latir volcanic field exposed in the Sangre de Cristo Mountains and inferred in the subsurface of the Rio Grande rift; combined in unknown proportions with undivided Proterozoic basement rocks (Xu); these rocks are subdivided on the map of Lipman and Reed (1989)

**XYu**

**Proterozoic basement rocks, undivided** (Paleoproterozoic and Mesoproterozoic) – Undivided Proterozoic crystalline rocks exposed in the Sangre de Cristo Mountains and inferred in the subsurface of the Rio Grande rift; combined in unknown proportions with undivided Tertiary igneous rocks (Tu); these rocks are subdivided on the map of Lipman and Reed (1989)
Mapping Credits and Acknowledgments

Guadalupe Mountain quadrangle

Previous mapping by Pazzaglia (1989) in the area west of the mountain front was incorporated into our mapping of late Quaternary deposits and surfaces, and was refined based on our analysis of detailed aerial photography and field reconnaissance. Where mill tailings cover the original land surface, stereopaired, color aerial photography (at a scale of approximately 1:16,000) was used to infer the geology. Google Earth imagery (September, 2013) was used to draw the extent of the modern mill tailings. We incorporated some map elements from two unpublished volcanologic geologic maps of Guadalupe Mountain by Vail (1987) and R. Leonardson (courtesy of Chevron). South of Guadalupe Mountain, we also included appropriate parts of a reconnaissance study by Golder Associates (2007).

The digital cartographic work was performed by M. Mansell of the New Mexico Bureau of Geology & Mineral Resources.

Acknowledgments: We thank the many landowners in the map area who provided land ownership information and permitted us to traverse their properties. We are especially appreciative of the assistance of the staff of the BLM Wild Rivers Recreation Area. Bruce Walker of Chevron facilitated our access to Chevron Questa Mine lands. Dr. Tien Grauch and Dr. Ben Drenth of the USGS provided invaluable interpretation of the subsurface geology of the area with their high-resolution aeromagnetic map (Bankey et al., 2006) and gravity model.

Questa quadrangle

The current STATEMAP effort was concentrated on the western part of the quadrangle, westward from the basin/mountain contact and the Sangre de Cristo fault zone. Because of the existence of the 1:48,000-scale USGS geologic bedrock map by Lipman and Reed (1989), we made only local refinements to their depiction of the Proterozoic and Tertiary crystalline rocks of the Sangre de Cristo Mountains. Instead, we merged the USGS digital data coverage of the Lipman and Reed (1989) map with our 1:24,000-scale geologic mapping in the western part of the quadrangle. We apologize to the USGS authors for presenting their geology at a larger scale than intended, and applaud them for developing such an innovative geologic map in such a complex and high-relief area. We did perform interpretation of stereo-paired, color aerial photography (at a scale of approximately 1:16,000) on the primary surficial deposits (moraines, till, landslides) in the Sangre de Cristo Mountains, and provide an updated interpretation of those units on the map.

Where our bedrock/basin-fill contacts did not agree with those of Lipman and Reed (1989), our contacts were used. In places along the mountain front, Lipman and Reed (1989) mapped surficial deposits that we mapped as bedrock. In some of these cases, we could confidently infer the composition of the bedrock units, and labeled them as such. However, in other areas we were not able to infer the composition of the bedrock units, and therefore simply labeled the units as “Tertiary igneous rocks, undivided” (Tu). All of the faults shown along the Sangre de Cristo fault zone represent new mapping by the authors, and are based on 1:24,000-scale (or more detailed) field mapping and analysis of stereo-paired, color aerial photography (at a scale of approximately 1:16,000).

Unpublished geologic mapping exists in parts of the area of the Lipman and Reed (1989) map, especially around the molybdenum mine. However, none of that work has been incorporated into the current quadrangle map. Previous mapping by Pazzaglia (1989) in the area west of the mountain front was incorporated into our mapping of late Quaternary deposits and surfaces, and was refined based on our analysis of detailed aerial photography and field reconnaissance. Where mill tailings cover the original land sur-
face, stereo-paired, color aerial photography (at a scale of approximately 1:16,000) was used to infer the geology. Google Earth imagery (September, 2013) was used to draw the extent of the modern mill tailings. We incorporated some map elements from two unpublished volcanologic geologic maps of Guadalupe Mountain by Vail (1987) and R. Leonardson (courtesy of Chevron). South of Guadalupe Mountain, we also included appropriate parts of a reconnaissance study by Golder Associates (2007). Previous mapping of fault traces by Personius and Machette (1984), Menges (1988, 1990), and Kelson et al. (1998a, 1998b) also were considered and revised on the basis of our analysis of detailed aerial photography and field reconnaissance.

The digital cartographic work merging the Lipman and Reed (1989) map with the current STATEMAP work was performed by M. Mansell and K. Seals of the New Mexico Bureau of Geology & Mineral Resources.

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