Geologic Map of the Picuris Mountains, Rio Arriba and Taos Counties, New Mexico

by

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Scale 1:24,000

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Geologic Mapping and Cross Sections

The geologic maps used in this compilation combine six geologic maps of 7.5-minute quadrangles that were completed under the NMBGMR STATEMAP Program. The maps are credited as follows:

1. Taos SW quadrangle (Bauer et al., 1997)
2. Ranchos de Taos quadrangle (Bauer et al., 2000)
3. Taos quadrangle (Bauer and Kelson, 2001)
4. Los Cordovas quadrangle (Kelson and Bauer, 2003)
5. Peñasco quadrangle (Bauer et al., 2005)
6. Tres Ritos quadrangle (Aby et al., 2007)

Geologic mapping was done principally by Paul Bauer, Keith Kelson, and Scott Aby between 1997 and 2007. Bauer focused on mapping basement rocks and structures. Kelson focused on air photo interpretation, geologic and geomorphic mapping of surficial deposits and Tertiary rocks, and fault scarps in Quaternary deposits. Aby focused on mapping the Santa Fe Group rocks and other sedimentary deposits.

The compilation map shows the distribution of rock units and unconsolidated, surficial, sand and gravel deposits, as well as the locations of known and inferred faults. Some of the geologic units shown in the cross sections are not exposed at the surface in the study area, but are exposed in nearby areas where they have been mapped and analyzed. The physical characteristics of some of these units (such as composition, thickness, texture, and lateral extent) are based on work in these nearby areas.

A primary goal was to provide a conceptual model of the large-scale geologic structure of the rift basins using geologic cross sections. Our approach was to understand the surficial structural geology around the edge of the basin by detailed mapping, and then to infer the subsurface basin structure using that knowledge and all other available data sets, including:

- photographic imagery
- boreholes
- geophysics
- surface structure
- geomorphology
- hydrology

The locations of the cross sections were chosen to optimize geologic and hydrogeologic understanding, maximize the number of useful wells that could be incorporated into the section lines, and utilize the geophysical insights provided by our U.S. Geological Survey colleagues; Dr. V.J.S. Grauch and Dr. Benjamin J. Drenth. The topographic profiles were generated by ArcGIS software.

The geologic units shown in the cross sections originated from three principal data sources:

1. 1:24,000 geologic quadrangle maps,
2. Interpretations from borehole geology and borehole geophysics, and
3. Interpretations from three geophysical data sets—a high-resolution aeromagnetic survey, ground-magnetic surveys, and gravity modeling.

The relevance of the various data sets in creating the geologic map and cross sections is briefly summarized below.

AERIAL PHOTOGRAMMETRY AND FIELD MAPPING

As part of delineating bedrock units, faults, and basin-fill sediments, the mappers analyzed multiple sets of photographic imagery, all of which have a high degree of clarity and provide good information on surficial deposits and fault-related features. Because of their good coverage and high quality, the air-photo analysis primarily utilized 1:15,840-scale color images taken for the USFS from 1973–1975. Following our analysis of aerial photography, we conducted detailed mapping of geologic units and geomorphic features at scales of 1:24,000, 1:12,000, and 1:6,000. Our mapping delineated Quaternary deposits and surfaces, and Quaternary faults, fault scarps, and lineaments. Analysis of faults in all units (Proterozoic to Quaternary) included evaluations of fault geometries and kinematic data.

On bedrock faults, fault striations (slickenlines) were combined with kinematic indicators such as offset piercing lines or planes, and calcite steps to infer slip directions. Because of limited fault exposures in Quaternary deposits, we inferred slip directions based on fault scarp geometry, the map pattern of fault strands, and deflected drainages.

BOREHOLES

The geologic and geophysical data attached to the drill holes in the study area ranged from wells with no data, to wells with extensive analyses of lithologic cuttings, different types of borehole geophysics, and a variety of aquifer and water-quality tests. Domestic well records in the study area are marginally useful for defining the subsurface stratigraphy, as most well drillers do not record the detailed characteristics of well cuttings. In contrast, geologic logs created by on-site geologists who examined well cuttings are generally very helpful for defining the subsurface stratigraphy.

GEOPHYSICS

A number of existing and new geophysical studies in the area were incorporated into this investigation. Each of these geophysical techniques can be used alone to provide useful constraints on the subsurface geology, but the real value of these techniques is that when they are interpreted collectively by a geophysicist, they can provide immensely valuable, detailed information on the subsurface geology. Each of the geophysical studies used in the current study are summarized below.

1. Existing high-resolution aeromagnetic survey (Dr. V.J.S. Grauch, USGS). In 2003, Dr. Grauch began a regional aeromagnetic survey of the San Luis Basin (Grauch et al., 2004; Bankey et al., 2006; Grauch et al., 2015). For the current study, she reexamined parts of the existing data set in order to develop an aeromagnetic anomaly map of the study area that shows buried faults and buried volcanic rocks. This method can be effective at delineating buried, large-scale, horizontal and vertical variations in rock type.
2. New ground-magnetic surveys (Dr. V.J.S. Grauch, USGS). Dr. Grauch ran select ground-based magnetic traverses across the Picuris piedmont. This method can precisely locate buried faults and other features that juxtapose materials with different magnetic properties.
3. Gravity surveys and regional gravity model (Dr. Benjamin J. Drenth, USGS). Dr. Drenth has been collecting detailed gravity data, and incorporating these data into a regional gravity model interpretation of the San Luis Basin (Drenth et al., 2015). His main goal was to improve understanding of the thickness of the basin-fill materials and the geometry of the rift basin. The gravity method is especially useful for estimating the general depth to basement rocks and for locating large-offset basement faults.

DEVELOPMENT OF CROSS SECTIONS

The following list describes the general steps that were taken to create the geologic cross sections developed for this study:

1. Geologic contacts are picked off of the geologic map. The surface geology is taken from the geologic map and placed on the topographic profile of the cross section. Geologic contacts that are buried by thin surficial deposits were estimated. Some of the thinnest Quaternary surficial deposits are not shown on the cross sections.
2. The gravity model is used to define the depth to basement rocks in the cross sections. The base of each cross section is constrained by the depth-to-basement curve derived from the USGS gravity model. The depth-to-basement curve depicts a highly smoothed contact between basin-fill sediments and bedrock. In the model, both Paleozoic sedimentary rocks and Proterozoic crystalline rocks are considered to be bedrock.
3. Geologic information derived from wells and boreholes is added to the cross sections. Expertly studied wells can help control the regional thicknesses and depths of key stratigraphic formations, including some of the basin-fill units such as the Lama formation and thick clay horizons. Most of the basin-fill stratigraphy (Tesuque Formation, Chamita Formation, and Lama formation) consist of poorly sorted, clay-to-boulder sized, alluvial material that was eroded from the nearby mountains. Unless the compositions and proportions of rock clasts and the color of the sediment are well described, it is not possible to tell them apart in drill holes. Although the depictions of these units on the cross sections are based

principally on borehole data, local stratigraphic relationships, and an understanding of the sedimentary systems and geologic processes of the area, it is possible that the thicknesses of the various basin-fill units are still not accurately represented. For example, in many areas where there is no Servilleta Basalt in the subsurface, it is not possible to confidently place the contact between the Chamita Formation and the Lama formation.

4. Mapped and inferred faults are drawn onto the cross sections. For the purposes of this study, the dips of the inferred Embudo faults were estimated to be between 70 and 80 degrees northward, unless evidence existed for some other orientation. In all cases, the geometries of the normal faults drawn in the cross sections are intentionally simplified as single inclined planes, when in fact all of the mapped normal faults in this area have much more complex geometries. They are typically curved, segmented, branched, and composed of multiple overlapping fault planes. Where exposed, faults in bedrock typically display wide fracture zones with high permeabilities, whereas faults in basin-fill sediments commonly display narrow, clay-rich cores with lower permeabilities.
5. Interpretations from geophysics are added to cross sections. With consultations from the USGS geophysicists, any additional information gleaned from the geophysics is added to the cross section. For example, this could include evidence for deeply buried volcanic rocks.
6. Conceptual models of volcanic and sedimentary processes are incorporated into the cross sections. For example, in this part of the basin, Servilleta Basalt lavas flowed predominantly south and southeast, and therefore would be expected to thin across Embudo fault scarps and interact in complex ways with north- and northwest-prograding alluvial fans from the Picuris and Sangre de Cristo Mountains.
7. Information from the hydrology is added to the cross sections. Hydrologic information such as the locations of spring zones, water levels in wells, the locations of streams and acequias, and variations in field parameters such as groundwater temperature, may be included on the cross sections. Where we have studied the hydrogeology of springs in Taos County, we have found that the location and characteristics of springs are strongly influenced by the geology (Bauer et al., 2007). Specifically, springs tend to occur where contrasts in the hydraulic properties of the rocks exist. Such contrasts can be created by faults, by original variations in rock properties, and by post-depositional effects such as cementation.
8. Formation contacts are drawn onto the cross sections. Due to a lack of stratigraphic markers in the southern Taos Valley, the dips of the geologic units are generally unknown. Therefore, unless evidence exists for depicting local dips, contacts have been drawn as sub-horizontal. In most of the study area, thicknesses of buried basin-fill units are poorly constrained, and so the cross sections show approximate formation thicknesses.

9. The cross sections are checked against the geophysical models. After each cross section has been drawn, it is checked by our USGS colleagues against the geophysical models from the aeromagnetic and gravity surveys. Where the geophysical model is robust, this is an excellent way to fine tune the geologic model. For example, the aeromagnetic model might suggest that a volcanic layer shown in a cross section should be thicker or thinner, or that a fault must juxtapose materials with more extreme variations in magnetic properties. This iterative process between geologist and geophysicist is a powerful tool for developing well-constrained geologic models.

Depiction of faults in the cross sections

The fault structures depicted in the cross sections were established from three data sources:

1. Mapped faults from the geologic map. These faults are displayed with a high degree of certainty and are referred to as "mapped faults."
2. Faults inferred from the magnetic and gravity surveys. These faults are displayed with a moderate to high degree of certainty and referred to as "geophysical faults."
3. A conceptual model of the geometry and kinematics of the northern Rio Grande rift. Such faults must exist, but their exact locations are shown with a low degree of certainty. They are referred to as "inferred faults."

The geologic map shows a large number of mapped faults, including:

1) Segmented oblique-slip fault splays of the Embudo fault zone along the north flank of the Picuris Mountains
2) Normal faults of the Sangre de Cristo fault zone in the northeastern study area
3) Intrabasinal normal faults of the Los Cordovas fault zone
4) Bedrock strike-slip faults of the Picuris-Pecos fault system

Modern geophysical techniques using high resolution magnetic data and gravity data are capable of defining buried faults in Rio Grande rift basins, such as in the southern Taos Valley. U.S. Geological Survey geophysicists, Dr. V.J.S. Grauch and Dr. Benjamin J. Drenth, have refined these techniques in the Rio Grande rift. They are currently capable of processing the data in ways that allow them to accurately draw the locations of faults that create geophysical anomalies. There is good correspondence between the mapped faults and the geophysically defined faults, which elevates our confidence in the delineation of buried faults by such geophysical techniques. Gravity modeling by Dr. Drenth also provides an extremely useful tool for estimating the thickness of basin-fill deposits in the rift basin. This technique yields a depth-to-basement curve for the cross sections. As the basement deepens away from the edge of the rift, numerous buried (inferred) faults must exist in order to deepen the basement.

Description of Map Units

SEDIMENTARY ROCKS AND DEPOSITS OF THE RIO GRANDE RIFT AND ADJACENT HIGHLANDS

af **Artificial fill and disturbed land (Modern to historic)**—Excavations and areas of human-deposited fill and debris; shown only where aerially extensive.

Qal **Alluvium (Holocene)**—Generally brownish and/or reddish, poorly to moderately sorted, angular to rounded, thinly to thickly bedded, loose silt and silty sand with subordinate coarse lenses and thin to medium beds of mostly locally derived clasts; mapped in active channels, floodplains, low (young) alluvial terraces, tributary-mouth fans, and some valley-slope colluvial deposits; weak to no soil development; a single piece of charcoal from the northern fork of the upper Rito Cieneguilla in the Carson quadrangle, about 2 m above the floor of the modern wash, returned a conventional ^{14}C age of 2,795 ± 50 BP; three charcoal samples from the Trampas quadrangle yielded conventional ^{14}C ages of 3,275 ± 150 BP, 2,645 ± 125 BP, and 1,800 ± 55 BP; estimated at up to 7 m thick.

Qc **Colluvium (Holocene to middle Pleistocene)**—Mostly locally derived, light- to dark-brown, orange, and rarely reddish, poorly to moderately sorted, angular to well-rounded, silty to sandy conglomerate/breccia with clasts locally to >1 m; mapped on hill slopes and valley margins only where it obscures underlying relations; estimated at generally less than 5 m thick.

Qad **Alluvium in closed depressions (Holocene to latest Pleistocene)**—Light- to dark-brown, very thin- to medium-bedded, loose, massive, sandy to silty beds with thin, discontinuous layers of pebbles and rare cobbles (to ≈15 cm) found on Toreva (rotational) blocks associated with landslide complexes; at least several meters thick locally.

Qtr **Travertine deposits (Holocene to Pleistocene)**—Small travertine deposits located along extinct, fault-related springs in the Ranchos de Taos quadrangle.

Qac **Alluvial and colluvial deposits (Holocene to Pleistocene)**—Poorly exposed gravel and sand composed of Tertiary volcanic clasts and/or granitic clasts and gruss; overlies Tpl and Ttc+Tpt in a complexly faulted area in Miranda Canyon (Ranchos de Taos quadrangle); approximately 5 to 10(?) m thick.

Qls **Landslides in the Rio Grande gorge and tributaries (Holocene to Late Pleistocene)**—Poorly sorted rock debris and sand-to-boulder debris transported downslope; occurs on slopes marked by hummocky topography and downslope-facing scarps; includes small earth flow, block-slump, and block-slide deposits; includes large, rotational, Toreva slide blocks within the Rio Grande and Rio Pueblo de Taos (Taos SW quadrangle) gorges, which include large, rotated and detached blocks of intact Servilleta Basalt (**Tsb**); south of the Rio Grande, landslide deposits do not form well-defined lobes, as they do to the north, and may be partly colluvial; the southern deposits are poorly exposed, except in road cuts along the highway just north of Rinconada, where the deposits are arranged in thick, apparently tabular bodies with a range of compositions.

Qlb **Landslides of basalt (Holocene? to Late Pleistocene)**—Landslide deposits containing intact blocks of Tertiary basalt flows and abundant, subangular to angular basalt blocks; mapped separately only on slopes below the Ocaté (Vadito) basalt (**Tob**).

Qe **Eolian deposits (Holocene to Late Pleistocene)**—Light-colored, well-sorted, fine- to medium-grained sand and silt deposits that are recognized as laterally extensive, low-relief, sparsely vegetated, mostly inactive, sand dunes and sand sheets that overlie the Servilleta Basalt (**Tsb**) on the Taos Plateau; rare gravel lag; weak to moderate soil development; northeast-trending longitudinal dune-crest orientations indicate that the predominant wind direction was from the southwest; up to several meters thick.

Qg **Alluvial and minor colluvial deposits at high levels (Holocene to Pleistocene)**—Typically buff to brownish, rounded to well-rounded, crudely bedded, uncemented, quartzite-rich conglomerate and sandy conglomerate; maximum clast size up to 1 m but commonly about 60 cm; includes both primary Quaternary terrace gravels and reworked deposits derived from them; mapped south of the Picuris Mountains; two main types of **Qg** are present, one entirely dominated by quartzite clasts probably of the Rio de las Trampas drainage (Trampas quadrangle), and one containing ≈10% well-rounded, well-lithified Paleozoic sandstone cobbles probably of the Embudo Creek drainage (Trampas and Peñasco quadrangle); poorly exposed, locally includes multiple levels of closely spaced, small terrace remnants; estimated maximum thickness of about 10 m.

Qse **Slope wash and eolian deposits (Holocene to early Pleistocene?)**—Poorly exposed, light-brown to tan, moderately well-sorted to moderately poorly sorted, massive(?) silt, fine- to medium-grained sand, and rare pebble lenses/beds(?); overlies older rocks on Mesa de la Cejita (Velarde and Trampas quadrangles) and appears to be a combination of mostly reworked eolian material (silt and fine-grained sand) and locally derived, coarser material.

Qqg **Quartzite-rich alluvial and colluvial(?) deposits (late? Quaternary)**—Distinctive deposits composed of Proterozoic quartzite clasts from 2 m to about 3 m in diameter, rare Pilar Formation (**Ytp**) slate clasts to about 7 cm, and extremely rare schist clasts to about 5 cm.

Alluvial Fan Deposits

Qfy **Young alluvial fan deposits (Holocene to latest Pleistocene)**—Poorly sorted deposits of silt, sand, pebbles, cobbles, and boulders; deposits are typically clast-supported and poorly bedded; pebble and cobble clasts are typically imbricated; clasts consist primarily of sedimentary rocks, quartzite, slate, schist, metavolcanic rocks, granitic rocks, and Tertiary granitic and volcanic units; uppermost sediments are commonly silty sand, probably overbank deposits; weak to moderate pedogenic development, including A, Bw, Bwk and Bk soil horizons and Stage I to II calcium carbonate development; the terrace deposits of map unit **Qty** unconformably overlie the local bedrock and are typically on valley floors of large to medium drainages, whereas **Qfy** exists as young mountain-front fans and valley fill in small tributaries; up to 5 m thick.

Qfo **Alluvial fan deposits, undivided (Late to Middle Pleistocene)**—Poorly sorted deposits of silt, sand, and pebbles; deposits are typically matrix-supported and poorly bedded; clasts consist primarily of Paleozoic sedimentary rocks and Proterozoic granitic and metamorphic rock types; on Pilar Mesa the deposit is dominated by slate pebbles and cobbles; between Arroyo del Alamo (Taos SW quadrangle) and Arroyo Hondo (Carson and Taos SW quadrangles) the deposit is typically gravel remnants preserved on interfluves; moderate pedogenic development, including A, Bt, Btk and Bk soil horizons and Stage III and IV calcium carbonate development; upper soil horizons are commonly affected by surface erosion; exists as mountain-front fans and probably overlaps with units **Qf2** through **Qf4**, but not assigned to other fan units because of lack of well-defined age control, clear stratigraphic position, and distinct lithologic characteristics; up to 3 m thick.

Qf4 **Alluvial fan deposits in canyons and arroyos (Late to Middle? Pleistocene)**—Poorly sorted silt, sand, pebbles, and boulders; clasts consist primarily of granitic and metamorphic rocks north of the Rio Pueblo de Taos (Taos SW quadrangle) and granitic, metamorphic and sedimentary rocks south of the Rio Pueblo de Taos; clasts also include basaltic rock types along the Arroyo Seco (Arroyo Seco, Taos, and Los Cordovas quadrangles) and along the Rio Pueblo de Taos downstream of Los Cordovas; associated soils have Stage III to IV calcium carbonate development and thick argillic Bt soil horizons with 7.5YR to 10YR hues; the upper soil horizons may be affected by surface erosion; modified from Kelson (1986); finer-grained to the north, away from the Picuris Mountains range front; grouped into unit **Qfo** northeast of the Rio Grande del Rancho (Ranchos de Taos quadrangle).

Qf3 **Alluvial fan deposits in canyons and arroyos (Late to Middle Pleistocene)**—Poorly sorted silt, sand, pebbles, and boulders; Stage II to III calcium carbonate development; clasts consist primarily of quartzite, slate, and schist; granitic clasts also exist east of Arroyo del Alamo (Taos SW quadrangle).

Qf2 **Alluvial fan deposits in canyons and arroyos (Late to Middle? Pleistocene)**—Poorly sorted silt, sand, pebbles, and boulders; clasts consist primarily of granitic and metamorphic rocks north of the Rio Pueblo de Taos (Taos SW quadrangle) and granitic, metamorphic and sedimentary rocks south of the Rio Pueblo de Taos; associated soils have Stage III to IV calcium carbonate development, thick argillic Bt soil horizons with 7.5YR to 10YR hues; upper soil horizons may be affected by surface erosion; modified from Kelson (1986); finer-grained to the north, away from the Picuris Mountains range front; grouped into unit **Qfo** northeast of the Rio Grande del Rancho (Ranchos de Taos and Tres Ritos quadrangles).

Qf1 **Alluvial fan deposits in canyons and arroyos (Middle to early Pleistocene)**—Poorly sorted silt, sand, pebbles, and boulders; clasts consist primarily of quartzite, slate, and schist; granitic clasts are also present east of Arroyo del Alamo (Taos SW quadrangle); finer-grained to the north, away from the Picuris Mountains range front; Stage III to IV calcium carbonate development, although soil horizons are commonly affected by surface erosion; **Qf1** is differentiated from the Lama formation of the Santa Fe Group (**QTl**) by larger clast size (Kelson, 1986), less oxidation, poor sorting, absence of abundant manganese oxide staining, and clasts that are less weathered; ash probably within **Qf1** deposits at locality near Stakeout Road (Ranchos de Taos quadrangle) dated at 1.27 ± 0.02 Ma ($^{40}Ar/^{39}Ar$ method, W. McIntosh, personal communication, 1996); where exposed to the south the unit is up to 12 m thick.

Terrace Deposits

Qty **Young stream-terrace deposits (Holocene to latest Pleistocene)**—Poorly sorted deposits of silt, sand, pebbles, cobbles, and boulders; deposits are typically clast-supported and poorly bedded; pebble and cobble clasts are typically imbricated; clasts consist primarily of sedimentary rocks, quartzite, slate, schist, metavolcanic rocks, granitic rocks, and Tertiary granitic and volcanic units; uppermost sediments are commonly silty sand, probably overbank deposits; weak to moderate pedogenic development, including A, Bw, Bwk and Bk soil horizons and Stage I to II calcium carbonate development; the terrace deposits of map unit **Qty** unconformably overlie the local bedrock and are typically on valley floors of large to medium drainages, whereas **Qfy** exists as young mountain-front fans and valley fill in small tributaries; up to 5 m thick.

Qto **Stream terrace deposits, undivided (Holocene to Late Pleistocene)**—Poorly sorted deposits of silt, sand, and pebbles; deposits are typically matrix-supported and poorly bedded; clasts consist primarily of Paleozoic sedimentary rocks and Proterozoic granitic and metamorphic rock types; on Pilar Mesa the deposit is dominated by slate pebbles and cobbles; between Arroyo del Alamo (Taos SW quadrangle) and Arroyo Hondo (Carson and Taos SW quadrangles) the deposit is typically gravel remnants preserved on interfluves; moderate pedogenic development, including A, Bt, Btk and Bk soil horizons and Stage III and IV calcium carbonate development; upper soil horizons are commonly affected by surface erosion; typically occurs as isolated remnants on ridge crests, and is probably correlative with terrace levels one through four; up to 3 m thick.

Qt4rp **Stream terrace deposits in canyons and arroyos (Late to Middle? Pleistocene)—** Poorly sorted silt, sand, pebbles, and boulders; clasts consist primarily of granitic and metamorphic rocks north of the Rio Pueblo de Taos (Taos SW quadrangle) and granitic, metamorphic and sedimentary rocks south of the Rio Pueblo de Taos; clasts also include basaltic rock types along the Arroyo Seco (Arroyo Seco, Taos, and Los Cordovas quadrangles) and along the Rio Pueblo de Taos downstream of Los Cordovas; associated soils have Stage III to IV calcium carbonate development and thick argillic Bt soil horizons with 7.5YR to 10YR hues; the upper soil horizons may be affected by surface erosion; modified from Kelson (1986); finer-grained to the north, away from the Picuris Mountains range front.

Qt3rp **Stream terrace deposits in canyons and arroyos (Middle to Late Pleistocene)**— Poorly sorted silt, sand, pebbles, and boulders; Stage II to III calcium carbonate development; clasts consist primarily of quartzite, slate, and schist; granitic clasts also exist east of Arroyo del Alamo (Taos SW quadrangle).

Qt2rp **Stream terrace deposits in canyons and arroyos (Middle? Pleistocene)—**Poorly sorted silt, sand, pebbles, and boulders; clasts consist primarily of granitic and metamorphic rocks north of the Rio Pueblo de Taos (Taos SW quadrangle) and granitic, metamorphic and sedimentary rocks south of the Rio Pueblo de Taos; associated soils have Stage III to IV calcium carbonate development, thick argillic Bt soil horizons with 7.5YR to 10YR hues; the upper soil horizons may be affected by surface erosion; modified from Kelson (1986); finer-grained to the north, away from the Picuris Mountains range front.

Qt1rp **Stream terrace deposits in canyons and arroyos (Middle Pleistocene)**—Poorly sorted silt, sand, pebbles, and boulders; clasts consist primarily of quartzite, slate, and schist; granitic clasts are also present east of Arroyo del Alamo (Taos SW quadrangle); finer-grained to the north, away from the Picuris Mountains range front; Stage III to IV calcium carbonate development, although soil horizons are commonly affected by surface erosion; where exposed to the south the unit is up to 12 m thick.

Terrace Deposits of the Rio Grande

Qtrg **Rio Grande terrace gravels (Pleistocene?)**—Pebble- to cobble-size gravel deposits preserved as small remnants inset into Quaternary landslide deposits north and northeast of Rinconada; mapped only in the Trampas quadrangle; identifiable as Rio Grande alluvium by the inclusion of Proterozoic Glenwoody Formation (Xvg) clasts derived from the Pilar cliffs, just southwest of the village of Pilar on the Carson quadrangle, and rounded cobbles of Servilleta Basalt (Tsb); approximately 5 m thick.

Qt2rg **Stream terrace deposits of the Rio Grande (early to Middle? Pleistocene)**—Poorly sorted silt, sand, pebbles, and boulders; clasts consist primarily of granitic, metamorphic, intermediate volcanic, basalt, and sedimentary rocks; locally clasts of Tertiary Amalia Tuff may be present; associated soils have Stage III to IV calcium carbonate development, thick argillic Bt soil horizons, and 7.5YR to 10YR hues in soil Bt horizons; upper soil horizons may be affected by surface erosion; may be mantled locally by unit Qe; modified from Kelson (1986); estimated at 1 to 10 m thick.

Qt1rg **Stream terrace deposits of the Rio Grande (early to Middle? Pleistocene)**—Poorly sorted sand, pebbles, and cobbles; clasts consist of basalt, quartzite, slate, schist and other metamorphic rock types, volcanic rock types, and (rarely) sandstone and limestone; overlies the Servilleta Basalt (Tsb) north of Pilar Mesa, but is inset into Tsb on Pilar Mesa in the Carson quadrangle; locally may contain clasts of Tertiary Amalia Tuff; where preserved, associated relict soils have Stage III to IV calcium carbonate development, thick argillic Bt soil horizons, and 7.5YR hues in soil Bt horizons; upper soil horizons commonly affected by surface erosion; may be mantled locally by unit Qe; estimated at 1 to 10 m thick.

Qt0rg **Stream gravel deposited by ancestral Rio Grande (early? To Middle? Pleistocene)**—Poorly sorted sand, pebbles, and cobbles; clasts consist of basalt, quartzite, slate, schist, other metamorphic rock types, and volcanic rock types; very rare Amalia Tuff clasts; associated with the broad, highest terrace west of the Rio Grande; upper soil horizons commonly affected by surface erosion; locally mantled by eolian sand; estimated at several meters thick.

VOLCANIC ROCKS

Taos Plateau Volcanic Field

Tsb **Servilleta Basalt (Pliocene)**—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 communication, 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; locally subdivided into lower Servilleta Basalt (**Tsbl**), middle Servilleta Basalt (**Tsbm**), and upper Servilleta Basalt (**Tsbu**) by Dungan et al., (1984); flow packages are 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 ± 0.03 Ma for the lowest basalt near the Gorge Bridge (Los Cordovas quadrangle), to 3.59 ± 0.08 Ma for the highest basalt flow at the Gorge Bridge, broadly consistent with previous results by Appelt (1998); two samples were analyzed from the Guadalupe Mountain quadrangle: one at the base of the upper Servilleta Basalt lava flow section at La Junta Point yielded an $^{40}Ar/^{39}Ar$ age of 3.78 ± 0.08 Ma (sample 10RG05, M. Cosca, personal communication, 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 ± 0.08 Ma (sample RT08GM02, M. Cosca, personal communication, 2014).

Tvto **Rhyodacite of Tres Orejas (Pliocene)**—Dark, phenocryst-poor, locally flow layered rhyodacite; phenocrysts of augite and hypersthene are sparse and small; SiO^2 is 62 to 64% (Lipman and Mehnert, 1979); the uppermost Servilleta Basalt flows locally overlap the flanks of Tres Orejas on the Carson quadrangle.

Ocaté Volcanic Field

Tob **Ocaté (Vadito) basalt (Miocene)**—Dark-gray, vesicular, olivine tholeiite basalt flow found on a high mesa east of the Village of Vadito in the east-central map area, and as scattered, isolated remnants to the west; east-to-west traces of scattered exposures may indicate the original course of the basalt flow along a Pliocene paleovalley; $^{40}Ar/^{39}Ar$ whole-rock date of 5.67 ± 0.12 Ma confirms its time equivalence to rocks of the ca. 5.7 Ma Ocaté volcanic field to the east; locally up to 10 m thick.

San Juan Volcanic Field

Tbo **Older basaltic rocks (Oligocene?)**—In cross section only. Within the study area, one well (RG-83352) penetrates a lava flow that is probably considerably older than the Servilleta Basalt; the drillers log lists "basalt" from 840 to 900 ft, and "fractured basalt" from 900 to 920 ft; given that the surface unit is the Chama-El Rito Member of the Tesuque Formation (**Ttc**, Miocene), the 80-ft-thick lava flow may be Oligocene in age; such Oligocene lavas do exist at the surface north of the study area, where they are known as the Conejos Formation (ca. 30 to 29 Ma) and the Hinsdale Formation (ca. 26 Ma) (Thompson and Machette, 1989; Thompson et al., 1991); these lavas are related to the San Juan volcanic field, which predates the formation of the structural Rio Grande rift; approximately 24 m thick.

RIO GRANDE RIFT AND PRE-RIFT DEPOSITS

Tg? **High-level gravel (Pliocene)**—Unexposed, moderately well-sorted, rounded to subrounded gravel dominated by quartzite clasts with possibly some Tertiary volcanic clasts and/or Paleozoic sandstone clasts up to about 5 cm in diameter; this deposit is mapped only on the hill north of Vadito, and is inferred from float of quartzite-rich gravel on the north side of the hill; the south side of the hill is mantled by relatively coarse gravel/cobbles (up to about 50 cm) that contain the above clasts plus common, subrounded to subangular, basalt clasts that are either mixed with a pre-basalt deposit that is coarser than the north-side exposures (such as an eroded gravel that post-dates the basalt), or derived from an unidentified pre-**Tbo** basalt that contributed clasts to **Tg**; the inferred gravel layer is estimated to be 1 to 3 m thick.

Santa Fe Group

Basin-fill clay, silt, sand, pebbles, cobbles, and boulders of the Rio Grande rift. In the map area, the unit is at least 1,000 m thick.

QTg **Alluvial and minor colluvial deposits at high levels of the Santa Fe Group (late Pliocene and/or Quaternary)**—Terrace gravels and more angular basement-derived alluvium and/or colluvium located south of the Picuris Mountains; the alluvium and colluvium has partly buried or rarely interfingers with the terrace gravels; gravel composition varies with local basement composition and the local drainage systems; commonly preserved as relatively thin “ribbons” of gravel along ridges, with extensive aprons of gravel on slopes below; it is unclear whether these rocks represent one geomorphic surface or multiple geomorphic surfaces across the map area, as they have not been correlated or profiled; the base of the gravel is not exposed but, at maximum, is about 10 m thick.

QTl **Lama formation of the Santa Fe Group (Pliocene to early? Pleistocene)**—Poorly sorted sand, pebbles, and cobbles; clasts consist 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 the area north of the Taos Municipal Airport (Los Cordovas quadrangle), and southerly flow direction in areas north and west of the Rio Pueblo de Taos, with northwesterly flow direction in areas southeast of the Rio Pueblo de Taos; well drillers records in the Questa area show clay layers 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 area; correlative with 1) 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), 2) Kelson's (1986) informal "Basin Fill deposit," 3) the unit previously informally called "Blueberry Hill formation" in the Taos area, and 4) Pazzaglia's (1989) late Neogene-Quaternary rift fill sequence (unit **Q1**) which he informally named the Lama formation; herein, for this study area, 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 at 5.55 ± 0.37 Ma near Cerro Azul (Taos Junction quadrangle, D. Koning, personal communication, 2015) 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 (southwest of the map area) that roughly coincides with the Chamita/Lama contact in the 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 of 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 from the lowermost Lama formation in a road cut near the Red River Fish Hatchery (Guadalupe Mountain quadrangle, elevation ca. 7,160 ft) was probably derived from nearby ca. 5 Ma volcanic units (R. Thompson, personal communication, 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 Bed in the Jemez Mountains (elevation ca. 7,660 ft, M. Machette, USGS, personal communication, 2008) to the southwest of the map area; thickness ranges from zero to an exposed thickness of about 25 m at the southwestern end of Blueberry Hill (Taos quadrangle), but may be considerably thicker in other parts of the map area.

Tcc **Clay layer in the Lama formation of the Santa Fe Group (Pliocene)**—Distinctive, thin, light-gray clay layer that is locally exposed in the walls of the Rio Grande gorge, downstream from the confluence with the Rio Pueblo de Taos; the clay is composed of very small (20 to 50 microns), well-sorted crystals of quartz and feldspar in a clay matrix that most likely formed in a lake that existed behind a basalt-dammed ancestral Rio Grande; the clay lies within the clastic beds of the Lama formation (**QTl**), above the lowermost Servilleta Basalt; this clay layer has hydrologic significance between the Taos Junction bridge and Pilar, as on the north slope of the gorge, as it is spatially related to a series of small springs and seeps that exist at elevations of approximately 6,200 ft; the clay layer extends downstream, where it hosts a number of larger springs that emerge from the north gorge wall downstream from Pilar; the known, exposed lateral extent of the layer is a minimum of 17 km (11 mi) in the gorge; additionally, the clay likely extends up the Rio Pueblo de Taos, where it is observed in several of the wells used in this study; estimated to be 1 to 3 m thick. See the Explanation of Map Symbols for the symbology used in the map.

Chamita Formation of the Santa Fe Group

Tc **Chamita Formation of the Santa Fe Group, undivided (Miocene)—**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 include the rock types above in addition to subangular and subrounded volcanic clasts derived locally from adjacent volcanic highlands of the Taos Plateau volcanic field; the top of Tc is herein defined as the sediments below the youngest Servilleta Basalt flows.

Tcpm **Pilar Mesa member of the Chamita Formation, Santa Fe Group (Miocene)—**Very pale-brown to light-yellowish-brown, moderately to well-sorted, subangular to rounded, mostly tabular, thin- to thick-bedded, loose to weakly(?) cemented, very fine to coarse sand and silty sand interbedded with dark-colored, moderately to very poorly sorted, angular to subrounded (often platy), medium- to thick-bedded, mostly clast-supported lenses and beds of sandy conglomerate; conglomerates contain clasts of Proterozoic quartzite, Tertiary volcanic rocks, Pilar Formation slate (Ytp), Paleozoic sandstone, siltstone, and limestone, granitic rocks, and rare amphibolite, carbonate nodules, and rip-ups of fines resembling adjacent sandstone interbeds; this unit was informally described as the Cieneguilla member of the Tesuque Formation by Leininger (1982); approximately 230 m thick.

Chamita and Tesuque Formations of the Santa Fe Group

Tc+Tto **Chamita Formation and Ojo Caliente Sandstone Member of the Tesuque Formation, Santa Fe Group, undivided (Miocene)—**In cross section only. Tc and Tto undivided, see descriptions of individual units.

Tesuque Formation of the Santa Fe Group

Rio Grande rift related basin-fill deposits of clay, silt, sand, pebbles, cobbles, and boulders.

Ttbc **Cejita Member of the Tesuque Formation, Santa Fe Group (Lithosome B) (Miocene?)—**Buff to greenish, moderately to poorly sorted, medium- to thick-bedded, sandy conglomerate to pebbly sandstone and subordinate coarse- to fine-grained silty sandstone containing rounded to subangular clasts of Proterozoic quartzite, Paleozoic sandstone, siltstone, and limestone, and Tertiary volcanic clasts; overlies both the Ojo Caliente Sandstone Member and Dixon member of the Tesuque Formation; Lithosome B refers to the lithologic designations of Cavazza (1986), also see Koning and Aby (2003); age range of 13.2 to 7.0 Ma based on regional relationships (Koning and Aby, 2005).

Tto **Ojo Caliente Sandstone Member of the Tesuque Formation, Santa Fe Group (Miocene)**—Very pale-brown (10 YR7/4), well- to moderately well-sorted, subrounded to rounded, loose to moderately well-indurated sandstone; this unit is a distinctive eolian sand dune deposit sourced from the southwest (Galusha and Blick, 1971); dominant grain size is fine sand; $CaCO^3$ concretions are abundant, brown, and 1.3 to 5.0 cm thick; QFL proportions near Dixon (Velarde, NM) average 62% quartz, 28% feldspar, 10% lithics and LvLsLm ratio averages 82% Lv, 8% Ls, and 10% Lm (Steinpress, 1980); thin reddish-brown, finely laminated siltstone horizons exist locally; tabular cross-beds are common, with sets over 4 m in height; the best exposures are in roadcuts along NM-68, northeast of Pilar; in the map area, this unit underlies the Pilar Mesa member (**Tcpm**) of the Chamita Formation (**Tc**) below an interfingering(?) contact, and some of the sand in the Pilar Mesa member is probably reworked Ojo Caliente Sandstone Member and/or sand derived from the same source during Pilar Mesa member time; age range of 13.5 to 10.9 Ma is based on regional relationships (Koning et al., 2005); approximately 250 m thick.

Ttqa **Quartzite-rich unit of the Tesuque Formation, Santa Fe Group (Miocene)**—Mostly light-colored (buff to very pale-brown), moderately(?) to poorly sorted, loose to weakly cemented, medium to thick-bedded(?), silty sandstone(?) to sandy cobble conglomerate composed of quartzite and <25% granitic clasts; this unit is more granitic-rich to the south on the Truchas quadrangle where tephra layers, high in the stratigraphic section in the western part of the quadrangle, yielded $^{40}Ar/^{39}Ar$ ages of 11.7 and 11.3 Ma (Smith et al., 2004); in the Truchas quadrangle the lower section is probably older than 15 Ma based on provisional correlations to strata in adjacent quadrangles (Smith et al., 2004); in the Truchas quadrangle the total thickness is approximately 500 m.

Ttd **Dixon member of the Tesuque Formation, Santa Fe Group (middle Miocene)**—Red, tan, beige, and locally green, sandy to clayey silt and silty clay beds about 0.1 to 6(?) m thick, interbedded with tan, brownish, reddish, and characteristically greenish, moderately to very poorly sorted, often preferentially carbonate-cemented, thinly to thickly bedded conglomerates and fine- to coarse-grained, arkosic sandstones between ≈0.5 and ≈5 m thick; conglomerates contain abundant, poorly to moderately well-rounded clasts of Proterozoic quartzite and Paleozoic sandstone, limestone, and siltstone; sedimentary features other than plane lamination are not common but include ripple marks, cross-beds, and lateral accretion (point-bar) foresets; contacts between beds are typically abrupt and the bases of sandstones and conglomerates are commonly scoured with from 0.01 to 1 m of relief; imbrication of clasts is locally moderately well developed; paleocurrent indicators (imbrications and the strikes of channel walls) indicate transport primarily from the south, east, and northwest; sandstones and conglomerates are preferentially cemented with calcium carbonate; carbonate cement locally forms a sparry white matrix between grains; in this area, Smith et al. (2004) demonstrated that the Dixon member and Cejita Member of the Tesuque Formation are indistinguishable in the field where not separated by the Ojo Caliente Sandstone; age of ≈13 to 11.8 Ma (latest Barstovian) is based on fossils (Tedford and Barghoorn, 1993); minimum of 250 m thick.

Ttcu **Upper part of the Chama-El Rito Member of the Tesuque Formation, Santa Fe Group (Miocene)—**Very pale-brown to light-yellowish-brown, moderately to poorly sorted, subangular to subrounded, thinly to thickly bedded, tabular, loose to moderately carbonate-cemented, fine- to coarse-grained, silty sandstone interbedded with moderately to poorly sorted, subangular to subrounded, medium- to thick-bedded, tabular to broadly lenticular(?), sandy conglomerate composed of variable amounts of Proterozoic quartzite, Pilar Formation slate (**Ytp**), schist, Tertiary volcanic rocks, Paleozoic sandstone, limestone and siltstone, granitic rocks, and rare rip-up clasts; the lower contact is gradational (interfingering?) with the rest of Chama-El Rito Member (**Ttc**); the lower contact is drawn at approximately 10% Paleozoic clasts; the upper contact is not exposed but is probably gradational and interfingering with the Ojo Caliente Sandstone Member (**Tto**); largely covered by Quaternary alluvium, however, some moderately good exposures overlie **Ttc** in Agua Caliente Canyon; some beds of **Ttc** near the contact contain anomalously high numbers of sandstone and granitic clasts and some Pilar Formation slate which is similar to the Pilar Mesa member (**Tcpm**); these beds underlie the Ojo Caliente Sandstone, which defines the top of the Tesuque Formation of Galusha and Blick (1971) in the Carson quadrangle, so they are included in **Ttc** here rather than defining a separate member for these rocks; age range of 14 Ma to 11 Ma is based on the age of overlying and underlying units; where unfaulted the unit is at least 200 m thick.

Ttc **Chama-El Rito Member of the Tesuque Formation, Santa Fe Group (Miocene)—** Buff, whitish, pink, red and brownish, moderately to very poorly sorted, subangular to subrounded, tabular to lensoidal(?), thinly to very thickly bedded, massive, plane-bedded, or cross-bedded, loose to carbonate-cemented muddy siltstone to silty, very fine to very coarse sandstone interbedded with moderately to poorly sorted, mostly subrounded, medium- to very thick-bedded tabular beds and broad lenses of silty/sandy and sandy pebble conglomerate; clasts consist mostly of Tertiary volcanic rocks and quartzite with lesser amounts of Paleozoic sandstone, granitic rocks, Pilar Formation (**Ytp**) slate, schist, and rare amphibolite;

ranges in age regionally from possibly >22 Ma to ≈13 Ma (Aby, 2008); thickness unknown, but is expected to range considerably in the subsurface.

Older Deposits of the Santa Fe Group

Tbca **Basal colluvial and alluvial deposits of the Santa Fe Group (Miocene?)—** Alluvial and colluvial material underlying **Ttc**, **Ttd**, and **Tptc** in many locations; clast compositions are variable but are primarily derived from local Proterozoic units; a ≈20-cm-thick tephra bed sampled from a road cut in the town of Trampas (13S 432003mE 3998789mN, NAD83) yielded a plagioclase $^{40}Ar/^{39}Ar$ date of 22.7 ± 0.4 Ma; approximately 3 to 30 m thick.

Tesuque Formation of the Santa Fe Group and Picuris Formation

Ttc+Tpt **Chama-El Rito Member of the Tesuque Formation, Santa Fe Group and/or tuffaceous member of the Picuris Formation, undivided (Miocene? to Oligocene)—**Interbedded and/or complexly faulted, poorly exposed, sparse outcrops of tuffaceous and pumiceous silty sandstones (**Tpt**) and volcaniclastic sandstone and conglomerate (**Ttc**); stratigraphic/temporal relations between the tuffaceous members of the Picuris Formation (**Tpt**) and the Chama-El Rito Member (**Ttc**) are discernible (and clearly 'layer cake') in the southern Picuris Mountains, however, locally the tuffaceous member is either absent or not exposed along most of the range front; along the northeastern edge of the map area are poorly exposed, and possibly complexly faulted, outcrops of both tuffaceous and volcaniclastic rocks that indicate possible interfingering of the two units; elsewhere, these rocks were referred to as the middle tuffaceous member of the Picuris Formation (Aby et al., 2004); age is less than ≈25 Ma based on abundant clasts of 25 Ma Amalia Tuff, but minimum age is unknown; thickness in the map area is unknown.

Picuris Formation

Tp **Picuris Formation, undivided (Oligocene to Miocene)—**In cross section only. In the Picuris Mountains area (Aby et al., 2004) consists of an upper member of tuffaceous and pumiceous silty sandstones and volcaniclastic sandstone and conglomerate; a member of buff to white and/or pinkish, silty sandstone to fine cobble conglomerate and non-friable to strong, very fine-lower- to very coarse-upper-grained, very poorly to moderately sorted, rounded to subangular, thinly to thickly bedded, silica-cemented silty to pebbly sandstone that locally contains a basal portion of poorly sorted pebbly/gravelly sandstone and/or cobble/boulder conglomerate composed exclusively of Proterozoic clasts; a member of light-buff, yellowish, and locally white, ash-rich, quartzose, silty, fine sand to pebbly, pumiceous sandstone; a lower member of red, greenish, and yellowish, moderately to very poorly sorted, subangular to subrounded, pebbly/silty sandstone and mudstone containing very thick(?) to thin beds and/or lenses and/or isolated clasts of subangular to rounded Proterozoic quartzite (up to 3 m across) and massive quartzite conglomerate; paleo-flow measurements indicate source to the north (Rehder, 1986); age range is from at least 34.5 Ma to less than 25 Ma; thickness unknown, but at least 450 m thick in the Picuris Mountains area.

Tpt **Tuffaceous member of the Picuris Formation (early Miocene to late Oligocene)**—Light-buff, yellowish, and locally white, ash-rich, quartzose, silty, fine-grained sand to pebbly, pumiceous sandstone; very friable to somewhat friable, moderately to very poorly sorted, commonly bimodal, and massive; very thickly to thinly bedded with locally well-developed fining upward sequences; most sandstone beds contain a small percentage of medium-lower- to coarse-upper-grained sand of Pilar Formation (**Ytp**) slate and quartzite; thin to thick (5 cm to 1.5 m) interbeds and channel-fills of buff to black, friable, moderately to poorly sorted, subangular to subrounded Pilar Formation slate and quartzite-rich and/or Tertiary pumice-rich conglomerate; the lower portion, just west of Cerro Blanco (Trampas quadrangle) and just east of the granitic highland in Section 29, T023N R012E, is poorly sorted, fine- to coarse-grained, grussy, pebbly sand; small-scale fining upward sequences indicative of fluvial deposition are exposed on the slopes of Cerro Blanco; near the abandoned power substation in Section 32, T023N R012E the deposit contains rare pebbly/gravely channels that are rich in granite, epidote, slate, amphibolite, and schist(?), and a single exposure of boulder conglomerate composed of Peñasco quartz monzonite porphyry, quartzite, and amphibolite; exposures north of the Rio Pueblo drainage contain white ash beds (15 to 65 cm); some ash layers are distinctly bioturbated; some conglomerate beds contain abundant, rounded Tertiary pumice lapilli; lapilli in lower portions of the unit are white or pink, mafic-poor, with phenocrysts of quartz and plagioclase; near, and at, the upper contact is a biotite-rich pumice; the lower contact is not exposed in the map area; the upper contact is mapped as the base of the first silica-cemented bed in the section; a primary Amalia Tuff ash fall identified within the middle member at Cerro Blanco and similar ash beds exists on the hill just northwest of Picuris Pueblo (Peñasco quadrangle); pumice from the Amalia Tuff eruption has been identified at several places along the southeastern edge of the Picuris Mountains; two additional populations of pre- and post-caldera pumice at 23 Ma and 27 Ma have been identified; based on $^{40}Ar/^{39}Ar$ geochronology, this unit was deposited starting about 28 Ma in the northern Picuris Mountains (based on the age of the Llano Quemado breccia) and starting about 25 to 26 Ma in the southern Picuris Mountains (based on the age of an ash that is low in the section); deposition ended by at least 18.6 Ma in the northern Picuris Mountains and by 19.8 Ma in the southern Picuris Mountains based on ages of basalt clasts in **Ttc** (Aby et al., 2004; Bauer et al., 2005); approximately 125 m thick.

Tptc **Cemented part of the tuffaceous member of the Picuris Formation (early Miocene)**—Buff to white and/or pinkish, silty sandstone to fine cobble conglomerate and non-friable to strong, very fine-lower- to very coarse-upper-grained, very poorly to moderately sorted, rounded to subangular, thinly to thickly bedded, silica-cemented silty to pebbly sandstone; locally contains a basal portion of poorly sorted pebbly/gravelly sandstone and/or cobble/boulder conglomerate composed exclusively of Proterozoic clasts; in exposures along NM-76 between Chamisal and Peñasco (the 'Chamisal exposures' of Aby et al., 2004) the lowest, exposed, cemented part of the tuffaceous member is at least 13 m of moderately well-sorted, thickly bedded, sub-rounded to angular, cobble and boulder conglomerate composed of Proterozoic granite (46%), quartzite (26%), amphibolite (26%), phyllite (1%), and schist (1%); the upper contact is placed at the top of the last silica-cemented bed, and locally displays flame structures; rare paleocurrent indicators show transport from the northwest, north, and northeast; age is probably between about 23 Ma and 20 Ma based on $^{40}Ar/^{39}Ar$ ages of pumice clasts in this unit, and a basalt clast in the overlying rocks (Aby et al., 2004); approximately 10 to 35 m thick.

Tplq **Llano Quemado breccia member of the Picuris Formation (Oligocene)**—Light-gray to red, monolithologic volcanic breccia of distinctive extremely angular, poorly sorted, light-gray, recrystallized rhyolite clasts in a generally reddish matrix; rhyolite clasts contain phenocrysts of biotite, sanidine, and quartz; highly lithified due to partial welding of the matrix rather than silica or carbonate cement; ridge-former; the unit shows both clast and matrix support; the beds are generally 1 to 8 m thick; clasts are up to 15 cm in diameter and overall clast size decreases southward; less than 1% of clasts are Proterozoic slate and weathered Tertiary volcanic rocks; the breccia is interpreted as a series of flows from a now-buried, nearby rhyolite vent (Rehder, 1986); $^{40}Ar/^{39}Ar$ date on sanidine from a rhyolite clast collected 1 km southwest of Ponce de Leon Springs is 28.35 ± 0.11 Ma; apparent thicknesses of 5 to 45 m, although subsurface extent is unknown.

Tpa **Andesitic porphyry of the Picuris Formation (age unknown, possibly Oligocene)**—Poorly exposed, reddish-gray, andesitic porphyry that is exposed only in a single small exposure in northern Miranda Canyon where it appears to underlie **Tplq**; age unknown, although it may be related to the volcanic component of the **Tplq**.

Tpl **Lower member of the Picuris Formation (Oligocene)**—Mostly poorly exposed, red, greenish, and yellowish, moderately to very poorly sorted, subangular to subrounded, pebbly/silty sandstone and mudstone containing very thick(?) to thin beds and/or lenses and/or isolated clasts of subangular to rounded Proterozoic quartzite (up to 3 m across) and massive quartzite conglomerate; commonly highly weathered with fractured clasts; most available exposures consist of very well-carbonate-cemented quartzite pebble and cobble conglomerate intervals exposed near mapped faults; the lower contact is placed at the first accumulation of diverse Proterozoic clasts (quartzite, Pilar Formation slate [**Ytp**], ± schist); the upper 10 m in Agua Caliente Canyon (Carson to Peñasco quadrangles) is a well-exposed bed of well-sorted, quartzite-cobble conglomerate (Figure 7 of Aby et al., 2004); the orientation of 95 well-imbricated clasts in this interval suggest derivation from the northeast (average paleo-transport direction is 143°), at odds with a previous interpretation that this unit was derived from the Picuris Mountains to the southeast (Leininger, 1982); this unit was informally named the "Bradley conglomerate member" of the Tesuque Formation (Leininger, 1982) for exposures near the Village of Pilar, but that name has been abandoned; this unit has also been referred to as the "lower conglomerate member" of the Picuris Formation (Aby et al., 2004) but, locally, much of the unit is fine-grained; near the top(?) of the section in Agua Caliente Canyon is an ash layer dated at 34.5 ± 1.2 Ma by $^{40}Ar/^{39}Ar$ (Aby et al., 2004); regionally, this unit contains variable amounts of intermediate-composition volcanic rocks (dated by $^{40}Ar/^{39}Ar$ at 32.4 to 28.8 Ma; Aby et al., 2007), and fluvially reworked Llano Quemado breccia (28.35 Ma); the oldest ashes are dated at 35.5 Ma and 35.6 Ma (Aby et al., 2004), but the maximum age of the unit is unknown; where not faulted the unit is at least 250 m thick.

Older Tertiary Units

Th **Older Tertiary rocks (Oligocene)**—In cross section only. Volcanic, volcaniclastic, and clastic rocks that predate the Tesuque Formation; may include the Hinsdale Formation, Los Pinos Formation, and similar units.

SEDIMENTARY ROCKS OF THE TAOS TROUGH

PPu **Pennsylvanian sedimentary rocks of the Taos Trough, undivided (Pennsylvanian)**—Poorly exposed; greenish, reddish, yellowish, buff, tan, black, and brown; very friable to firm; sandy to clayey; thinly to thickly bedded; poorly to moderately well-cemented(?), sandy to clayey siltstone, mudstone, and shale interbedded with mostly greenish and brownish, firm to very strong, poorly to moderately well-sorted, poorly to moderately well-rounded, thin- to very thickly bedded, moderately to very well-cemented, quartzose, feldspathic, and arkosic, silty to pebbly sandstone and sandy conglomerate and less common thin- to thick-bedded, grayish and blackish limestone of the Alamitos and Flechado Formations; contains a rich assortment of fossils; sandstones commonly contain plant fragments that have been altered to limonite(?); contacts between beds are generally sharp, rarely with minor scour (less than ≈20 cm); the lower contact is sharp, planar(?), and disconformable(?) where it overlies Mississippian rocks; the lower contact is mapped at the top of the Del Padre Sandstone Member (**Mdp**) or highest Mississippian carbonate, or at the base of the lowest sedimentary bed where Mississippian rocks are absent; conglomeratic layers in the lower part of the unit locally contain rare, sometimes banded, chert pebbles; equivalent to the Sandia, Madera, and La Posada Formations to the south; colluvial deposits have not been mapped on the Tres Ritos quadrangle, but most of the Pennsylvanian rocks are covered by brown to nearly black, loose, very poorly sorted, rounded to angular, massive- to very crudely bedded, sandy to silty conglomerate and pebbly to silty sand; this material is clearly colluvial based on its landscape position and the random orientation of larger clasts within a matrix of usually dark, organic-rich fines; windthrow (movement of soil by toppling of trees) is thought to be an active process in the map area, and is probably responsible for the pervasive colluvial mantle; fusulinids collected in the Taos quadrangle are Desmoinesian in age (Bruce Allen, personal communication, 2000); Miller et al. (1963) measured an incomplete section of 1,756 m along the Rio Pueblo near the Comales Campground (Tres Ritos quadrangle), and an aggregate thickness of Pennsylvanian strata in the map area of >1,830 m.

IPlst **Limestone, Pennsylvanian sedimentary rocks of the Taos Trough (Pennsylvanian)**—Light-gray limestone in scattered discontinuous layers; fossiliferous to non-fossiliferous; fossils include phylloid algae, crinoids, brachiopods, and other shell fragments; well-bedded to poorly bedded; outcrops are typically highly weathered and, locally, are highly fractured; limestone represents a very small percentage (<1%) of the volume of Pennsylvanian rock in the map area.

IPbs **Basal sandstone, Pennsylvanian sedimentary rocks of the Taos Trough (Pennsylvanian)**—Mostly white with some yellowish, brownish, and/or reddish streaks and staining, very hard, moderately well-sorted, angular to moderately well-rounded, medium- to thick-bedded(?), well to very well-silica-cemented quartz sandstone, pebbly sandstone, and minor breccia(?); this well-indurated unit can be difficult to distinguish from the Ortega Formation (Xho) quartzite, as both rock types break across grains; this unit is also similar to the Del Padre Sandstone (Mdp, Mississippian) as they occupy similar stratigraphic positions and are virtually identical in some hand samples; however, the basal sandstone has slightly more matrix, sparse, altered feldspar grains, generally poorer rounding of grains, and a less diverse range of colors than the Del Padre Sandstone; the lower contact is mapped at the top of Proterozoic rocks; the upper contact is mapped at the top of the highest well-cemented sandstone; partial erosion of Mississippian carbonates regionally makes it likely that the Pennsylvanian basal sandstone directly overlies the Del Padre Sandstone in places; in such cases the two units would be indistinguishable as mappable units, and the Del Padre Sandstone would be included within the basal Pennsylvanian sandstone on the map.

Arroyo Peñasco Group

Mu **Sedimentary rocks of the Arroyo Peñasco Group, undivided (Mississippian)**—In cross section only. Undivided sedimentary Mississippian rocks of the Taos trough.

Mt **Tererro Formation of the Arroyo Peñasco Group (Mississippian: Meramecian and Chesterian)—**Near Ponce de Leon Springs; consists of 1 to 2 m of basal stromatolitic, limy sandstone overlain by about 7 m of dolomitic limestone, overlain by about 12 m of calcitic dolomite with stromatolites and bedded and nodular chert (Armstrong and Mamet, 1990); approximately 20 m thick.

Mc **Espiritu Santo Formation and Tererro Formation carbonates, Arroyo Peñasco Group (Mississippian: Osagean)—**Where rarely exposed, the carbonate-rich rocks at the top of the Del Padre Sandstone (**Mdp**) grade into overlying Tererro Formation (**Mt**) carbonate sedimentary rocks; on the Ranchos de Taos quadrangle near Ponce de Leon Springs, the Tererro Formation consists of 1 to 2 m of basal stromatolitic, limy sandstone overlain by about 7 m of dolomitic limestone, overlain by about 12 m of calcitic dolomite with stromatolites and bedded and nodular chert (Armstrong and Mamet, 1990); Espiritu Santo and Tererro rocks (**Mes**) are lumped due to their thinness, poor exposure, and the disagreements among published descriptions and stratigraphic sections (Miller et al., 1963; Armstrong and Mamet, 1979; Baltz and Meyers, 1999); thickness is approximately 20 m.

Mes **Espiritu Santo Formation of the Arroyo Peñasco Group, undivided (Mississippian: Osagean)—**The basal Del Padre Sandstone Member (**Mdp**) is composed of a thin basal conglomerate, quartz sandstone, and minor limestone beds at top; an upper, carbonate-rich section grades into overlying Tererro Formation.

Mdp **Del Padre Sandstone Member of the Espiritu Santo Formation, Arroyo Peñasco Group (Mississippian: late Tournaisian)—**White, tan, yellowish, green, red, and/or mottled, fine-upper- to very coarse-upper-grained, strong-to-very strong, moderately to very well-sorted, well-rounded to subangular, thinly to very thickly bedded, mostly horizontally laminated to low angle cross-bedded, quartz-overgrowth cemented sandstone, pebbly sandstone, sandy conglomerate, and minor breccia(?); contacts are generally sharp and parallel, although minor (<20 cm) scouring exists locally; jointing is prominent; exposures are good relative to other Paleozoic rocks due to its resistance to erosion, but is variable in general; lichens typically obscure sedimentary features and bedding even where exposure is relatively good; unconformably overlies Proterozoic rocks in much of the Sangre de Cristo Mountains of northern New Mexico (Armstrong and Mamet, 1979); Miller et al. (1963) reported an unusually thick (≈50 m) section of the Del Padre north of the Rio Pueblo in Osha Canyon (Peñasco quadrangle) just west of the mica mine, however, a similar exposure reported by Miller et al. (1963) contains Pennsylvanian fossils (Cather, et al., 2007), and therefore the exposures in Osha Canyon, may also be Pennsylvanian; differentiating the Del Padre Sandstone from the Pennsylvanian basal sandstone is not feasible in areas of poor exposure; however, the presence or absence of the Espiritu Santo carbonates can be useful in distinguishing the two; the basal contact of the Del Padre is herein mapped at the lowest identifiable clastic beds, although such a selection can be problematic where the Del Padre overlies the Ortega Formation (Xho) quartzite, as the two are similar; the upper contact is mapped at the top of the highest strongly cemented sandstone bed; in the Rio Pueblo section at Comales Campground, reported thicknesses are ≈19.5 m (Miller et al., 1963), ≈17 m (Armstrong and Mamet, 1979) and ≈8 m (Baltz and Meyers, 1999); this mapping supports the higher estimates.

METAMORPHIC AND PLUTONIC ROCKS OF THE PICURIS MOUNTAINS

breccia **Mixed fault breccia (Tertiary? to late? Proterozoic)—**Fault breccia composed of a mixture of Proterozoic Hondo Group (Xhu), Vadito Group (Xvu), and granitic rock along the Tertiary Picuris-Pecos fault; the unit is a distinct ridge former where the breccia is strongly solidified.

Plutonic & Metaplutonic Rocks

Zd **Diorite dike (age unknown, probably Neoproterozoic)—**Dark-green-gray quartz diorite dikes intruded into Proterozoic rocks; dikes are vertical, with strikes clustered around an azimuth of 150°; composed of pale-green clinopyroxene (Cr-diopside?), zoned plagioclase (labradorite?), and minor quartz, magnetite, and ilmenite; commonly altered to chlorite and clay; pyroxene and feldspar show normal plutonic textures; locally, dikes are laced with carbonate veins; generally less than 1 m wide; contacts between diorite and country rock are sharp and commonly contain zones of brecciation and faulting; faults are sub-vertical with dip-slip fault striations; dikes are parallel to the Pilar-Vadito fault and other southeast-striking faults of the Picuris Mountains. See the Explanation of Map Symbols for the symbology used in the map.

Yp **Pegmatite (age unknown, probably Mesoproterozoic)—**Includes both simple (quartz-K-feldspar-plagioclase-muscovite) pegmatites and complex zoned pegmatites containing rare minerals in the Trampas quadrangle; simple pegmatites are by far the most abundant in the map area; pegmatite bodies typically are dikes or lenses, locally aligned parallel to country rock foliation; 2 cm to 15 m thick; no apparent spatial relationship exists between pegmatite bodies and plutonic bodies, and no evidence exists to suggest that pegmatites are connected to plutons at depth; more than one generation of pegmatite formation is represented, and at least one generation is younger than the youngest granite at 1,450 Ma (Long, 1976). See the Explanation of Map Symbols for the symbology used in the map.

Yhp **Harding pegmatite (Mesoproterozoic)**—Complex, asymmetrically zoned pegmatite body in the schists and amphibolite of the Vadito Group (**Xvu**, Jahns and Ewing, 1976) in the southern Picuris Mountains; the disk-shaped body is elongate down-dip and inclined in a plane that dips 10° to 15° south; the body is about 350 m long, and its thickness ranges from 1 m at the edge to about 25 m at the core; major minerals include quartz, albite, microcline, muscovite, lepidolite, and spodumene; principal accessory minerals are beryl, garnet, microlite, and tantalite-columbite; about 40 other minerals have been identified (Jahns and Ewing, 1976); lath-shaped spodumene crystals are up to 5 m long; in general, from top to bottom, the eight lithologic units of the body are beryl zone, quartz zone, quartz-lath spodumene zone, "spotted rock" unit, rose muscovite-cleavelandite unit, cleavelandite unit, perthite zone, and aplite zone; replacement features are common; Northrup and Mawer (1990) concluded that the pegmatite is internally deformed, probably syntectonically as the melt was emplaced in locally dilatant extension fractures that developed late in the brittle-ductile shearing history; an age of 1,366 Ma based on Rb-Sr of whole-rock samples and mineral separates (Brookins et al., 1979) could be considered a minimum age for crystallization.

Ypqm **Peñasco quartz monzonite (Mesoproterozoic)**—Biotite quartz monzonite to granodiorite; composed of quartz, plagioclase, microcline, and biotite; euhedral 1 mm sphene crystals are common; accessory minerals are muscovite, allanite, epidote, magnetite-hematite, apatite, and zircon; locally contains tabular megacrysts of Carlsbad-twinned microcline up to 9 cm in length; myrmekite and albite rims on plagioclase are common; massive to weakly foliated, except locally along contacts where the foliation is well developed; generally concordant with country rock contacts and foliation; no compositional border zone; mafic microgranitoid inclusions are common, especially near borders; intrusive into the Rana quartz monzonite (**Xrqm**); U-Pb zircon isotopic age of about 1,450 Ma (Bell, 1985); Daniel et al. (2013) calculated a mean $^{207}Pb/^{206}Pb$ zircon age of 1,450 ± 10 Ma.

Yppqm **Pegmatitic phase of the Peñasco quartz monzonite (Mesoproterozoic)**—Coarse-grained, quartz, K-feldspar, and plagioclase granitic body with pronounced myrmekitic texture; distinctive intergrowth of plagioclase and vermicular quartz is common; no visible foliation; located in the southeastern corner of the Trampas quadrangle, and probably represents a high-level phase of the Peñasco quartz monzonite (**Ypgm**).

Xmg **Miranda granite (Paleoproterozoic)**—Exposed east of the Picuris-Pecos fault only; typically consists of pink to white, medium-grained, mica-rich, granitic rock with euhedral megacrysts of feldspar; these granitic rocks are everywhere weathered looking, fairly equigranular, and commonly crumbly; appears to intrude the Rio Pueblo Schist (**Xvrp**) along its southern contact; pegmatites are locally voluminous; contains at least one tectonic foliation; three closely spaced, orthogonal joint sets cause this rock to weather into small, angular blocks; age unknown, but it is similar in occurrence and texture to the ca. 1.6 Ga Tres Piedras Granite of the east-central Tusas Mountains to the northwest of the map area.

Xrqm **Rana quartz monzonite (Paleoproterozoic)**—Medium-grained, biotite quartz monzonite to granodiorite; composed of quartz, plagioclase, microcline, and lesser amounts of biotite and magnetite-hematite; accessory minerals are sphene, allanite, zircon, apatite, and epidote; plagioclase is extensively altered to sericite, epidote, and clinozoisite; generally well-foliated rock with local areas of weak foliation and zones of ductile shearing; foliation is generally parallel to the dominant foliation in the country rock; contact with the Puntiagudo granite porphyry (Xpgp) is a ductile shear zone; contains a discontinuous, fine-grained border zone of leucocratic muscovite granite; in general, strongly discordant with compositional layering in the country rock; U-Pb zircon isotopic age of 1,674 ± 5 Ma (Bell, 1985).

Xrqmb **Border phase of the Rana quartz monzonite (Paleoproterozoic)**—Includes fine-grained porphyritic granite of quartz-muscovite-plagioclase-microcline, and medium-grained muscovite granite and quartz monzonite; accessory minerals are allanite, epidote, zircon, hematite, biotite, and garnet; distinctly more leucocratic than the main body of Rana quartz monzonite; contact with Xrqm is gradational; border-zone rocks commonly project out into country rocks as dikes or tongues; well-developed foliation is concordant with the regional foliation trend.

Xpgp **Puntiagudo granite porphyry (Paleoproterozoic)**—Quartz monzonite to granodiorite; phenocrysts of Carlsbad-twinned microcline (< 1 cm) and rounded quartz in fine- to medium-grained matrix of plagioclase, K-feldspar, biotite, and muscovite; accessory minerals are epidote, allanite, sphene, and zircon; displays a local, narrow, fine-grained border zone; displays a sharp, discordant contact with Vadito Group (Xvu) schists; locally, thin dikes of fine-grained rock project into the country rock; the contact with the Rana quartz monzonite (Xrqm) is a zone of intense ductile shearing; a pervasive, moderately to well-developed foliation is parallel to regional foliation; U-Pb zircon isotopic age of 1,684 ± 1 Ma (Bell, 1985).

Xgp **Picuris Pueblo granite (Paleoproterozoic)**—Located on the west side of the Picuris-Pecos fault only; medium- to coarse-grained granitic rocks that show a variety of local textures ranging from coarse-grained, pink, feldspar-rich rock to white, quartz-rich rock; in thin section these rocks show interlocking mosaics of microcline, plagioclase, quartz, biotite, and iron-oxide minerals; most samples exhibit considerable alteration of feldspars and mica; these granitic rocks are intimately interlayered with supracrustal Vadito Group (Xvu) country rock; blocks of orthoquartzite within the plutonic rock suggest an intrusive relationship between the two, although south-dipping ductile faults may exist as well; contacts between granitic rock and supracrustal rock invariably trend east, parallel to bedding in the country rock; this name supersedes the informally named Granite of Picuris Peak of Bauer (1988); Daniel et al. (2013) calculated a mean $^{207}Pb/^{206}Pb$ zircon age of 1,699 ± 3 Ma.

Metasedimentary Rocks

Marqueñas Formation

Ym **Marqueñas Formation, undivided (Mesoproterozoic)**—Fine- to medium-grained, grayish, texturally immature, schistose quartzite; cross-beds are small-scale features defined by black mineral laminae; also includes a variety of metaconglomerates containing dominantly rounded quartzose clasts in a quartz-mica matrix; previously considered to be part of the ca. 1,700 Ma Vadito Group (Xvu), but U-Pb analyses of detrital zircons from a metaconglomerate were interpreted to constrain the basal unit to be less than about 1,450 ± 7 Ma in depositional age (Gray et al., 2015).

Ym3 **Northern metaconglomerate of the Marqueñas Formation (Mesoproterozoic)**—Predominantly composed of flattened quartzite pods; micaceous quartzite matrix contains scattered clasts, up to 10 cm long, of metasedimentary quartzite (66%), felsic schist (34%), and traces of vein quartz; alternating lithologic layers that might indicate original bedding are absent; gradational with the Marqueñas Formation quartzite (Ym2) to the south; $^{207}Pb/^{206}Pb$ analyses on detrital zircons yielded peak ages of 1,716 Ma and 1,457 Ma (Daniel et al., 2013); on the Trampas quadrangle this unit is approximately 150 to 180 m thick.

Ym2 **Quartzite of the Marqueñas Formation (Mesoproterozoic)**—Fine- to medium-grained, grayish, texturally immature, schistose quartzite; can be sub-divided into a lower massive gray quartzite and an upper cross-laminated quartzite (Scott, 1980); contains abundant cross-beds that range from small-scale features defined by black mineral laminae to large festoons with cross-laminations several centimeters thick; cross-beds consistently young to the north; pebble-rich layers also define bedding; contacts with adjacent metaconglomerates are gradational; $^{207}Pb/^{206}Pb$ analyses on detrital zircons yielded peak ages of 1,711 Ma, 1,697 Ma and 1,471 Ma (Daniel et al., 2013); where exposed 0.5 km east of Cerro de las Marqueñas (Trampas quadrangle) the unit is approximately 200 m thick.

Ym1 **Southern metaconglomerate of the Marqueñas Formation (Mesoproterozoic)**—Polymictic metaconglomerate containing rounded clasts of quartzite (54%), silicic metavolcanic rock and quartz-muscovite schist (40%), and white vein quartz in a muscovite quartzite matrix; clasts are flattened and constricted in the dominant foliation; aspect ratios average 1:2:3 to 1:2:6, with extremes of 1:2:16 or greater; in general, clast size increases southward and westward; quartzite clasts are up to 1 m long; the matrix averages about 30% of the volume of the rock; minor phases in the matrix include ilmenite, biotite, magnetite, hematite, zircon, and tourmaline; the contact with Vadito Group (**Xvu**) rocks may represent a 250 million-year-old angular unconformity (Gray et al., 2015); $^{207}Pb/^{206}Pb$ analyses on detrital zircons yielded peak ages of 1,716 Ma and 1,472 Ma (Daniel et al., 2013); U-Pb analyses of zircons in a metarhyolite clast yielded an age of 1,450 ± 7 Ma, interpreted as a maximum depositional age for the base of **Ym1** (Gray et al., 2015); 0.5 km east of Cerro de las Marqueñas (Trampas quadrangle) the unit is approximately 150 m thick.

Trampas Group (Informal)

Ytu **Trampas group, undivided (Mesoproterozoic)**—In cross section only. Schist, quartzite, metaconglomerate, phyllite, and slate deposits of the Piedra Lumbre (**Ytpl**) and Pilar Formations (**Ytp**); previously considered to be part of the ca. 1,680 to 1,700 Ma Hondo Group; this informal group name was proposed by Daniel et al. (2013) based principally on ages of detrital zircons in the Piedra Lumbre and Pilar Formations.

Ytpl **Piedra Lumbre Formation of the Trampas group (Mesoproterozoic)**—Includes several distinctive rock types: 1) quartz-muscovite-biotite-garnet-staurolite phyllitic schist with characteristic sheen on crenulated cleavage surfaces; euhedral garnets are 1 mm, biotite books are 2 mm, and scattered anhedral staurolites are up to 5 mm in diameter; 2) finely laminated light-gray phyllitic quartz-muscovite-biotite-garnet schist and darker bluish-gray fine-grained biotite quartzite to metasiltstone; quartzite layers are 1 cm to 1 m thick; and 3) light-gray to gray garnet schist with lenses of quartzite to metasiltstone; calc-silicate layers exist locally; original sedimentary structures including graded bedding are preserved; well-developed cleavage parallel to both layering and axial surfaces of small intrafolial isoclinal folds; dominant layering in much of this unit is transpositional; in the core of the Hondo syncline, the unit is thicker, contains a greater variety of rock types, and is gradational with the Pilar Formation; U-Pb analyses of detrital zircons from a quartzite in the upper part of the section (unit **Ytplq**?) were interpreted to constrain the unit to be less than about 1,470 Ma in depositional age (Daniel et al., 2013); apparent thickness is 200 to 400 m.

Ytplq **Quartzite of the Piedra Lumbre Formation, Trampas group (Mesoproterozoic)**—Massive to layered, light-colored, cross-bedded micaceous quartzite; locally garnet-bearing; approximately 25 m thick.

Ytplp **Phyllite of the Piedra Lumbre Formation, Trampas group (Mesoproterozoic)**—Dark-gray to black, fine-grained, garnet-bearing phyllite; crops out in the core of the Hondo syncline east of the Pilar-Vadito fault.

Ytp **Pilar Formation of the Trampas group (Mesoproterozoic)—**Dark-gray to black, carbonaceous phyllitic slate; extremely fine-grained homogeneous rock except for rare, 1- to 2-cm-thick, light-colored bands of quartz and muscovite that may represent original sedimentary bedding; in thin section, the fine-grained matrix consists of quartz (50 to 70%), muscovite (15 to 30%), and prominent streaky areas of graphitic material; lenticular porphyroblasts (0.1 to 0.5 mm) are altered to yellow-brown limonite; pervasive slaty cleavage is locally crenulated; displays small isoclinal folds locally; basal 1.5-m-thick, black to blue-black, medium-grained, garnet quartzite is distinctive; garnet porphyroblasts are anhedral, oxidized, and red-weathered; gradational with the Piedra Lumbre Formation (**Ytpl**); Daniel et al. (2013) calculated a mean ^{207}Pb/^{206}Pb zircon age of 1,488 ± 6 Ma for a 1- to 2-m-thick, white, schistose layer that was interpreted as a metamorphosed tuff, and therefore represents the depositional age of the sedimentary protolith; thickness unknown due to extreme ductile deformation.

Hondo Group

Xhu **Hondo Group, undivided (Paleoproterozoic)—**Schist and quartzite units of the Ortega (**Xho**) and Rinconada Formations (**Xhr**).

Rinconada Formation

Xhr **Rinconada Formation of the Hondo Group, undivided (Paleoproterozoic)—** Undivided schists and quartzites near the Pilar-Vadito fault in the Carson quadrangle that are pervasively fractured and faulted; U-Pb analyses of detrital zircons from two quartzite units were interpreted to constrain the unit to be less than about 1,700 Ma in depositional age (Daniel et al., 2013).

Xhr6 **R6 schist member of the Rinconada Formation, Hondo Group (Paleoproterozoic)—**Tan, gray, silver quartz-muscovite-biotite-staurolite-garnet schistose phyllite interlayered with fine-grained, garnet-bearing, muscovite quartzite; euhedral staurolites (<5 cm) abundant in some layers; small euhedral garnets (<2 mm) throughout; strong parting along well-developed foliation; sharp contact with the Pilar Formation (**Ytp**) might represent a significant unconformity; approximately 90 m thick.

Xhr5 **R5 quartzite member of the Rinconada Formation, Hondo Group (Paleoproterozoic)—**Variety of white to blue medium-grained quartzites interlayered with fine-grained schistose quartzites and quartzose schists; measured section by Hall (1988) from top to bottom: 1) tan to white, friable, thinly layered, cross-bedded micaceous quartzite; 2) blue, medium-grained, thickly layered, resistant saccharoidal quartzite; locally cross-bedded; 3) white to tan, friable schistose quartzite layered with blue, medium-grained saccharoidal quartzite; thin layers of fine-grained quartz-muscovite-biotite schist; basal 1.5 m massive blue medium-grained quartzite; 4) tan, thinly layered, micaceous quartzite layered with quartz-rich muscovite schist; abundant cross-bedding; 5) blue and white streaked, thickly bedded, medium-grained quartzite with abundant cross-bedding; and 6) tan, thinly layered, micaceous quartzite interlayered with quartz-rich quartz-muscovite schist; abundant cross-bedding; gradational contact with **Xhr6**; approximately 75 m thick.

Xhr4 **R4 schist member of the Rinconada Formation, Hondo Group (Paleoproterozoic)**—Medium- to coarse-grained, silvery gray, quartz-muscovite-biotite-staurolite-garnet schist containing one or more distinctive 0.5- to 2.0-m-thick layers of glassy blue quartzite; rusty red-weathering garnetiferous white quartzite; massive, extremely hard, red-weathering, olive-brown biotite-staurolite-garnet-orthoamphibole rock; white, glassy, hornblende quartzite; gray biotite-hornblende calc-schist; mylonitic blue to pink and blue glassy quartzite; and white to gray calcite marble. The latter four rock types are not present on the south limb of the Copper Hill anticline, but are present in the Trampas quadrangle on both the upright and overturned limbs of the Hondo syncline in Sections 7, 8, 9 and 10, T023N R011E; a well-exposed reference section of this thicker **Xhr4** sequence can be found on the south-facing slope and crest of the ridge making up the northern half of the SW quarter of Section 8, T023N R011E in the Trampas quadrangle (Hall, 1988); sharp contact with **Xhr5**; about 50 to 175 m thick.

Xhr3 **R3 quartzite member of the Rinconada Formation, Hondo Group (Paleoproterozoic)**—Interlayered cross-bedded quartzites and pelitic schists; a distinctive marker layer near the center of the unit is a 25-m-thick, white, thinly bedded, ridge-forming quartzite; sharp contact with **Xhr4**; approximately 75 m thick.

Xhr3q **R3 cross-bedded quartzite member of the Rinconada Formation, Hondo Group (Paleoproterozoic)**—White, gray, bluish-green, and blue, medium-grained, thinly to thickly bedded, resistant quartzite with abundant cross-beds.

Xhr3s **R3 schist member of the Rinconada Formation, Hondo Group (Paleoproterozoic)**—Locally includes two mappable layers of pelitic schist that resemble **Xhr4** and upper **Xhr1/2**.

Xhr1/2 **R1/R2 schist member of the Rinconada Formation, Hondo Group (Paleoproterozoic)**—Lower unit of fine- to medium-grained, tan to silver, quartz-muscovite-biotite schist with small euhedral garnets (<2 mm) and scattered euhedral staurolite twins (<1.5 cm); near the base are black biotite books (<2 cm) and on the upright limb of the Hondo syncline in Section 7, T023N R011E are spectacular, andalusite porphyroblasts up to 8 cm across; an upper unit of gray to tan, red-weathering, coarse-grained quartz-muscovite-biotite-staurolite-albite-garnet schist contains interlayers of 1 to 10 cm, red-, gray-, or tan-weathering, fine-grained, muscovite-garnet quartzite; abundant staurolites are twinned, euhedral, and up to 3 cm in diameter; abundant garnets are euhedral and small (<2 mm); the unit shows strong parting along foliation planes; sharp to gradational contact with **Xhr3**; lower and upper unit have previously been subdivided into R1 and R2 members, respectively, based on mineralogy (Nielsen, 1972); approximately 265 m thick.

Ortega Formation

Xho **Ortega Formation of the Hondo Group, undivided (Paleoproterozoic)**—Gray to grayish-white, medium- to coarse-grained quartzite; generally massive and highly resistant to weathering; locally well-cross-bedded, with kyanite or sillimanite concentrated in thin, schistose, muscovite-rich horizons; cross-beds are defined by concentrations of black iron-oxide minerals; common accessory minerals are ilmenite, hematite, tourmaline, epidote, muscovite, and zircon; gradational contact with the Rinconada Formation (**Xhr**); U-Pb analyses of detrital zircons from two quartzite layers were interpreted to constrain the unit to be less than about 1,700 Ma in depositional age (Daniel et al., 2013); 800 to 1,200 m thick.

Xho6 **Andalusite quartzite of the Ortega Formation, Hondo Group (Paleoproterozoic)**—Clean, white to tan, sugary quartzite interlayered with lenses and layers of massive, foliated, grey knobby andalusite quartzite; layers range from centimeters to meters thick; fine muscovite and scattered kyanite, sillimanite, and fuchsite are present in the quartzite; andalusites are large, lentil-shaped, poikiloblastic grains, with up to 50% quartz inclusions, mantled by coarse muscovite crystals; matrix is fine quartz, coarse kyanite, fine muscovite, euhedral rutile, and minor hematite and tourmaline; equivalent to **Oq3** of Williams (1982); mapped only on Copper Hill in the Trampas quadrangle where the unit is several meters thick.

Xho5 **Kyanite quartzite of the Ortega Formation, Hondo Group (Paleoproterozoic)**—Sugary to vitreous quartzite characterized by kyanite blades and distinctive opalescent quartz eyes; bedding-parallel, kyanite-rich layers give unit a vague foliation; fine muscovite grains are scattered between quartz grain boundaries; rutile is the predominant heavy mineral; on Copper Hill, a foliated iron-stained rock containing kyanite and staurolite grains (<0.5 cm), overlies the kyanite quartzite; equivalent to **Oq2** of Williams (1982); mapped only on Copper Hill in the Trampas quadrangle where the unit ranges from 3 to 5 m thick.

Xho4 **Massive gray quartzite of the Ortega Formation, Hondo Group (Paleoproterozoic)**—Massive, light- to dark-gray, vitreous quartzite with dark layers of rutile, hematite, and ilmenite that define cross-bedding; fine muscovite is commonly present on quartz grain boundaries and kyanite is commonly associated with dark layers; this unit is host to much of the fracture-filling, oxidized copper mineralization on Copper Hill and La Sierrita on the Trampas quadrangle; mineralization is related to upward migration of host fluids during Proterozoic retrograde metamorphism (Williams and Bauer, 1995); upper part is equivalent to **Oq1** of Williams (1982); mapped only on Copper Hill in the Trampas quadrangle where the unit is approximately 30 m thick.

Xho3 **Mixed quartzites of the Ortega Formation, Hondo Group (Paleoproterozoic)—** Various quartzites including reddish coarse-grained quartzite, brown medium-grained quartzite, gray quartzite, garnet-bearing dark quartzite, and tan cross-bedded quartzite; mapped only on La Sierrita ridge (Trampas and Peñasco quadrangles), where the unit is approximately 250 m thick.

Xho2 **Black quartzite of the Ortega Formation, Hondo Group (Paleoproterozoic)**— Dark-gray to black, massive, medium-grained quartzite; commonly cross-bedded, and generally contains a well-developed extension lineation defined by kyanite; mapped only on La Sierrita ridge (Trampas and Peñasco quadrangles); approximately 200 m thick.

Xho1 **Laminated schist of the Ortega Formation, Hondo Group (Paleoproterozoic)**— Reddish to orange-brown to white quartz-muscovite schist containing thin interlayers of light quartz-rich and darker mica-rich schist; exposed only in a small area in the core of the Copper Hill anticline (Trampas and Peñasco quadrangles); base is unexposed.

Xhow **Massive white quartzite of the Ortega Formation, Hondo Group (Paleoproterozoic)**—Massive, white to light-gray, vitreous quartzite with dark layers of rutile, hematite, and ilmenite that define cross-bedding; fine muscovite is commonly present on quartz grain boundaries, and kyanite commonly is associated with the dark layers; northeast of the Pilar-Vadito fault, most of the Ortega Formation consists of this unit plus the underlying reddish quartzite (**Xhor**).

Xhor **Reddish quartzite of the Ortega Formation, Hondo Group (Paleoproterozoic)**— Reddish, coarse-grained quartzite; probably equivalent to some of the **Xho2**/**Xho3** section southwest of the Pilar-Vadito fault; generally sharp contact with **Xhow**.

Xhos **Quartz-mica schist of the Ortega Formation, Hondo Group (Paleoproterozoic)—** White to pink, quartz-muscovite schist with quartz eyes; typically contains kyanite and andalusite; this unit has mineralogy and textures that are transitional between the Vadito Group feldspathic schist (**Xvf**) and the Hondo Group (**Xhu**) quartzites.

Xhosq **Schistose quartzite of the Ortega Formation, Hondo Group (Paleoproterzoic)—** Thin horizon of white, muscovite-rich, well-bedded quartzite located northeast of the Pilar-Vadito fault, west of Picuris Canyon (Taos SW and Peñasco quadrangles);

may be equivalent to part of the quartz-mica schist of the Ortega Formation (**Xhos**).

Xhog **Gray quartzite of the Ortega Formation, Hondo Group (Paleoproterozoic)—** Medium-gray, fine-grained, vitreous quartzite with well-developed, south-plunging, kyanite extension lineation; much of this unit is a quartz mylonite, with abundant evidence for grain size reduction and dynamic recrystallization; shearing is spatially related to the adjacent Plomo fault; located northeast of the Pilar-Vadito fault, near Picuris Canyon (Taos SW and Peñasco quadrangles).

Metasedimentary and Metaigneous Rocks

Vadito Group

Xvu **Vadito Group, undivided (Paleoproterozoic)—**Vadito Group metavolcanic, metavolcaniclastic, and metasedimentary rocks; U-Pb analyses of detrital zircons from a schist and a conglomerate layer were interpreted to constrain the unit to be less than about 1,700 Ma in depositional age (Daniel et al., 2013).

Xvf **Felsic schist of the Vadito Group, undivided (Paleoproterozoic)—**Includes a variety of quartz-muscovite-plagioclase schists; coarser-grained felsic rocks are tan to pinkish, quartz-plagioclase-muscovite-biotite, opaque, slightly schistose units with polycrystalline quartz eyes (2 to 8 mm); eyes are slightly flattened in foliation and probably represent relict phenocrysts of felsic volcanic rocks; trace minerals include sphene, apatite, and tourmaline; finer-grained felsic rocks are similar in mineralogy to coarser units, but lack the abundant quartz eyes; small, red, idioblastic garnets are rare; small, lensoidal bodies of tan to orange-red, garnet-bearing, quartz-muscovite, opaque schist are found locally; many of the felsic schist bodies appear to be intrusive into Vadito Group schists.

Xvg **Glenwoody Formation of the Vadito Group (Paleoproterozoic)—**Feldspathic quartz-muscovite schist and quartzose schist exposed in isolated exposures along the northern flank of the Picuris Mountains and in the Pilar cliffs; white, light-gray, pink, or green; commonly contains megacrysts of feldspar and rounded and flattened quartz in a fine-grained matrix of quartz, muscovite and feldspar; contact with overlying Ortega Formation (**Xho**) is a south-dipping ductile shear zone; pervasive extension lineation in schist plunges south; upper 40 m of schist is pinkish, and contains anomalous manganese and rare earth elements, and unusual minerals such as piemontite, thulite, and manganese-andalusite (viridine); L.T. Silver reported a preliminary U-Pb zircon age of ca. 1,700 Ma (Bauer and Pollock, 1993); may be equivalent to the Rio Pueblo Schist (**Xvrp**) and the ca. 1,700 Ma Burned Mountain Formation of the Tusas Mountains; base unexposed; minimum of about 200 m thick.

Xvrp **Rio Pueblo Schist of the Vadito Group (Paleoproterozoic)**—East of the Picuris-Pecos fault only; well-bedded, white, gray, and pink feldspathic quartz-muscovite quartz-eye schist; locally composed of up to 40% coarse, white muscovite flakes in a matrix of granular quartz and feldspar; quartz-eyes are abundant and are consistently flattened in the dominant foliation plane; the Miranda granite (**Xmg**) intrudes and crosscuts layering in the schists; along the southern contact with a massive gray quartzite; a manganese-rich horizon occurs stratigraphically below the quartzite; piemontite and altered porphyroblasts that might be pseudomorphs after manganese-andalusite are found along the schist-quartzite contact; this mineralized horizon is similar to that exposed in the Glenwoody Formation (**Xvg**) of the Pilar cliffs in the Carson and Trampas quadrangles.

Xvrpw **Muscovite member of the Rio Pueblo Schist, Vadito Group (Paleoproterozoic)**—Well-bedded, white, muscovite-quartz schist exposed in isolated patches in the mica mine area of the Tres Ritos quadrangle; composed of coarse, white muscovite flakes in a matrix of granular quartz and feldspar; probably a highly altered part of the Rio Pueblo Schist; hosts the best mica deposits and all of the major mica mines; thickness unknown.

Xvht **Transitional rocks of the Vadito Group (Paleoproterozoic)**—Exposed on the east side of Picuris Canyon (Taos SW and Peñasco quadrangles); includes a variety of rock types intermediate in mineralogy and texture between the metavolcanic rocks of the Vadito Group and metasedimentary rocks of the Hondo Group (**Xhu**); conglomeratic schistose quartzite, white quartz-muscovite feldspathic schist, gray quartzite and metaconglomerate, conglomeratic quartzite and schistose quartzite with clasts of bull quartz, quartzite, and fine-grained black rock, schistose metaconglomerate, and quartz-eye conglomerate; gradational eastward along strike with feldspathic schists (**Xvf**) of the Vadito Group; might be equivalent to part of transitional section south of Kiowa Mountain (Las Tablas quadrangle) in the Tusas Mountains (Bauer and Williams, 1989), however, in this map area it has been disrupted by the Plomo fault.

Xvq **Micaceous quartzites and metaconglomerates of the Vadito Group, undivided (Paleoproterozoic)**—Includes both lenticular micaceous quartzite bodies and scattered metaconglomerates; micaceous quartzites are variably colored, and consist mainly of granoblastic quartz grains, aligned muscovite grains, and layered concentrations of opaque minerals; local conglomerate horizons delineate bedding; the major metaconglomerate units in the area crop out southwest of Cerro Alto (Trampas quadrangle, referred to as the Embudo Creek quartzite by Bell, 1985) and in the southeastern Picuris Mountains; the metaconglomerate consists of rounded, predominantly quartzite clasts in a quartz-muscovite matrix; sedimentary features such as cross-beds and ripple marks are well preserved;

numerous thin lenses of quartzite and metaconglomerate, too thin to subdivide, are also found scattered within the amphibolite and schist units of the Vadito Group; a cross-bedded, feldspathic quartzite in the southeastern Picuris Mountains yielded a detrital zircon age peak of 1,715 Ma (sample CD10-10 of Daniel et al., 2013); detrital zircons collected from a quartz pebble metaconglomerate near the Harding Pegmatite Mine yielded a peak age of 1,707 Ma (sample J10-PIC7 of Daniel et al., 2013).

Xvqb **Quartz-biotite rock of the Vadito Group (Paleoproterozoic)**—Lenses and discontinuous layers of gray, quartz-biotite rock found in schist and amphibolite; light- to medium-gray, fine-grained quartz-biotite-(± muscovite) rock with local green epidote pods and veins; other minerals visible in thin section include plagioclase, microcline, sphene, garnet, hematite, and ilmenite; these rocks are similar to sills of the Cerro Alto metadacite (**Xvcam**).

Xvcam **Cerro Alto metadacite of the Vadito Group (Paleoproterozoic)**—Gray metadacite composed of fine-grained quartz, plagioclase, microcline, biotite, and muscovite; relict phenocrysts of quartz and/or feldspar are <4 mm long; accessory minerals are epidote, allanite, sphene, magnetite, and zircon; the main mass of metadacite is a stock-like body with sharp intrusive contacts with the country rock, especially along the western margin; abundant isolated sills are contained in adjacent amphibolites; the unit is crosscut by other plutonic rocks, and found as xenoliths within them; a moderately well-developed foliation is parallel to the regional trend; this body may be the remnant of a larger subvolcanic complex originally emplaced at a fairly shallow level within the Vadito Group; Daniel et al. (2013) calculated a mean $^{207}Pb/^{206}Pb$ zircon age of 1,710 ± 10 Ma that is interpreted to represent the age of crystallization.

Xvs7 **Fine-grained quartz-muscovite-chlorite schist of the Vadito Group (Paleoproterozoic)**—Includes several varieties of schist; fine-grained quartz-muscovite schist with scattered porphyroblasts of staurolite and biotite (<3 cm); grades to fine-grained, pale olive-green quartz-muscovite-chlorite schist with 1 to 2 mm garnets, 2 to 25 mm staurolites, and 0.5 to 2 mm biotites; locally shows compositional layers of 1-mm-thick, gray quartz-rich rock and <6-mm-thick, greenish, quartz-muscovite-chlorite schist; small grains (0.1 mm) of tourmaline, apatite, and sphene or monazite.

Xvs6 **Andalusite phyllitic schist of the Vadito Group (Paleoproterozoic)**—Silver-blue to silver-green, quartz-muscovite-chlorite schist with 4 cm rounded knots of andalusite cores and alteration rims; 3 mm biotite porphyroblasts are randomly oriented; local compositional layers, 0.5 to 2 cm thick, of white quartzite and silver-blue phyllitic schist; 20- to 40-cm-long elongate pods of granular quartz, chlorite, muscovite, and minor copper oxides are aligned in the foliation.

Xvs5 **Streaky schist of the Vadito Group (Paleoproterozoic)**—Dark-gray to green, fine-grained quartz-muscovite-biotite, opaque schist; streaky look results from 1- to 2-mm-thick, lens-shaped bodies of white quartz-plagioclase-muscovite schist and gray, biotite-quartz-muscovite-chlorite, opaque schist; locally, <2 mm biotite porphyroblasts are present; lenses are strongly folded and transposed; microscopic garnets have overgrown the foliation; a quartz-rich schist in the southwestern Picuris Mountains yielded a detrital zircon peak age of 1,705 Ma (sample CD12-1 of Daniel et al., 2013).

Xvs4 **Streaky knotty phyllitic schist of the Vadito Group (Paleoproterozoic)**—Silver-gray to silver-green, very fine-grained to phyllitic, quartz-muscovite-chlorite schist interlayered with white, quartz-rich layers; layering is discontinuous and probably transposed; contains altered knots of muscovite and green chlorite, and distinctive pods of fine- to medium-grained granular quartz; gradational contact with streaky schist.

Xvs3 **Andalusite-biotite phyllitic schist of the Vadito Group (Paleoproterozoic)**—Silver-blue to gray-green, very fine-grained, quartz-muscovite-chlorite phyllitic schist with black, biotite porphyroblasts and coarse-grained, andalusite knots; compositional layering is defined by lenses and layers of light and dark phyllite and white quartzitic schist; andalusites are 1 to 20 cm, dark-gray-blue, unaltered masses that are slightly flattened in the plane of foliation, and contain included internal foliation trails; black, randomly oriented biotite porphyroblasts average 4 mm in diameter; minerals such as staurolite, plagioclase, and garnet are present locally; a distinctive marker horizon of cordierite-bearing, quartz-muscovite schist is present near the main amphibolite body; cordierite porphyroblasts are gray, up to 20 cm long, and typically exhibit an orthorhombic (pseudohexagonal) crystal habit; the foliation wraps around the cordierite porphyroblasts; in thin section, cordierites are optically continuous, and contain abundant quartz inclusions that define two relict included foliations; gradational with **Xvs1** to the northeast.

*Knotty quartz-muscovite-(±biotite) schist (**Xvs2**) of the Vadito Group*

Common rock type is divided into three mappable sub-units (**Xvs2a**, **Xvs2b**, **Xvs2c**,), each displaying gradational contacts with the others.

Xvs2a **Knotty quartz-muscovite-(±biotite) schist of the Vadito Group (Paleoproterozoic)**—Light-gray, fine-grained, quartz-muscovite, phyllitic schist with black speckles of biotite and opaque minerals; the most phyllitic unit in **Xvs2**; in general, these rocks become more quartzose and less phyllitic from northwest to southeast; all units contain altered knots of fine-grained muscovite, chlorite, and quartz.

Xvs2b **Knotty quartz-muscovite-(±biotite) schist of the Vadito Group (Paleoproterozoic)**—Contains a variety of fine-grained, quartz-muscovite-biotite schists with ubiquitous scattered, rounded, and elongate, altered porphyroblast knots.

Xvs2c **Knotty quartz-muscovite-(±biotite) schist of the Vadito Group (Paleoproterozoic)**—Similar to Xvs2b with the exception of less abundant knots of altered muscovite-chlorite-quartz; knots may be altered cordierite porphyroblasts.

Xvs1 **Pelitic schists of the Vadito Group, undivided (Paleoproterozoic)**—Includes a variety of pelitic to semi-pelitic schists; relatively massive, light-gray, fine-grained, quartz-muscovite schist with scattered flakes of black biotite (< 1 mm) and compositional layers defined by alternating quartz-rich and mica-rich horizons that are 1 to 25 mm thick; quartz-muscovite schist with porphyroblasts of biotite, garnet, and andalusite; fine-grained quartz-muscovite schist with scattered porphyroblasts of biotite; also includes local horizons of interlayered amphibolite.

Xvsa **Andalusite schist of the Vadito Group (Paleoproterozoic)**—Distinctive, black, biotite schist containing large knobs of andalusite; this unit is only a few meters thick and appears to pinch out laterally in both directions.

Xag **Amphibolite in granite of the Vadito Group (Paleoproterozoic)—**Includes a variety of amphibolite bodies, lenses, and layers within the Miranda granite (Xmg); the predominant rock type is fine- to medium-grained, dark-gray-green to black, weakly foliated amphibolite composed of blue-green to olive-green hornblende, interstitial quartz and plagioclase, sphene, and epidote; faint compositional layering is formed by 1- to 2-mm-thick white layers; epidote veins and zones are common.

Xva **Amphibolite of the Vadito Group (Paleoproterozoic)**—Includes a wide variety of amphibolite bodies, lenses, layers, and textures; the large amphibolite body south and east of the Harding pegmatite is a complex unit containing metamorphosed and deformed volcanic, sedimentary, and volcaniclastic rocks; the predominant rock type is fine- to medium-grained, dark-gray-green to black, weakly foliated amphibolite composed of blue-green to olive-green hornblende (0.1 to 0.7 mm), interstitial quartz and plagioclase (0.1 mm), sphene, and epidote; faint compositional layering is formed by 1- to 2-mm-thick white layers; epidote veins and zones are common, especially near pluton margins; fragmental amphibolites containing white felsic fragments and gray lithic fragments, elongated and flattened in the foliation of the fine-grained hornblende matrix, exist locally; subangular, gray, quartzite clasts, black, basaltic fragments, and epidote clasts also exist within the matrix; other rock types within the large amphibolite body include biotite schist, metadacite, felsic schists, quartzite, metagabbro, and various schists; smaller layers and lenses scattered throughout the Vadito schists are mainly fine- to medium-grained amphibolites that range considerably in texture and mineralogy.

Xvb **Fragmental biotite schist of the Vadito Group (Paleoproterozoic)**—Dark, schistose matrix of biotite-quartz-plagioclase contains varying percentages of clasts of: 1) white, gray, red, and black subrounded quartzite pebbles (1 to 15 cm); 2) dark-olive-green to brown, fine-grained, lithic fragments that are strongly flattened in foliation; 3) white, felsic fragments that are extremely flattened in foliation; and 4) boulder-sized, dark-green-black, fine-grained amphibolites; this unit also contains lensoidal bodies of metadacite.

Xvmix **Mixed metavolcanic rocks of the Vadito Group (Paleoproterozoic)**—Undivided amphibolites, fragmental amphibolites, biotite schist, fragmental biotite schist, and various felsic to mafic schistose units.

Xvd **Gneiss of the Vadito Group (Paleoproterozoic)**—Gneissic dioritic rock with interlayered quartz-biotite gneiss, felsic gneiss, and quartz-muscovite-biotite schist; grades into more schistose rock in the southern area of exposure; coarse pegmatites are common; exposed only in the southeastern Trampas quadrangle, where it is intruded by Rana quartz monzonite.

Proterozoic

XYu **Proterozoic rocks, undivided (Proterozoic)—**Supracrustal metamorphic rocks and plutonic and metaplutonic rocks.

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