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Geologic Map of the Abiquiu Quadrangle, Rio Arriba County, New Mexico

By Florian Maldonado

Pamphlet to accompany Scientific Investigations Map 2998

U.S. Department of the Interior
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Geologic Map of the Abiquiu Quadrangle, Rio Arriba County, New Mexico

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General Geology

The Abiquiu 1:24,000-scale quadrangle is located along the Colorado Plateau-Rio Grande rift margin in north-central New Mexico (figs. 1 and 2). The map area lies within the Abiquiu embayment (fig. 1), an early (pre-Miocene) extensional basin of the Rio Grande rift. Rocks exposed include continental Paleozoic and Mesozoic rocks of the Colorado Plateau and Cenozoic basin-fill deposits and volcanic rocks of the Rio Grande rift. Paleozoic units include the Late Pennsylvanian to Early Permian Cutler Group, undivided (ℙcu). Mesozoic units are Upper Triassic Chinle Group, undivided (₸cu), middle Jurassic Entrada Sandstone (Je), and Todilto Limestone Member (Jt) of the Wanakah Formation. Mesozoic rocks are folded in some areas and overlain disconformably by Cenozoic rocks. Cenozoic sedimentary rocks are composed of the Eocene El Rito Formation (Te), Oligocene Ritito Conglomerate (Trc), Oligocene–Miocene Abiquiu Formation (Ta), and Miocene Chama-El Rito (Ttc) and Ojo Caliente Sandstone (Tto) Members of the Tesuque Formation of the Santa Fe Group. Volcanic rocks include the Lobato Basalt (Tlb) (≈15–9 Ma, Aldrich and Dethier, 1990; ≈10–8 Ma, Bachman and Mehnert, 1978; Manley and Mehnert, 1981; and ≈10–8 Ma, samples A99, A50, and A48 (fig. 2), Maldonado and Miggins, 2007), the El Alto Basalt (Teb) (≈3 Ma, Manley and Mehnert, 1981; Baldridge and others, 1980; sample A13 (map, fig. 2), Maldonado and Miggins, 2007), and dacite of the Tschicoma Formation (Ttd) (≈2 Ma, Gardener and Goff, 1984). Quaternary deposits consist of inset ancestral axial and tributary Rio Chama deposits and Holocene floodplain alluvium, fan and pediment alluvium, and landslide colluvium. Axial or side stream terrace benches are found approximately 25–150 m above the present day Rio Chama channel. One set of terraces (Qt2) at about 120 m height is as old as 640 ka, based on the presence of the Lava Creek B ash in map area and east of the map area as indicated by Dethier and others (1990) and Gonzalez and Dethier (1991), although the ash was not found in map area by this author. Delineation of terrace alluvium is modified from Gonzalez (1993) and Gonzalez and Dethier (1993).

Tributary gravels beneath the Lobato Basalt (Tlb) and El Alto Basalt (Teb) contain clasts of a fluvial system that probably represent several ancestral Tertiary Rio Chama courses. Tops of these gravels are about 580 m and 395 m, respectively, above the modern Rio Chama. Clasts consist mostly of subrounded to well-rounded Paleozoic quartzite and granite, Tertiary volcanics, and traces of Pedernal Chert Member of the Abiquiu Formation (Moore, 2000) (referred to as Pedernal chert in this report). Gravels containing quartzite and Pedernal chert also are present under the lavas capping Sierra Negra (sample A49 (fig. 2), 5.56 Ma (plateau age), 5.44 Ma (isochron age) Maldonado and Miggins, 2007; ≈5 Ma, Baldridge and others, 1980) and the Servilleta Basalt flows at Black Mesa (≈4–3 Ma; Manley, 1976; Laughlin and others, 1993, unpub. report for Los Alamos National Laboratory, sample A51 (fig. 2), 3.69 Ma (plateau age), 3.45 Ma (isochron age) Maldonado and Miggins, 2007) northeast and east of the map area (fig. 2), respectively.

A major fault in the map area is the Cañones fault zone located in the northwest corner of map area (figs. 1, 2) that separates the Abiquiu embayment from the Colorado Plateau. The Abiquiu embayment is a shallow basin that forms the western margin of the Rio Grande rift (Baldridge and others, 1994), east of the deeper Española basin (fig. 2). The Cañones fault developed during deposition of the Abiquiu Formation (Ta), Oligocene Ritito Conglomerate (Trc), and the El Rito Formation (Te) based on the presence of these units on the Cerro Pedernal of the Colorado Plateau (fig. 1, Smith, 1995; Moore, 2000; Kelley and others, 2005) and the Abiquiu embayment (fig.1). The fault appears to have continued to be active for some time based on:

1) a dike referred to informally as the basaltic dike of Red Wash Canyon (Tbr) located in the northwest corner of map area intrudes the lower part of the Chinle Group of the Colorado Plateau Province and the Trc unit of the Abiquiu embayment (just west of map boundary). The dike, dated at 19.63±0.40 Ma (sample A65, fig. 2, map, Maldonado and Miggins, 2007) is offset approximately 2 km right-laterally by the Cañones fault. The dike has the same age as the Cerrito de la Ventana dikes (Tcd) (sample A23, map, fig. 2), 19.58±0.09 Ma (weight mean age), 19.22±0.30 Ma (isochron

age) Maldonado and Miggins, 2007) that intrude units Trc and Ta in the Abiquiu embayment,

2) the Lobato Basalt (10–8 Ma), with source in the embayment is found both on the Colorado Plateau and the embayment, and

3) latest offset is constrained by the presence of two different basalts (Lobato Basalt, Tlb and El Alto Basalt, Teb) on the Colorado Plateau with centers in the embayment. The Lobato Basalt is displaced across the Cañones fault whereas the El Alto Basalt (≈3 Ma) is not (Maldonado, 2004).

Other major faults related to rift formation located east from the Cañones fault are; Garcia, Cerrito Blanco, Barranca, Plaza Colorado, and Madera Canyon. These series of faults may be growth faults that form a zone of step faults that down-drop strata to the east, towards the Española basin (fig. 1), a deeper part of the Rio Grande rift.

Landslides are very common in the map area that have separated from their source outcrop. On Mesa de Abiquiu, south of Abiquiu and above Abiquiu Creek (see map), a major incipient fissure zone has formed near the edge of the El Alto Basalt (Teb). The zone strikes northeast and is about 3.5 km long with gaps as much as 1 m. This fissure zone may eventually form landslides affecting the Abiquiu Creek area.

Another important structure in the map area are blocks bounded by a low-angle fault referred to here as the Abiquiu fault (figs. 3, 4). The Abiquiu fault separates an upper plate from a lower plate. The upper plate is composed of the transitional zone (Ttoc) of the Ojo Caliente Sandstone (Tto) and Chama-El Rito (Ttc) Members of Tesuque Formation (fig. 4). In most areas, the lower plate consists of the Abiquiu Formation (Ta), but in the northern part of the Cerrito Blanco area (map, fig. 4), the lower plate consists of the Ritito Conglomerate (Trc). The upper plate may have originally formed a continuous sheet that formed as a mega-slide block that subsequently has been broken and eroded into smaller blocks. The blocks range from about 0.1 km to 3.5 km with the Rio Chama flowing thru the largest block (fig. 4). In the Cerrito Blanco area, referred to as "Battleship Rock" by Smith (1938), the upper and lower plates and Abiquiu fault have been offset by movement on the Cerrito Blanco fault (fig. 4) resulting in cementation of the upper plate. The upper plate was probably first fractured and shattered forming a "shattered breccia" by movement on the Abiquiu fault followed by solutions migrating up along the Cerrito Blanco fault zone cementing the upper plate. In the southwestern part of the map area, south of the Rio Chama, smaller blocks are present that may have been part of this large sheet. There (fig. 5), the upper plate is composed of the transitional zone (Ttoc) and basaltic dikes of Barranca (Tbb). In summary, the evidence for this sheet and the low-angle structure are the following:

1) upper plate above the low-angle fault (Abiquiu fault) is brecciated, intensely factured, and contains numerous faults with small displacements,

2) in some areas (northern part of Cerrito de Blanco) steep dips in the upper plate dip into the lower plate and form an angular discordance,

3) stratigraphically, the upper plate is out of place with some section missing; in the southern part of the Cerrito Blanco area, the upper plate overlies the Abiquiu Formation (Ta) and to the north, it overlies the Ritito Conglomerate (Trc),

4) in the northern part of the Cerrito Blanco area, the Chama-El Rito (Ttc) appears to overlie the Ojo Caliente (Tto) which could imply overturning of the upper plate or perhaps just intertonguing of these two units, and

5) south of the Rio Chama, in the western part of map area, south of the village of Barranca, dikes referred to as dikes of Barranca (Tbb) intrude the upper plate (Ttoc) and are truncated by the Abiquiu fault (fig. 5), suggesting that intrusion of the dikes are pre-detachment of the upper plate.

Older structures of Laramide age, are preserved as folds in the Mesozoic rocks in the northwestern part of the map area, and locally as small reverse faults (fig. 6) in the undivided Chinle Group in the Arroyo del Cobre area.

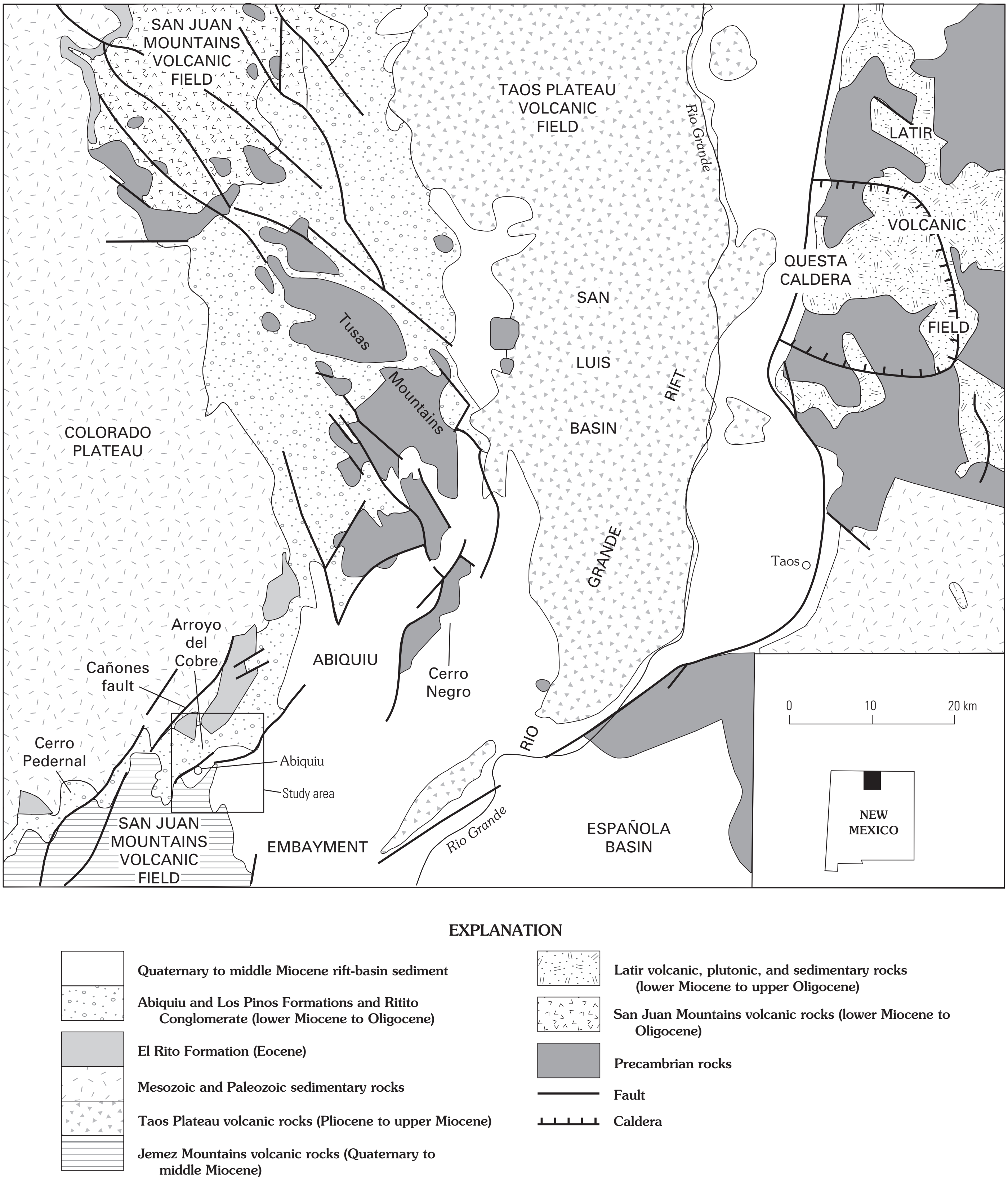

Figure 1. Generalized geologic map (modified after Smith, 1995) of north-central New Mexico showing study area.

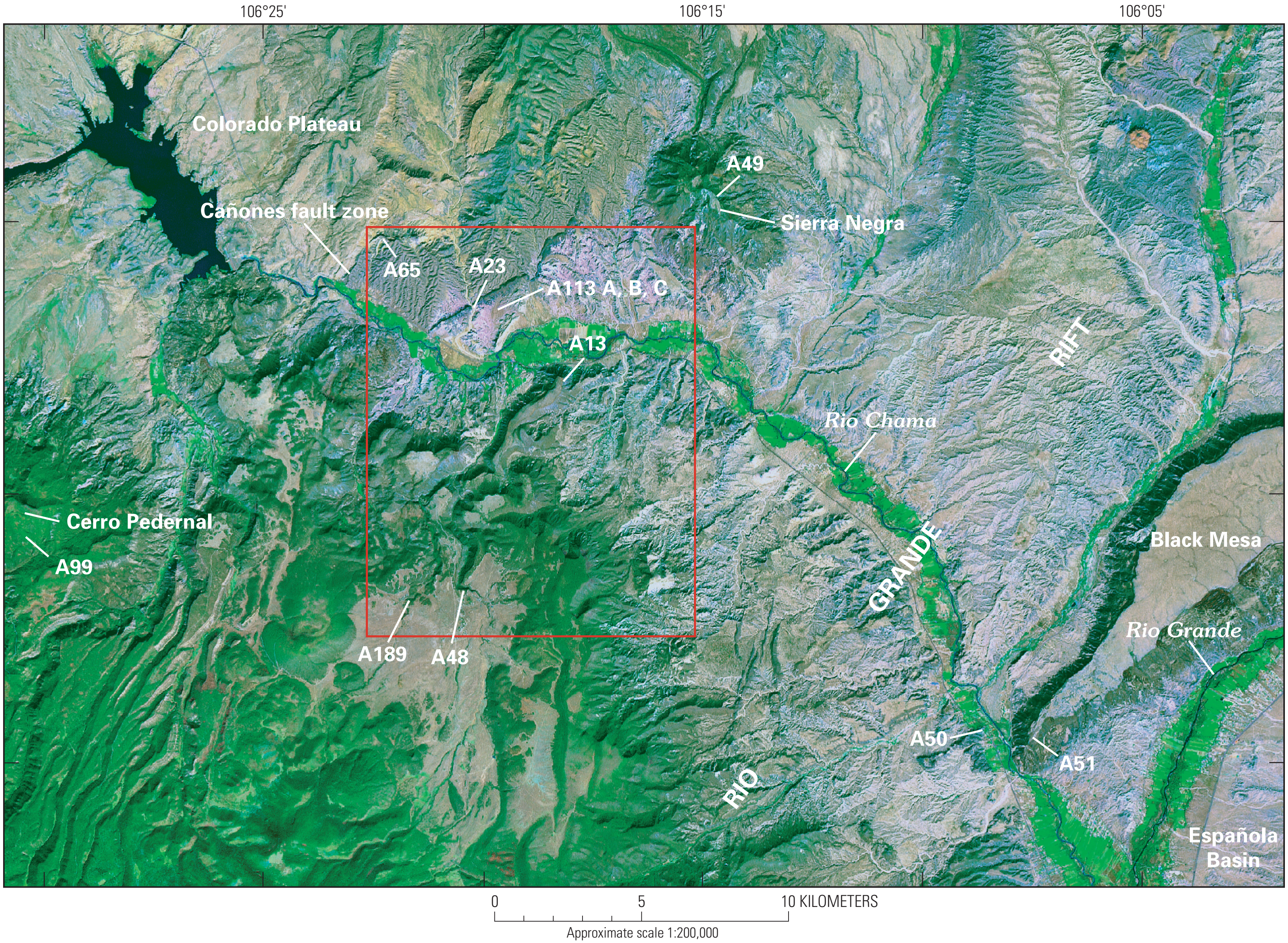

Figure 2. Landsat image of the Abiquiu quadrangle (shown in red) and contiguous areas showing sample locations (for example, A51) outside map area. Landsat image modified from Sawyer and others (2004).

Figure 3. Photograph showing panoramic view looking west towards Rio Chama and Cerro Pedernal (Colorado Plateau). Fault with hachures indicates block of unit Ttoc, possibly overlying unit Ta. See description of map units for labeled units.

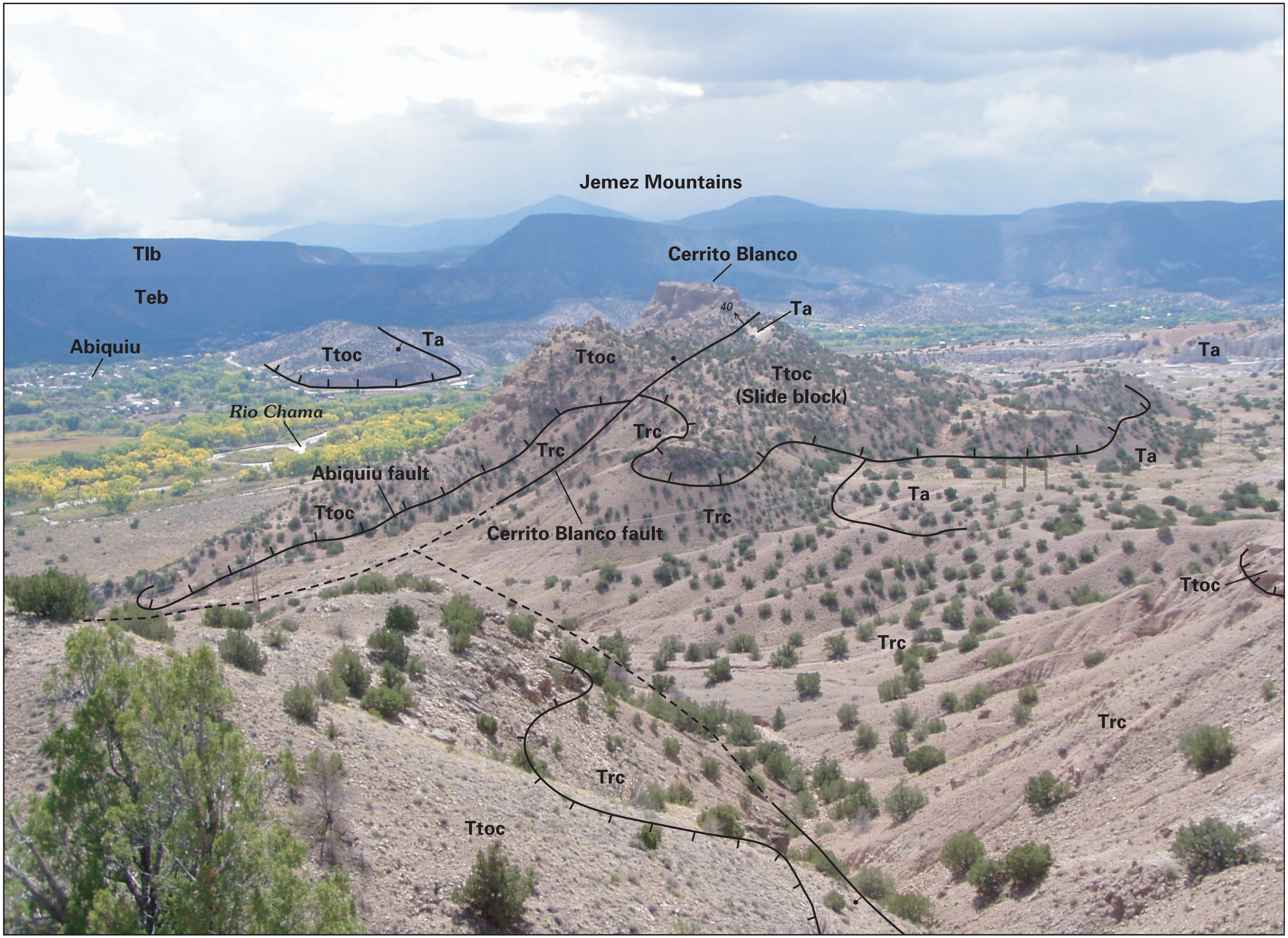

Figure 4. Photograph showing panoramic view looking south towards Cerrito Blanco, Abiquiu, and peaks of the Jemez Mountains. Fault with hachures indicates block of unit Ttoc. Dots indicate concealed faults. See description of map units for labeled units.

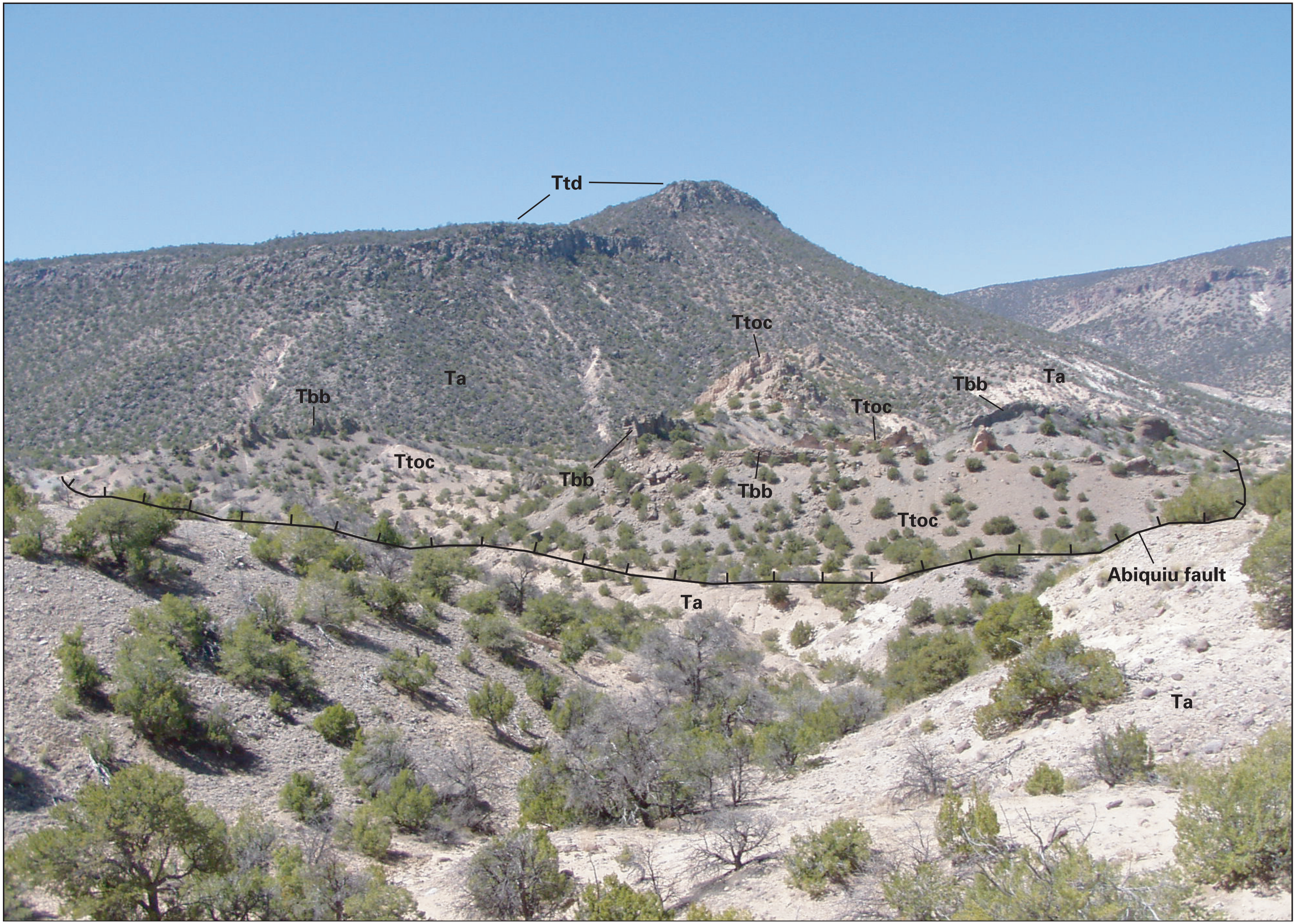

Figure 5. Photograph showing panoramic view looking southwest, south of Rio Chama and the village of Barranca, towards block of unit Ttoc intruded by basalt dikes of Barranca (Tbb). Fault with hachures indicates block of unit Ttoc. See description of map units for labeled units.

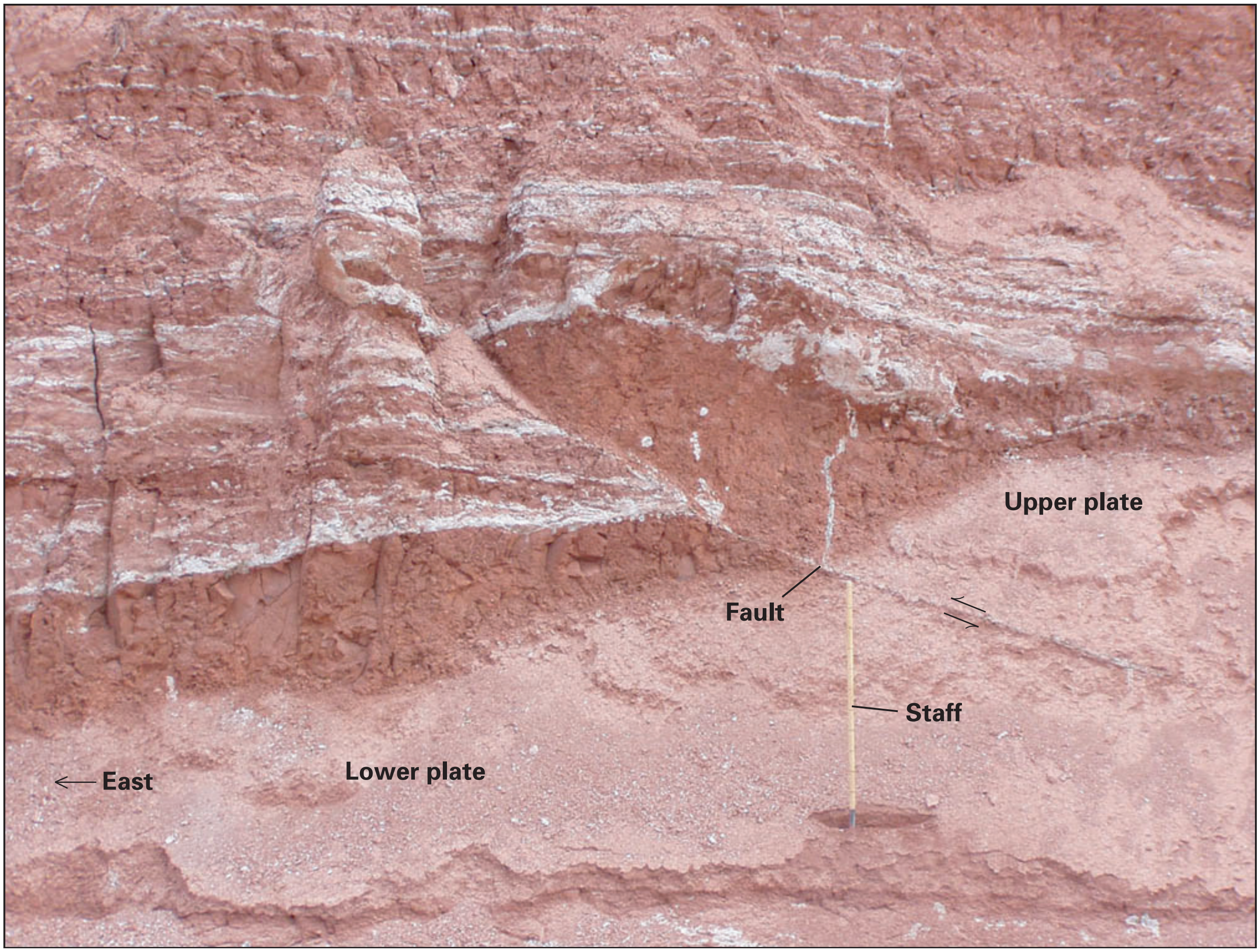

Figure 6. Photograph showing Laramide reverse fault in upper part of Chinle Group, Arroyo del Cobre area. Upper plate has moved to the east. Arrows indicate direction of movement. Staff is 2 m high.

Description of Map Units

Where eolian sand (Qe) forms a nearly continuous mantle (approximately 1 m to several meters thick) on an older unit, fractional map symbols are used (for example Qe/Teb). Other fractional map symbols include unit Qsc/Qay undivided and units undivided due to poor exposures on colluvium covered slopes (for example Qcb/Tto, Qcb/Ttc, Qcb/Ta, and Ttd/Ta). Sediment and rocks colors given in the map unit descriptions are based on the Geological Society of America Rock-Color Chart (1995). Grain size of sand deposits is defined using Wentworth's scale (Wentworth, 1922; Dutro and others, 1989): very fine (0.06–0.125 mm), fine (0.125–0.250 mm), medium (0.250–0.50 mm), coarse (0.50–1.0 mm), and very coarse (1.0–2.0 mm). Bed thickness is described after Ingram (1954): very thickly bedded (>1 m), thickly bedded (30–100 cm), medium bedded (10–30 cm), thinly bedded (3–10 cm), very thinly bedded (1–3 cm), thickly laminated (0.3–1 cm), and thinly laminated (<0.3 cm). Subdivisions of the Pleistocene and Holocene Epochs follow Morrison (1991); the age of the Pliocene–Pleistocene boundary at 1.8 Ma is adopted from Berggren and others (1995).

Alluvium, Colluvium, Eolian, Talus, and Landslide Deposits

Qrc **Main stream channel of modern Rio Chama (historic)**—The Rio Chama deposits consist of pale-yellowish-brown (10YR6/2) to moderate-yellowish-brown (10YR5/4), medium-grained sand and silt, and gravels. Gravels composed of angular to subangular, pebble- to boulder-size clasts of Precambrian metamorphic, Mesozoic sedimentary, and Tertiary volcanic and sedimentary rocks. Thickness approximately 5 m

Qfp **Floodplain of modern Rio Chama (historic)—** Deposits consist of pale-yellowish-brown (10YR6/2) to moderate-yellowish-brown (10YR5/4), well-sorted, subrounded to subangular, very fine grained to coarse-grained sand, silt, dusky-grayish-brown (10YR2/2) to moderate brown (5YR3/4) clay, and sparse gravel. Deposit surface is floor of inner valley of Rio Chama, formed by overbank deposits of sand, silt, and clay, and by sandy paleochannel deposits. These deposits are typically disturbed by agriculture and construction. Thickness variable, but generally about 5 m

Qsc **Side-stream channel deposits (Holocene)—**Unconsolidated deposits composed of clay, silt, fine- to coarse-grained sand, and gravels of angular to rounded pebble- to boulder-size clasts composed of quartzite, granite, quartz, schist, basalt, gneiss, intermediate volcanics (lavas and tuffs), and sandstone. Locally contain eolian sand deposits. Deposits found in stream channels draining into present Rio Chama derived from units Te, Trc, Ta, Ttc, Tto, Ttoc, Tcd, Tlb, Teb, Ttd, and locally from Mesozoic units and terrace deposits. Thickness variable, generally about 5 m

Qay **Young alluvium in Rio Chama valley bottom and north of Rio Chama (Holocene)—** Unconsolidated deposits composed of moderate-orange-pink (10R7/4) sand and gravels with local eolian sand deposits in lower part of valley bottom of Rio Chama valley. North of Rio Chama and west of Rancho de Abiquiu, sediments form higher unconsolidated fan deposits composed of moderate-orange-pink (5YR8/4) to moderate-reddish-orange (10R6/6) clay, silt, medium- to coarse-grained sand, and angular to subangular pebble to boulder-size gravels derived from units Te, Trc, Ta, Ttc, Ttoc, and Tcd. North of Rancho de Abiquiu, deposit is not a reddish color, but rather a lighter color that resembles unit Ta that is probably recycled Ta. Here, Qay is yellowish gray (5Y7/2) silt, medium-to coarse-grained sand with gravel lenses of mostly pebble and some boulder-size clasts of granite, gneiss, sandstone, basalt, quartzite, quartz, and schist. Thickness varies from 5 to 30 m

Qac **Alluvium and colluvium (Holocene)—**Deposits found predominately along slopes composed of unconsolidated moderate-orange-pink (10R7/4) silt, fine- to coarse-grained sand, and unsorted debris. Debris ranges from angular to subangular pebble- to block-size clasts derived from units Te, Trc, Ta, Ttc, Tto, Ttoc, Tcd, Tlb, Teb, Ttd, and locally from Mesozoic rocks in the Arroyo del Cobre area (fig. 1). Basalt is the dominant clast type south of Rio Chama. Locally contains poorly developed calcic soils. As much as 60 m thick

Qe **Eolian sand (Holocene)—**Light-brown (5YR6/4), fine- to medium-grained sand dunes that locally overlies unit Ta north of State Highway 84 and Rio Chama, in northwest part of map area. Approximately 15 m thick

Qae **Alluvium and eolian sand (Holocene)—**Unconsolidated fluvial silt and sand and locally windblown fine- to coarse-grained sand. Locally overlies units Ttd, Teb, and Tlb. Approximate thickness 1–5 m

Qcb **Colluvium deposits predominately of basaltic clasts (Holocene)—**Composed of unconsolidated angular, pebble- to boulder-size basaltic debris derived from units Teb, Tlb, and Tcd. Forms lag deposits (mostly Tlb) that mantle Tto south of State Highway 84. Locally, some exposures may contain quartzite clasts eroded from terrace deposits. As much as about 30 m thick

Qls **Landslide deposits (Holocene and Pleistocene)—** Largest landslide deposit overlies unit Ta, located in western part of map area south of Rio Chama. In adjacent Cañones quadrangle, deposit is found at base of Teb and Tlb (Manley, 1982; Moore, 2000; Kelley and others, 2005). Deposit composed of unconsolidated hammock deposits of Teb, Tlb, and Tto blocks. Locally, smaller deposits along Abiquiu Creek are derived from Teb and Tlb and overlie Tto. As much as 50 m thick

Axial Channel and Side-Stream Channel Deposits of the Ancestral Rio Chama

Fluvial deposits shown with an “a” in formation symbol represent axial deposits of ancestral Rio Chama. Deposits shown with an “s” in formation symbol indicate side-stream channel deposits of ancestral Rio Chama. Formation symbols without an “a” or an “s” indicate both axial and side stream, undivided. Nomenclature in most cases follows those of Dethier and others (1990), Gonzalez (1993), and Dethier and Reneau (1995). Units are differentiated based on height above present day Rio Chama channel (Qrc). Height is determined on highest contour found on deposit from present day Rio Chama channel.

Qt6 **Axial channel and side-stream channel deposits of ancestral Rio Chama, undivided (Pleistocene?)—**Predominately composed of coarse moderate-orange-pink (10R7/4) fine to coarse sand and occasional lenses of gravels. Gravels contain angular to well-rounded clasts composed of quartzite, sandstone, quartz, gneiss, schist, granite, intermediate volcanics (lavas and ash-flow tuff), tuffaceous sandstone, and basalt. Parallels present Rio Chama and is approximately 25 m above present Rio Chama channel. Thickness about 30 m

Qt5a **Axial channel deposits of ancestral Rio Chama (Pleistocene)—**Contains channel deposits of sandy gravel and occasional interbeds of fine-grained sand and silt overbank. Clasts are subrounded to well-rounded, pebble to boulder in size, predominately of Proterozoic quartzite with some volcanic (ash-flow tuffs, basalt, and intermediate lavas), schist, gneiss, and quartz, Cretaceous sandstone and conglomerate, and granitic clasts. Inset in units Ttc, Tcv, Trc, and Ta and parallel to present Rio Chama. About 45–55 m above present day Rio Chama channel. Thickness about 25 m

Qt5s **Side-stream channel deposits of ancestral Rio Chama (Pleistocene)—**Channel deposits contain mostly angular to rounded, pebble- to boulder-size clasts of Proterozoic quartzite, granitic, and metamorphic rocks. North of modern Rio Chama, deposits are reddish color with sand and clasts probably eroded from units Te and Trc. Side-stream channel deposits trend mostly north-south in Arroyo del Cobre and west of Madera Canyon areas and are inset in units Te, Trc, and Ta. Approximately 45–90 m above present day Rio Chama channel. Thickness about 10 m

Qt5 **Axial channel and side-stream channel deposits of ancestral Rio Chama, undivided (Pleistocene)—**Inset in unit Ta just west of Cerrito Blanco fault and north of Rio Chama. Deposits of sandy gravel and occasional interbeds of fine-grained sand. Clasts are subrounded to well-rounded, pebble to boulder in size, predominately of Proterozoic quartzite with some volcanic (ash-flow tuffs, basalt, and intermediate lavas), schist, gneiss, and quartz, Cretaceous sandstone and conglomerate, and granitic clasts. Approximately 45–80 m above present Rio Chama channel. Thickness about 10 m

Qt4a **Axial channel deposits of ancestral Rio Chama (Pleistocene)—**Deposits composed of angular to well-rounded pebble- to boulder-size clasts predominately of quartzite with lesser amounts of granite, metaconglomerate, quartz, schist, gneiss, Pedernal chert, basalt, and gabbro. Occasional grayish-orange (10YR7/4) interbedded fine- to coarse-grained sand. Inset in units Trc and Ttc and parallel to present Rio Chama. Approximately 50–60 m above present Rio Chama channel. Thickness about 15 m

Qt4s **Side-stream channel deposits of ancestral Rio Chama (Pleistocene)—**Gravels locally interbedded with grayish-orange (10YR7/4) to medium-reddish-orange (10YR6/6), fine- to coarse-grained sands. Gravels are subrounded to well-rounded pebble- to boulder-size clasts predominately of quartzite and granite with lesser amounts of gneiss, schist, quartz, basalt, intermediate volcanic clasts (lavas and ash-flow tuffs), gabbro, and sandstone. Clasts could be recycled from units Te, Trc, Ta, Ttc, and Tcd. Locally, contains poorly developed calcic soil or eolian sand. North of Rio Chama, west of Madera Canyon, unit is a reddish color, inset in units Ta and Ttc, in a north-south trend. Surface of deposit has a steep gradient and is approximately 135 m above present day Rio Chama. Thickness about 30 m

Qt4 **Axial channel and side-stream channel deposits of ancestral Rio Chama, undivided (Pleistocene)—**Gravels locally interbedded with grayish-orange (10YR7/4) to medium-reddish-orange (10YR6/6), fine- to coarse-grained sands. Gravels are subrounded to well-rounded pebble- to boulder-size clasts predominately of quartzite and granite with lesser amounts of gneiss, schist, quartz, basalt, and intermediate volcanic clasts (lavas and ash-flow tuffs). Inset in Ta west of Abiquiu and south of Rio Chama. Approximately 60 m above present day Rio Chama channel. Thickness about 15 m

Qt3a **Axial channel deposits of ancestral Rio Chama (Pleistocene)—**Grayish-orange-pink (5YR7/2) medium-grained sand interbedded with angular to well-rounded pebble- to boulder-size clasts of quartzite with lesser amounts of basalt, quartz, intermediate volcanics, metaconglomerate, gneiss, schist, and granite. Locally poorly developed calcic soil. Inset in Ta west of Abiquiu and south of Rio Chama. Approximately 65 m above present Rio Chama channel. Thickness about 20 m

Qt3s **Side-stream channel deposits of ancestral Rio Chama (Pleistocene)—**Gravels locally interbedded with grayish-orange (10YR7/4) to medium-reddish-orange (10YR6/6), fine- to coarse-grained sands. Gravels are subrounded to well-rounded pebble- to boulder-size clasts predominately of quartzite and granite with lesser amounts of gneiss, schist, quartz, basalt, intermediate lavas and ash-flow tuffs, gabbro, and sandstone. Clasts could be recycled from units Te, Trc, Ta, Ttc, and Tcd. In Madera Canyon area, north of Rio Chama, deposit inset in units Ta and Ttc and trends north-south. In lower reaches of Abiquiu Creek, south of Rio Chama, deposit inset in unit Ttoc, contains predominately basalt clasts, possibly derived from units Tlb and Teb and some quartzite. Approximately 150 m above present Rio Chama. Thickness about 45 m

Qt3 **Axial channel and side-stream channel deposits of ancestral Rio Chama, undivided (Pleistocene)—**Gravels with occasional grayish-orange (10YR7/4) sands. Gravels consist of angular to well-rounded pebble- to boulder-size clasts of quartzite, quartz, Pedernal chert, schist, granite, gneiss, basalt, gabbro, and intermediate ash-flow tuff and lavas. Fine- to coarse-grained interbedded sands are grayish-orange (10YR7/4). A thin deposit composed of basalt clasts and local eolian sands caps unit that probably represents the side-stream part of composite unit. Locally contains poorly developed calcic soils. Inset in Tto and Ttc east of Abiquiu and south of Rio Chama. Approximately 60 m above present day Rio Chama channel. Thickness about 15 m

Qt2a **Axial channel deposits of ancestral Rio Chama (Pleistocene)—**Gravels locally interbedded with silt and sand. Gravels composed of subrounded to rounded pebble- to boulder-size quartzite, metamorphic, granite, and intermediate tuffs and lavas with trace of basalt clasts. Inset in Tto and Ttc south of Rio Chama. Found 90–120 m above present Rio Chama channel. Thickness about 30 m

Qt2s **Side-stream channel deposits of ancestral Rio Chama (Pleistocene)—**Gravels locally interbedded with fine- to coarse-grained sands. Gravels are subrounded to well-rounded pebble- to boulder-size clasts predominately of quartzite and granite with lesser amounts of gneiss, schist, quartz, basalt, intermediate volcanic clasts (lavas and ash-flow tuffs), gabbro, and sandstone. Clasts could be recycled from units Te, Trc, Ta, Ttc, and Tcd. Locally, contains poorly developed calcic soil or eolian sand. North of Rio Chama, in Madera Canyon area, deposit inset in unit Ta. West of Abiquiu Creek and south of Rio Chama, deposit contains gravels composed of angular to subrounded clasts predominately of basalt with trace amounts of quartzite, intermediate tuffs and lavas, quartz, metaconglomerate, Pedernal chert, schist, and dacite of Tschicoma Formation (Ttd). Locally contains eolian sand on top of unit and poorly developed calcic soil. Approximately 150 m above present day Rio Chama channel. Thickness about 10 m

Qt2 **Axial channel and side-stream channel deposits of ancestral Rio Chama, undivided (Pleistocene)—**Gravels with local interbedded grayish-orange (10YR7/4) fine to medium sand. Gravels contain predominately angular to subrounded basalt with some quartzite, metaconglomerate, quartz, intermediate volcanic rocks (lava and ash-flow tuff), and traces of Pedernal chert. Basalt clasts and local eolian sands found at top of unit probably represent tributary side-stream part of unit. Contains interbedded Lava Creek B ash dated at 620 ka (Sarna-Wojcicki and others, 1987) east of map area and just east of Mesa de Abiquiu (Dethier and others, 1990; Gonzalez and Dethier (1991). Approximately 90–120 m above present day Rio Chama channel. Thickness about 30 m

Qt1s **Side-stream channel deposits of ancestral Rio Chama (Pleistocene)—**Located in west-central part of map area. Gravels interbedded with sands and overlain by eolian sands. Gravels consist of angular to subrounded pebble- to boulder-size clasts predominately of basalt, with trace amounts of dacite of Tschicoma Formation (Ttd), quartzite, and Pedernal chert. Approximately 215 m above present day Rio Chama channel. Thickness about 30 m

Intrusive, Extrusive, and Sedimentary Rocks

The volcanic and intrusive rocks are part of the northern Jemez Mountains volcanic field (fig.1) described by Smith and others (1970), Kelley (1978), Golf and others (1989), Gardener and Golf (1984), and many others. Recently (2007) a collection of papers describing the area was published by the New Mexico Geological Society, titled “Geology of the Jemez Region II” edited by Barry S. Kues, Shari A. Kelley, and Virgil W. Lueth.

Ttd **Dacite of Tschicoma Formation (Pliocene)—** Regionally, formation is composed predominately of Pliocene–Miocene porphyritic dacite, rhyodacite, and quartz latite lava flows and domes, (Smith and others, 1970) dated at 7–2 Ma (Gardener and Goff, 1984) and 5 Ma (Aldrich and Dethier, 1990). In map area, only Pliocene porphyritic dacite is present since it overlies Pliocene Teb. Porphyritic dacite is pale blue (5B6/2), grayish-blue (5PB5/2) to light-bluish-gray (5B7/1), and light-brownish-gray (5YR4/1) with plagioclase, biotite, and hornblende phenocrysts. Geochemistry (Maldonado and others, unpub. data) indicates some flows (sample A189, see map) are basaltic andesite. Unit overlies Teb, Tlb, and Ta where Teb and Tlb pinch out. As much as about 185 m thick

Teb **El Alto Basalt (Pliocene)—**Vesicular to dense, black (N1) to grayish-black (N2) multiple lava flows with local dark-reddish-brown (10R3/4) scoria. Geochemistry (Maldonado and others, unpub. data) indicates some flows (sample A13, see map) are trachybasalt. Geochemical sample (sample A196, fig. 2) collected from adjacent Cañones quadrangle to the west, mapped as El Alto by Manley (1982) and basaltic andesite of Cañones Mesa by Kelley and others (2005), indicates some flows are trachyandesite (Maldonado and others, unpub. data). Contains olivine, plagioclase, and pyroxene microphenocrysts set in a fine to coarse groundmass. Basalt is inset in Tto along Abiquiu Creek, and Ttc just east and southeast the town of Abiquiu in a paleovalley that trended in a northeastern direction towards present Rio Chama. Poor exposures of gravel and sand commonly are present under El Alto Basalt at Mesa de Abiquiu but not mapped separately. Better exposures are found locally in Arroyo de los Frijoles in the southwestern part of map area. Gravels are composed of angular to well-rounded pebble- to boulder-size clasts of granite, quartzite, Pedernal chert, intermediate porphyritic volcanic rocks (lavas and tuffs), gneiss, schist, and basalt that may represent an axial ancestral Rio Chama, equivalent to T4 of Gonzales (1993). Landside blocks composed of Teb and Tto are common, sliding on sands of Tto and fluvial sand and gravels of Ttc. Unit Teb is inset in Tlb, Ttc, and Tto. Overlain locally by Ttd in upper reaches of Abiquiu Creek. Locally (not mapped) soils developed on basalt and overlain by eolian sand. Unit has K/Ar ages of 3.1±01, 2.8±05 Ma (Manley and Mehnert, 1981), and 3.2±01 Ma (Baldridge and others, 1980), and $^{40}Ar/^{39}Ar$ ages of 2.86±0.05 Ma (plateau age) and 2.82±0.05 Ma (isochron age, sample A13, map, fig. 2), Maldonado and Miggins, 2007; Maldonado and others, 2007).

Tlb **Lobato Basalt (Miocene)—**Vesicular to dense, medium-gray (N5) to medium-dark-gray (N4), olivine, plagioclase, and augite-bearing multiple basaltic lava flows and local light brown (5YR5/6) scoria. Geochemistry (Maldonado and others, unpub. data) indicates flows (samples A48, A50, and A99, fig. 2) are tholeiitic basalts. Previous studies (Dethier and Manley, 1985; Aldrich and Dethier, 1990; Goff others, 1989) indicate olivine-phyric tholeiite and hawaiite. Overlies Tto and locally gravels. Gravel deposits may represent a tributary channel to ancestral Rio Chama (older than gravels that underlie unit Teb) equivalent to T1 unit of Gonzales (1993). Locally overlain by Qae and Ttd. Dated at 7.9±05 –7.8±07 Ma and 9.9±1.0 Ma (Manley and Mehnert, 1981), 9.6±0.3 Ma (Baldridge and others, 1980), and 9.8 Ma (Bachman and Mehnert, 1978) using the K/Ar method. K/Ar ages from Chili quadrangle east of map area have yielded 9.6±0.2 to 12.4±0.4 Ma (Dethier and others, 1986; Dethier and Manley, 1985). Sample (sample A50, fig. 2) from a dike south of town of Chile in Chile quadrangle dated at 10.11±0.13 Ma (plateau age) and 10.05±0.07 Ma (isochron age), and sample from map area (sample A48, fig. 2) dated at 9.57±0.11 Ma (isochron age) and 9.51±0.21 Ma (plateau age) using the $^{40}Ar/^{39}Ar$ method (Maldonado and Miggins, 2007; Maldonado and others, 2007). Lobato Basalt sample (sample A99, fig. 2) from Cerro Pedernal (Colorado Plateau, figs. 1, 3) west of map area dated at 7.87±0.10 Ma (plateau age) and 7.83±0.07 Ma (isochron age) (Maldonado and Miggins, 2007) using the $^{40}Ar/^{39}Ar$ method. Ranges from about 30 m to about 120 m thick

Tbb **Basaltic dike of Barranca (Miocene?)—**Basaltic dikes intrude detached block of Ttoc (fig. 5) in western part of map area, southwest of village of Barranca and south of Rio Chama. Dikes resemble Cerrito de la Ventana basaltic dikes (Tcd) except that Cerrito de la Ventana basaltic dikes are older than Ttoc. The Tbb dikes have to be younger than Ttoc (14–10 Ma) and may be related to Lobato dikes mapped to east and southeast of map area, in Medanales and Chili quadrangles, respectively, that intrude Ojo Caliente and Chama-El Rito Members. Dikes in the Chile quadrangle have been dated at 10.05±0.07 Ma (isochron age) and 10.11±0.13 Ma (plateau age) (Maldonado and Miggins, 2007) using the $^{40}Ar/^{39}Ar$ method; and 10.7±0.3, 10.6±0.3 (Koning and others, 2005), and 9.7±0.3 Ma (Baldridge and others, 1980) using the K/Ar method. Dikes in the Medanales quadrangle have been correlated to dated dikes in the Chilie quadrangle. These relationships suggest Lobato and Barranca dikes may be related. As much as 3 m thick

Tcd **Cerrito de la Ventana basaltic dike (lower Miocene)—**Basaltic olive-gray (5Y3/2) to medium-dark-gray (N4) dike that intrudes Ta and Trc north of Rio Chama in Arroyo del Cobre area (fig. 1), in northwestern part of map area and Ta south of Rio Chama. Dike partially alters Ta near contacts. Geochemistry indicates dike (Maldonado and others, unpub. data, sample A23, map) is tephrite-basanite. Smith and others (1970) and Kelley (1978) have mapped faults adjacent to Tcd dikes. Dated at 9.8 Ma (Bachman and Mehnert, 1978) using the K/Ar method. $^{40}Ar/^{39}Ar$ method, however, indicates ages of 19.58±0.09 Ma (weight mean age) and 19.22±0.30 Ma (isochron age, sample A23, fig. 2; Maldonado and Miggins, 2007; Maldonado and others, 2007). May be related to Tbr since both appear to be basaltic with similar age and geochemistry (Maldonado and others, unpub. data). As much as 3 m thick

Tbr **Basaltic dike of Red Wash Canyon (lower Miocene)—**Dusky-blue-green (5BG3/2) dike exposed in Red Wash Canyon in northwest part of map area. Intrudes Cutler Group, undivided (₱cu) of the Colorado Plateau Province and Trc of Abiquiu embayment in adjacent Cañones quadrangle (Manley, 1982) west of map area. Dike is offset right-laterally about 2 km to northeast by Cañones fault. Dike in Colorado Plateau portion dated at 19.63±0.40 Ma (sample A65, map, Maldonado and Miggins, 2007; Maldonado and others, 2007) using the $^{40}Ar/^{39}Ar$ method. Geochemistry indicates dike (samples A65, A108, fig. 2) is foidite to tephrite-basanite. As much as 1 m thick

Sedimentary Rocks

Tesuque Formation of the Santa Fe Group (Miocene)

Spiegel and Baldwin (1963) used the name Tesuque Formation for Miocene basin fill in the Española area and later Galusha and Blick (1971) subdivided the formation into several members that included the Ojo Caliente Sandstone (Tto) and Chama-El Rito (Ttc) Members, found in this quadrangle. As mapped by Kelley (1978), these two members are equivalent to the Skull Ridge and Pojoaque Members of the Tesuque Formation.

Tto **Ojo Caliente Sandstone Member (upper to middle Miocene)—**Represents a paleodune field composed mostly of eolian grayish-pink (5R8/2) to grayish-orange-pink (10YR8/2) crossbedded sand, fine- to coarse-grained, rounded to subrounded, moderately to well-sorted with occasional thin interbedded gravel beds composed mostly of volcanic clasts; occasional thin fluvial sand beds and reddish clay partings. Locally overlain by thin calcic soil. Varies from soft to very well cemented near faults; for example, along the Cerrito Blanco fault, where it cuts the Cerrito Blanco block (fig. 4). The Cerrito Blanco block contains very well-cemented sands that form cliffs with intervals of soft sand that form slopes (figs. 3, 4) Block probably represents a transitional zone with Ttc and is mapped as Ttoc. Block is bounded by a low-angle fault referred to informally as the Abiquiu fault (fig. 3) which is offset by the Cerrito Blanco fault (fig. 4). Manganese nodules are common along fault plane. In other areas (southeastern part of map area, south of Highway 84) unit is cemented, possibly by gypsum. Unit is overlain by flows of Teb and Tlb indicating that Tto member is older than about 9 Ma. Koning and others (2004) suggest that Tto member has an age range of 14–10 Ma based on work by Galusha and Blick (1971), May (1980; 1984), Goff and others (1989), and Aldrich and Dethier (1990). Unit is locally overlain predominately with basalt clasts of unit Qcb south of Highway 84 with traces of quartzite clasts. Approximately 335 m thick

Ttc **Chama-El Rito Member (middle to lower Miocene)—**Very pale-orange (10YR8/2) to grayish-orange (10YR7/4), well consolidated, fine to coarse grained, well-sorted, subrounded-to subangular sand with interbedded pebbly sand and thick interbedded gravels and occasional thin interbedded, grayish-orange (10YR7/4) to pale-reddish-brown (10R5/4) clay beds. Gravels contain subrounded to well-rounded, granule- to pebble-size clasts with occasional boulder-size clasts, predominately of volcanic origin. Clasts composed of andesite, basaltic andesite, basalt, and intermediate ash-flow tuffs, some composed of Amalia Tuff. Paleochannels are common. Locally overlain by thin calcic soil and colluvium deposits of unit Qcb and traces of pebble- to boulder-size quartzite, basalt, granite, quartz, and intermediate volcanic (ash-flow tuffs and lava flows) clasts. Koning and others (2005) suggest that Ttc member ranges in age from 16–13 Ma. Approximately 350–500(?) m thick. May (1984) indicates 340–550 m in other areas

Ttcv **Volcaniclastic unit—**Locally interbedded with Ttc north of Highway 84, northeastern part of map area. Unit contains fine- to coarse-grained tuffaceous sandstone interbedded with conglomerate-containing basaltic clasts. Sandstone is pale-greenish-yellow (10Y7/4) to moderate-greenish-yellow (10Y8/2) and thin bedded. Contains light-olive-brown (5Y5/6) and dusky-yellow (5Y6/4) bedded tuff. Locally contains blocks of Ta (as large as 48 by 80 m, fig. 7) and pebble- to boulder-size intermediate tuff and quartzite. Interpreted as an intrusive complex forming a tuff ring by Kelley (1978) and Baldridge and others (1994). Approximately 30 m thick

Ttoc **Transitional zone of Ojo Caliente Sandstone and Chama-El Rito Members (upper to middle Miocene)—**Composed of cemented sands and gravels of unit Ttc interbedded with cemented sands of unit Tto forming detached blocks. Largest detached block is found at Cerrito Blanco block area (fig. 3) north of Rio Chama and smaller ones, south of Rio Chama. These blocks are bounded by a low-angle fault informally referred to as the Abiquiu fault (figs. 3, 4). Cerrito Blanco block is offset by Cerrito Blanco fault (fig. 4). South of Rio Chama, dikes of Barranca (Tbb) intrude the blocks (fig. 5) that may be equivalent to Lobato volcanism. As much as 120 m thick

Abiquiu Formation and Ritito Conglomerate

The Abiquiu Formation was first named the “Abiquiu Tuff” by Smith (1938) and subsequent workers changed the name to Abiquiu Formation (Vazzana, 1980; Vazzana and Ingersoll, 1981; Smith, 1995; Moore, 2000; and Smith and others, 2002). The formation was divided into upper, middle, and lower members (Moore, 2000; Smith and others, 1995; Vazzana and Ingersoll, 1981; Church and Hack, 1939). The upper member is correlative to Los Pinos Formation (Barker, 1958; Bingler 1968; Manley, 1981) and is composed of volcaniclastic strata derived from the San Juan Mountains volcanic field, located north of map area (fig. 1; Ingersoll and others, 1990; Ingersoll and Cavazza, 1991). Bingler (1968) and Manley (1981) however interpreted a Latir volcanic field source, located northeast of map area (fig. 1). The middle member (Pedernal Chert Member) is not exposed in map area but mapped west of map area (Moore, 2000; Kelley and others, 2005) and is composed of calcite and chalcedony (Moore, 2000). The middle member may be considered the upper part of the lower member (Ritito Conglomerate). The lower member of Abiquiu Formation (Moore, 2000; Smith and others, 2002) is equivalent to the Ritito Conglomerate of Kelley (1978) and Barker (1958) and conglomerate of Arroyo del Cobre of Maldonado and Miggins (2007), but separated here from the Abiquiu Formation and the term “Ritito Conglomerate” is reinstated. The unit is composed of conglomerates that contain predominately Precambrian crystalline clasts derived from the Tusas Mountains, located north of map area (fig. 1; Smith, 1938; Vazzana, 1980; Smith, 1995) but is void of Tertiary volcanic clasts. Based on this, the unit is separated from the Abiquiu Formation. Therefore the upper member of Abiquiu Formation will be referred to as just the Abiquiu Formation.

Ta **Abiquiu Formation (lower Miocene and upper Oligocene)—**Light-gray (N7) to yellowish-gray (5Y8/1), occasionally crossbedded, thin- to thick-bedded tuffaceous sandstone, siltstone, pebbly sandstone, and occasional gravel beds, and locally (southwest and north-central part of map area) thin interbedded, moderate-orange-pink (10R7/4), moderate-reddish-brown (10R4/6) or pale-reddish-brown (10R5/4) mudstone. Gravel and pebbly zones contain mostly intermediate volcanic clasts (lavas and ash-flow tuffs) with some Proterozoic clasts. Volcanic clasts consist of Amalia Tuff and a biotite- and hornblende-rich volcanic rock classified as trachydacite and trachyandesite based on geochemistry (sample A113 A, B, C; Maldonado and others, unpub. data). The Amalia Tuff clasts, dated at 27–23 Ma (Peters, 1999; Peters and McIntosh, 2000) are common towards top of unit and as large as 55 by

Figure 7. Photograph showing panoramic view looking southeast towards unit Ttcv with block of unit Ta. See description of map units for labeled units.

40 cm. The biotite- and hornblende-rich volcanic rocks are common towards base of unit and as large as 60 by 50 cm; possibly from Latir volcanic field (Questa Caldera, fig. 1). An olivine-nephelinite lava flow near top of unit has yielded a K/Ar date of 18.9 Ma (Baldridge and others, 1980) south of Cerro Negro, approximately 18 km northeast of Abiquiu (fig. 1), but the 19.6 Ma old Cerrito de la Ventana dike intrudes unit Ta (Maldonado and others, 2007) in map area. Manley and Mehnert (1981) report a K/Ar date of 15.9 Ma for a dike that intrudes Abiquiu Formation 6 km north of Sierra Negra (fig. 2). Basalts dated at 26.8, 24.3, 18.8, 17.7, and 15 Ma (Lipman and Mehnert, 1975, 1979) are interlayered with Los Pinos Formation, a unit equivalent to Abiquiu Formation (May, 1980; Manley, 1981) as defined on this map. Baldridge and others (1980) dated basalts interlayered in Abiquiu Formation at about 25 and 22 Ma. Proterozoic clasts consist of pebble- to boulder-size quartzite, granite, schist, and gneiss. Locally, at base of Ta, lower beds are interbedded with beds of Trc and locally upper beds are interbedded with gravels of Ttc. Smith (1995) divided what he referred to as the upper member into three stratigraphic intervals not mapped separately here. Interval I (lower interval) is composed of interbedded tuffaceous sandstone, siltstone, and pebbly sandstone derived from the San Juan Mountains, Tusas Mountains, and Latir volcanic field (Questa Caldera, fig. 1). Interval II contains pumiceous debris-flow deposits derived from the Latir volcanic field. Interval III consists of pebbly sandstone and sandstone also derived from the Latir volcanic field. About 150 m thick

Trc **Ritito Conglomerate (Oligocene)—**Moderate-orange-pink (10R7/4) to moderate-reddish-orange (10R6/6) and moderate-reddish brown (10R5/4) arkosic conglomeratic beds interbedded with moderate-orange-pink (10R7/4), fine- to coarse-grained arkosic sands and siltstones with muscovite. Conglomerate contains angular to well-rounded clasts. Clasts include, in descending order of abundance, Proterozoic quartzite, granite, metavolcanic, quartz, schist, gneiss, and traces of Mesozoic sandstone and Paleozoic chert derived from Tusas Mountains (Vazzana and Ingersoll, 1981), northeast of map area (fig. 1). Clast range from granules to boulders in size, and are in a coarse, sandy, moderate-orange-pink (10R7/4) matrix. Contact with underlying Te occurs as a moderate-orange-pink (5YR8/4) to moderate-reddish-orange (10R6/6) sandstone interbedded with mudstone and siltstone interval. Unit has been mapped as lower member of Abiquiu Formation (Moore, 2000; Smith and others, 2002) and equivalent to conglomerate of Arroyo del Cobre (Maldonado and Miggins, 2007). The lower member is separated from Abiquiu Formation since it has no Tertiary volcanic clasts and the Ritito Conglomerate of Barker (1958) is reinstated. Approximately 210 m thick

Te **El Rito Formation (Eocene)—**Upper part is moderate-orange-pink (5YR8/4) to moderate-reddish-orange (10R6/6), well-consolidated, fine- to coarse-grained sandstone interbedded with mudstone and siltstone; sandstones are locally crossbedded. Lower part is predominately moderate-orange-pink (5YR8/4), moderate-reddish-orange (10R6/6), and grayish-pink (5R8/2) conglomerate with some medium to coarse sandstones, locally crossbedded. Conglomerate is clast supported and contains predominately subrounded to well-rounded granule- to boulder-size clasts of Proterozoic quartzite eroded from Precambrian rocks in Tusas Mountains (Smith and others, 1961), northeast of map area. Proterozoic schist, granite, and trace amounts of metavolcanic clasts are also present, occasionally in a sandy matrix. Locally, at base in Arroyo del Cobre, unit contains quartzite boulder-rich bed. In the Arroyo del Cobre area, unit Te is inset in Je where Jt is missing, or in ŦRcu where both Je and Jt are missing. These relationships suggest a large, north-south trending paleochannel of Laramide age. Locally includes unmapped Qac. As much as about 180 m thick

Jt **Todilto Limestone Member of Wanakah Formation (Middle Jurassic)—**Composed of upper and lower parts. Upper part is composed of gray to white gypsum beds (Manley, 1982) that may not be present in quadrangle. Lower part consists of dark-gray (N3) calcareous shale, grayish-orange-pink (10R8/2), medium-grained calcareous sandstone, and pale-yellowish-brown (10YR6/2), platy, thin- to thick-bedded limestone. Missing in Arroyo del Cobre area but present west of arroyo. Exposed thickness about 20 m

Je **Entrada Sandstone (Middle Jurassic)—**Grayish-yellow (5Y8/4) to moderate-yellow (5Y7/6), grayish-orange-pink (10R8/2) to very pale-orange (10YR8/2), and moderate-reddish-orange (10R6/6) crossbedded eolian sand. Sand is well-sorted, fine- to medium-grained quartz grains. Occasional interbedded shales and conglomerate. Exposed thickness about 20 m thick

TRcu **Chinle Group, undivided (Upper Triassic)—** Exposed only in upper reaches of Arroyo del Cobre in northwest corner of map area. In quadrangle, group is composed of Petrified Forest and Rock Point Formations of Lucas (1993). Composed of reddish-brown, purplish-red, and light-green interbedded sandstone, siltstone, and shale. Fossiliferous. Locally offset by small-scale (about 1 m) northeast-southwest striking reverse faults (fig. 6) of Laramide age; top to the east, suggesting east-verging thrusts. Exposed thickness about 120 m

IPcu **Cutler Group, undivided (Late Pennsylvanian to Early Permian)—**Exposed only in Red Wash Canyon area, in northwest corner of map area, where it is intruded by Tbr. Divided into Arroyo del Aqua Formation and El Cobre Canyon Formation by Lucas and Krainer (2005). Arroyo del Aqua Formation is composed of Early Permian, moderate-reddish brown (10R4/6), light-greenish gray (5GY8/1), and pale red (10R6/2) siltstone; moderate-reddish brown (10R4/6), pale-reddish brown (10R5/4), and yellowish-gray (5Y8/1) sandstone, and minor conglomerate. El Cobre Canyon Formation is composed of Late Pennsylvanian to Early Permian pale-reddish brown (10R5/4) and pale red (10R6/2) siltstone; pale-reddish brown (10R5/4), grayish-red (10R4/2), and yellowish-gray (5Y8/1) sandstone, and minor conglomerate. Approximately 125 m thick

PzMz **Paleozoic and Mesozoic rocks, undivided (Late Pennsylvanian to Upper Triassic)—**Composed mostly of sandstone, siltstone, shale, limestone, and minor conglomerate. Shown only in cross section

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