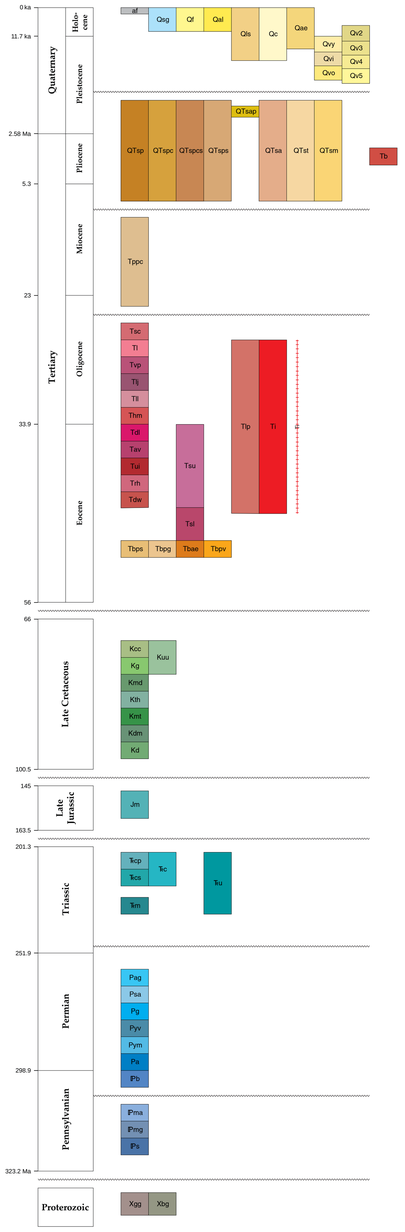
Correlation of Map Units



Description of Map Units

CENOZOIC

Quaternary

- af — Artificial fill (Holocene)
- Qsg — Sand and gravel (Holocene)
- Qf — Floodplain deposits (Holocene)
- Qal — Alluvium (Holocene)
- Qls — Landslide deposits (late Pleistocene)
- Qc — Colluvium and talus (late Pleistocene to Holocene)
- Qae — Eolian deposits (late Pleistocene to Holocene)
- Qvy — Younger valley-fill and piedmont alluvium (late Pleistocene)
- Qvi — Intermediate-age valley-fill and piedmont alluvium (late? Pleistocene)
- Qvo — Older valley-fill and piedmont alluvium (middle? Pleistocene)
- Qv2 — Arroyo deposits and piedmont alluvium (late Pleistocene to Holocene)
- Qv3
- Qv4
- Qv5

Neogene & Quaternary

Santa Fe Group

- QTsp — Piedmont facies of the Sierra Ladrones Formation, undivided (Quaternary)
- QTspc — Conglomeratic piedmont lithofacies of the Sierra Ladrones Formation (early Pliocene to middle Pleistocene)
- QTspcs — Conglomerate and sandstone piedmont lithofacies of the Sierra Ladrones Formation (early Pliocene to middle Pleistocene)
- QTsps — Sandstone-dominated piedmont lithofacies of the Sierra Ladrones Formation (early Pliocene to middle Pleistocene)
- QTsap — Pumice and ash deposits of the Sierra Ladrones Formation (early Pleistocene)
- QTsa — Axial-river lithofacies of the Sierra Ladrones Formation (early Pliocene to middle Pleistocene)
- QTst — Transitional axial-piedmont lithofacies of the Sierra Ladrones Formation (early Pliocene to middle Pleistocene)
- QTsm — Lacustrine lithofacies of the Sierra Ladrones Formation (early Pliocene to middle Pleistocene)
- Tb — Basalt flow at Black Mesa (early Pliocene)
- Tppc — Conglomeratic piedmont lithofacies of the Popotosa Formation (late Oligocene to late Miocene?)

Paleogene

Mogollon Group

- Tsc — South Canyon Tuff (late Oligocene)
- Tl — Lemitar Tuff (early Oligocene)
- Tvp — Vicks Peak Tuff (early Oligocene)
- Tlj — La Jencia Tuff (early Oligocene)
- Tll — Luis Lopez Formation (early Oligocene)
- Tip — La Jara Peak Basaltic Andesite (late Eocene to late Oligocene)

Datil Group

- Thm — Hells Mesa Tuff (early Oligocene)
- Tdl — Dacite lava (late Eocene)
- Tav — Tuff of Arroyo Veranito (late Eocene)
- Tul — Unidentified ignimbrite (late Eocene)
- Trh — Rock House Canyon Tuff (late Eocene)
- Ti — Andesite to basaltic andesite dikes and sills (late Eocene to late Oligocene)
- Tdw — Datil Well Tuff (late Eocene)

Spears Group

- Tsu — Upper Spears Group (late Eocene to early Oligocene)
- Tsl — Lower Spears Group (middle to late Eocene)

Baca Formation

- Tbps — Sedimentary-clast dominated piedmont lithofacies (middle Eocene)
- Tbpg — Basement-dominated piedmont lithofacies (middle Eocene)
- Tbae — Sandstone and conglomerate containing clasts of well-rounded quartzite and metavolcanics lithofacies (middle Eocene)
- Tbpv — Tongues of piedmont sandstone and conglomerate that contain 10–50% volcanic detritus (middle Eocene)

MESOZOIC

Late Cretaceous

- Kuu — Undivided Late Cretaceous strata (Late Cretaceous)
- Kcc — Crevasse Canyon Formation of the Mesaverde Group (Coniacian to Santonian?)
- Kg — Gallup Sandstone of the Mesaverde Group (late Turonian to early Coniacian)
- Kmd — D-Cross Tongue of the Mancos Shale (late-middle Turonian to latest? Turonian)
- Kth — Tres Hermanos Formation (middle Turonian)
- Kmt — Tokay Tongue of the Mancos Shale (middle Cenomanian to Turonian)
- Kdm — Dakota Sandstone and lower part of Tokay Tongue of Mancos Shale, undivided (middle Cenomanian)
- Kd — Dakota Sandstone (middle Cenomanian)

Jurassic

- Jm — Morrison Formation (Late Jurassic)

Triassic

- Tic — Chinle Formation (Late Triassic)
- Ticp — San Pedro Arroyo Member of the Chinle Formation (Late Triassic)
- Tics — Shinarump Member of the Chinle Formation (Late Triassic)
- Tkm — Moenkopi Formation (Middle Triassic)
- Tku — Triassic strata, undivided (Middle and Late Triassic)

PALEOZOIC

Permian

- Pag — Artesia Group (Guadalupian)
- Psa — San Andres Formation (Leonardian)
- Pg — Glorieta Sandstone (Leonardian)
- Pyv — Los Vallos Formation (Leonardian)
- Pym — Meseta Blanca Formation (Leonardian)
- Pa — Abo Formation (Wolfcampian to Leonardian)

Pennsylvanian

- IPb — Bursum Formation of the Madera Group (early Wolfcampian)
- IPma — Atrasado Formation of Madera Group (Desmoinesian, Missourian, and Virgilian)
- IPmg — Gray Mesa Formation of the Madera Group (Desmoinesian)
- IPs — Sandia Formation (Atokan)

PROTEROZOIC

- Xgg — Tajo Pluton (Proterozoic)
- Xbg — Biotite gneiss (Proterozoic)

Explanation of Map Symbols

- Contact—Identity and existence are certain. The location is accurate where solid, approximate where dashed, or concealed where dotted.
- Fault (generic; vertical, subvertical, or high-angle; or unknown or unspecified orientation or sense of slip)—Identity and existence are certain; where questionable or unspecified, features will be queried. The location is accurate where solid, approximate where dashed, or concealed where dotted.
- Normal fault—Identity and existence are certain; where questionable or unspecified, features will be queried. The location is accurate where solid, approximate where dashed, inferred where short-dashed, or concealed where dotted.
- Low-angle normal fault—Identity and existence are certain; where questionable or unspecified, features will be queried. The location is accurate where solid, approximate where dashed, inferred where short-dashed, or concealed where dotted. Half-circles on upper plate of Quebradas detachment fault.
- Reverse fault—Identity and existence are certain. The location is accurate where solid, approximate where dashed, inferred where short-dashed, or concealed where dotted. Rectangles on upthrown block.
- Thrust fault—Identity and existence are certain. Location is accurate where solid, approximate where dashed, or concealed where dotted. Sawteeth on upper plate.
- Fault-breccia zone or zone of broken rock around fault.
- Dike (Ti)—Identity and existence are certain. Location is accurate where solid or approximate where dashed.
- Anticline—Identity and existence are certain. Location is accurate where solid, approximate where dashed, or concealed where dotted.
- Overturned anticline—Identity and existence are certain. The location is accurate where solid or approximate where dashed. Beds on one limb are overturned; arrows show dip direction of limbs.
- Antiformal sheath fold—Identity and existence are certain. Location is accurate.
- Syncline—Identity and existence are certain. Location is accurate where solid, approximate where dashed, or concealed where dotted.
- Overturned syncline—Identity and existence are certain. Location is accurate where solid, approximate where dashed, or concealed where dotted. Beds on one limb are overturned; arrows show dip direction of limbs.
- Monocline—Identity and existence are certain, and questionable where queried. Location is accurate where solid, approximate where dashed, or concealed where dotted. Arrow shows direction of dip.
- Horizontal bedding.
- Inclined bedding—Showing strike and dip.
- Vertical bedding—Showing strike.
- Overturned bedding—Showing strike and dip.
- Inclined fault—Showing dip value and direction.
- Fault showing local right-lateral strike-slip offset. Arrows show relative motion.
- Upper plate movement direction—Arrow showing approximate direction of motion of upper plate of Quebradas detachment fault, based on geometry of truncation of strata in hanging-wall ramp by fault.
- Small, minor inclined joint—Showing strike and dip.
- Small, minor vertical or near-vertical joint—Showing strike.
- Inclined flow banding, lamination, layering, or foliation in igneous rock—Showing strike and dip.
- Vertical flow banding, lamination, layering, or foliation in igneous rock—Showing strike.
- Plunging fold—Large arrowhead shows direction of plunge.
- Small, minor anticline, vertical or near-vertical axial surface—Showing strike.
- Small, minor overturned anticline, vertical or near-vertical axial surface—Showing strike. Beds on one limb are overturned; arrows show dip direction of limbs.
- Small, minor syncline, vertical or near-vertical axial surface—Showing strike.
- Small, minor overturned syncline, vertical or near-vertical axial surface—Showing strike. Beds on one limb are overturned; arrows show dip direction of limbs.
- Fluvial transport direction.
- Water well, type unspecified.
- Las Cañas geomorphic surface
- A A′ — Cross section line and labels

Comments to Map Users

A geologic map displays information on the distribution, nature, orientation, and age relationships of rocks and deposits, and the occurrence of structural features. Lithologic and fault contacts are irregular surfaces that form boundaries between different ages or types of units. Data depicted on this geologic map may be based on any of the following: field geologic mapping, a compilation of published and unpublished work, and/or photogeologic interpretation. Locations of contacts are not surveyed but are plotted by relative position on a topographic or orthophotographic base map; therefore, the accuracy of contact locations depends on the scale of mapping and the geologist's interpretation.

Resizing this map would cause the details of the map to be misrepresented and result in erroneous interpretations. Using this product at a scale different than originally intended requires verification of site-specific conditions with detailed surface mapping or subsurface exploration. Topographic and cultural changes may not be shown due to recent development.

Cross sections are constructed based on the author's interpretations of geologic mapping and available geophysical and subsurface (drill hole) data. Cross sections should be used to understand the map area's general geologic framework and not be the sole source of information for locating or designing wells, buildings, roads, or other human-made structures.

Point symbols can be set to rotate around a point of observation using their azimuth values. The point of observation can be one of three possibilities: the trailing end—or tail—opposite the arrowhead or other ornamentation of the symbol; the midpoint—or center of the symbol; or the head of the symbol. See the symbol codes described in the GIS data (FGDC_Symbols nonspatial table) for attributes that describe the azimuth measurement convention and the location of the point of observation for each symbol.

The views and conclusions in these map documents are those of the authors and should not be interpreted as necessarily representing the official policies, expressed or implied, of the State of New Mexico or the U.S. Government.

1:36,000

1 0.5 0 1 Mile

2,000 0 2,000 4,000 6,000 8,000 10,000 Feet

1 0.5 0 1 Kilometer

Contour Interval 50 Feet

National Geodetic Vertical Datum of 1929

North American Datum of 1927 (NAD27)
Projection and 1,000-meter grid: Universal Transverse Mercator, Zone 13S, shown in blue.
10,000-foot ticks: New Mexico Coordinate System of 1927 (Central Zone), shown in red.

Digital base map data.....U.S. Geological Survey, 2019
Contours and hillshades.....IFSAR 4.5 m Digital Terrain Model, 2007

MN

Magnetic Declination
December 2024
7° 74' East
At Map Center

Map Location

San Acacia	La Joya	Becker SW	Corro Montoso
Lemitar	Mesa Del Yeso	Sierra De La Cruz	Sierra Large North
Socorro	Loma De Las Cañas	Bustos Well	Sierra Large South
Luis Lopez	San Antonio	Calzon Agua Buena	Prairie Spring
Indian Well Wilderness	San Antonio SE	Corro De La Campana	Corro De La Campana SE

New Mexico Bureau of Geology and Mineral Resources
Memoir 51

Original mapping of these quadrangles was funded by STATEMAP and the New Mexico Bureau of Geology and Mineral Resources (Dr. J. Michael Timmons, *Director and State Geologist*; Dr. Matthew J. Zimmerer, *Geologic Mapping Program Manager*).

Geologic Map of the Quebradas Region, Socorro County, Central New Mexico

December 2024

by

Steven M. Cather

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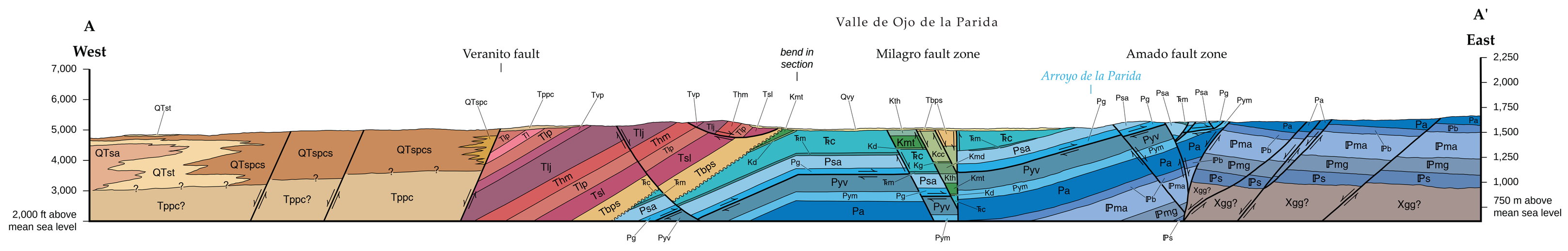
This and other STATEMAP quadrangles are available for free download in both PDF and ArcGIS formats at:

https://geoinfo.nmt.edu

https://doi.org/10.58799/M-51

Digital layout and cartography by the NMBGMR GIS Services Program:
Phil L. Miller, Amy L. Dunn, Ann D. Knight, Tyler Askin, and Hannah N. Hunt

Geologic Cross Section A–A'



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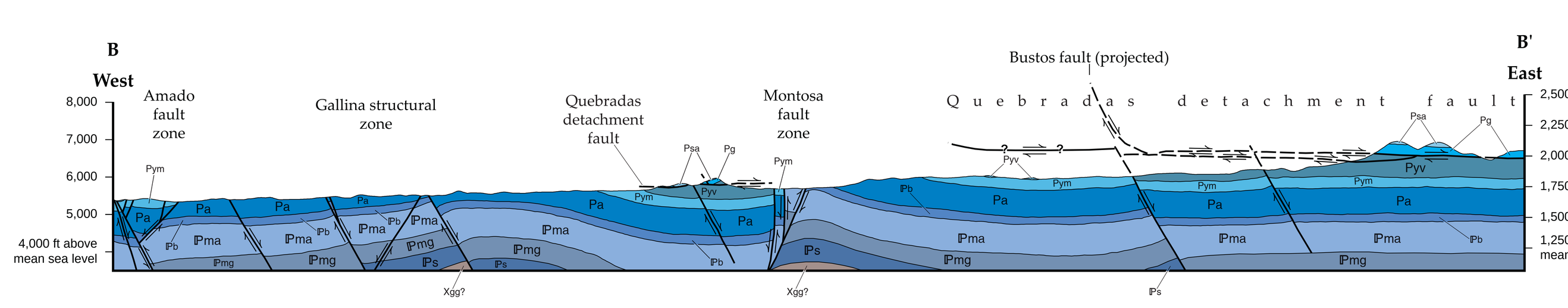

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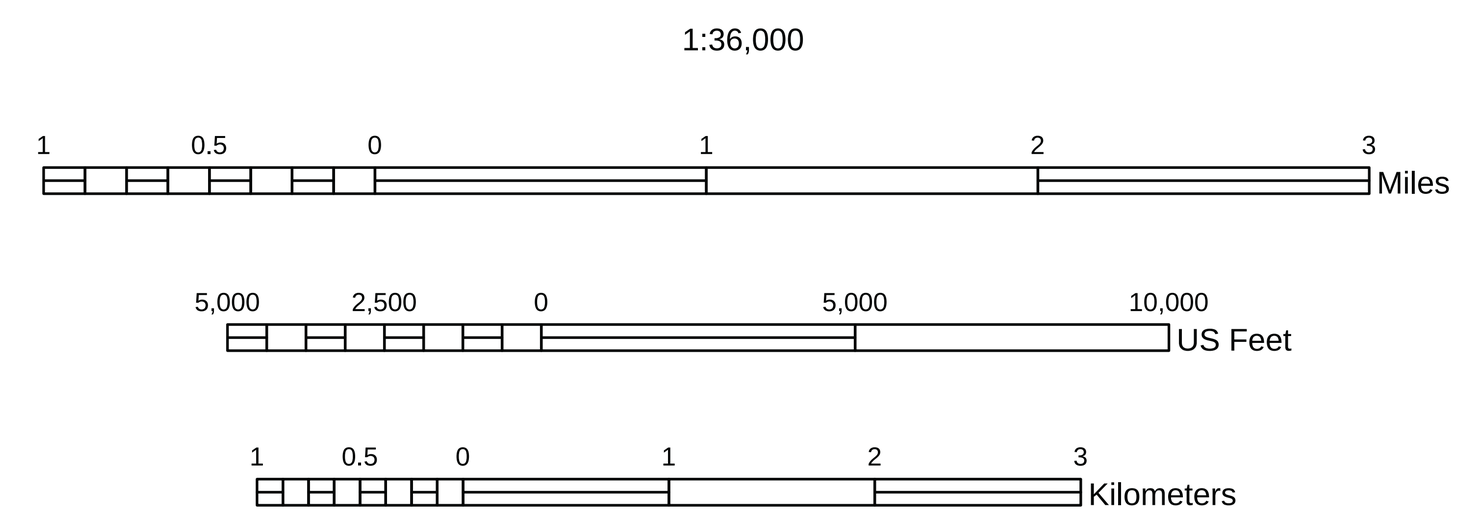
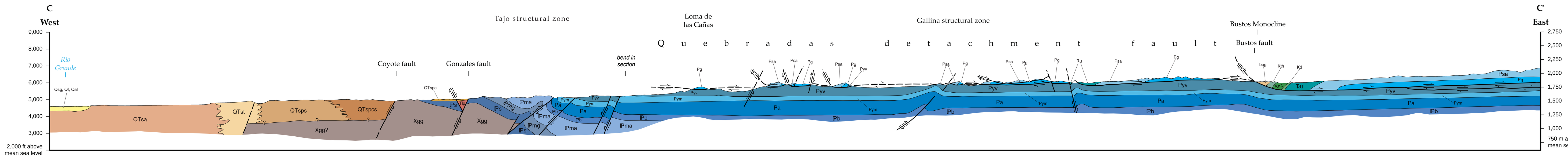
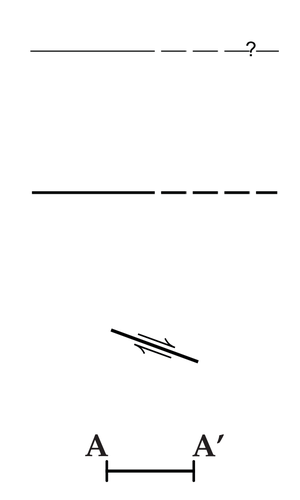


Geologic Cross Section C–C'



Explanation of Map Symbols



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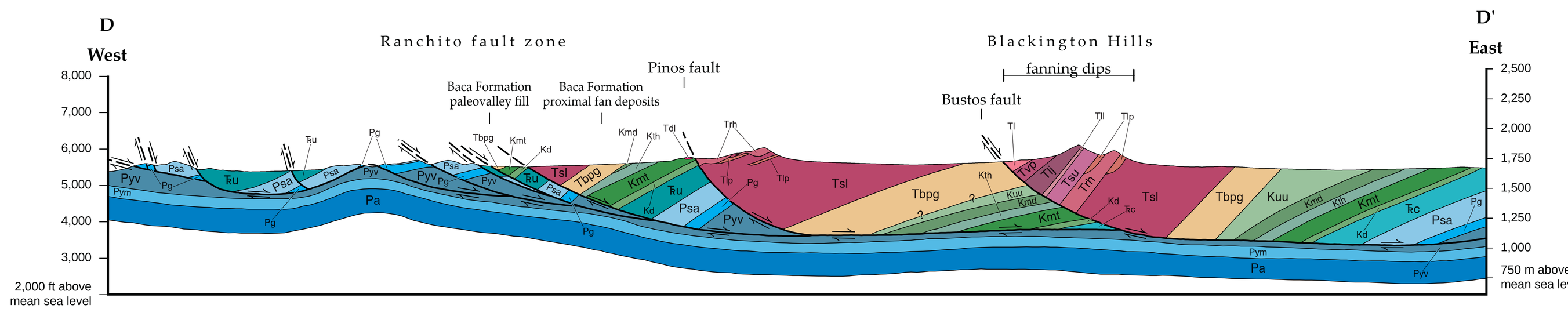
Fault (generic; vertical, subvertical, or high-angle; or unknown or unspecified orientation or sense of slip)—Identity and existence are certain. Location is accurate where solid and approximate where dashed.

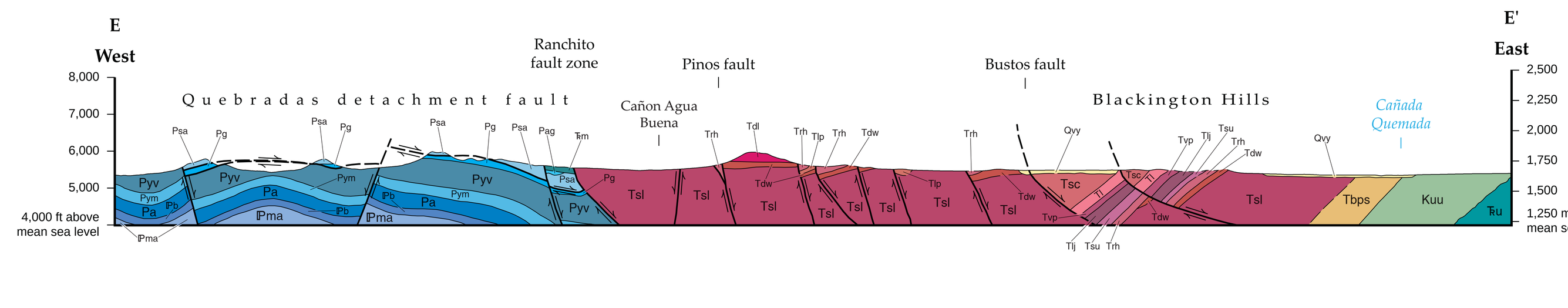
Fault in cross section showing local up/down offset—The arrows show the relative motion along the fault plane.

Cross section line and label

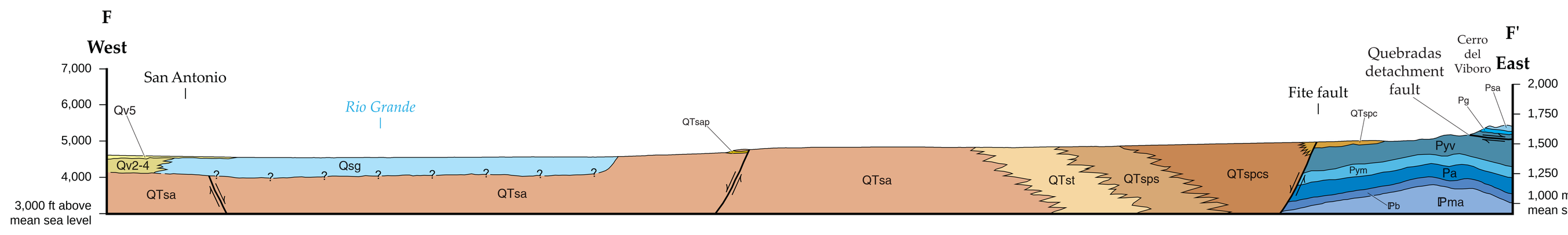
Geologic Cross Section D–D'



Geologic Cross Section E–E'



Geologic Cross Section F–F'



New Mexico Bureau of Geology and Mineral Resources
Memoir 51

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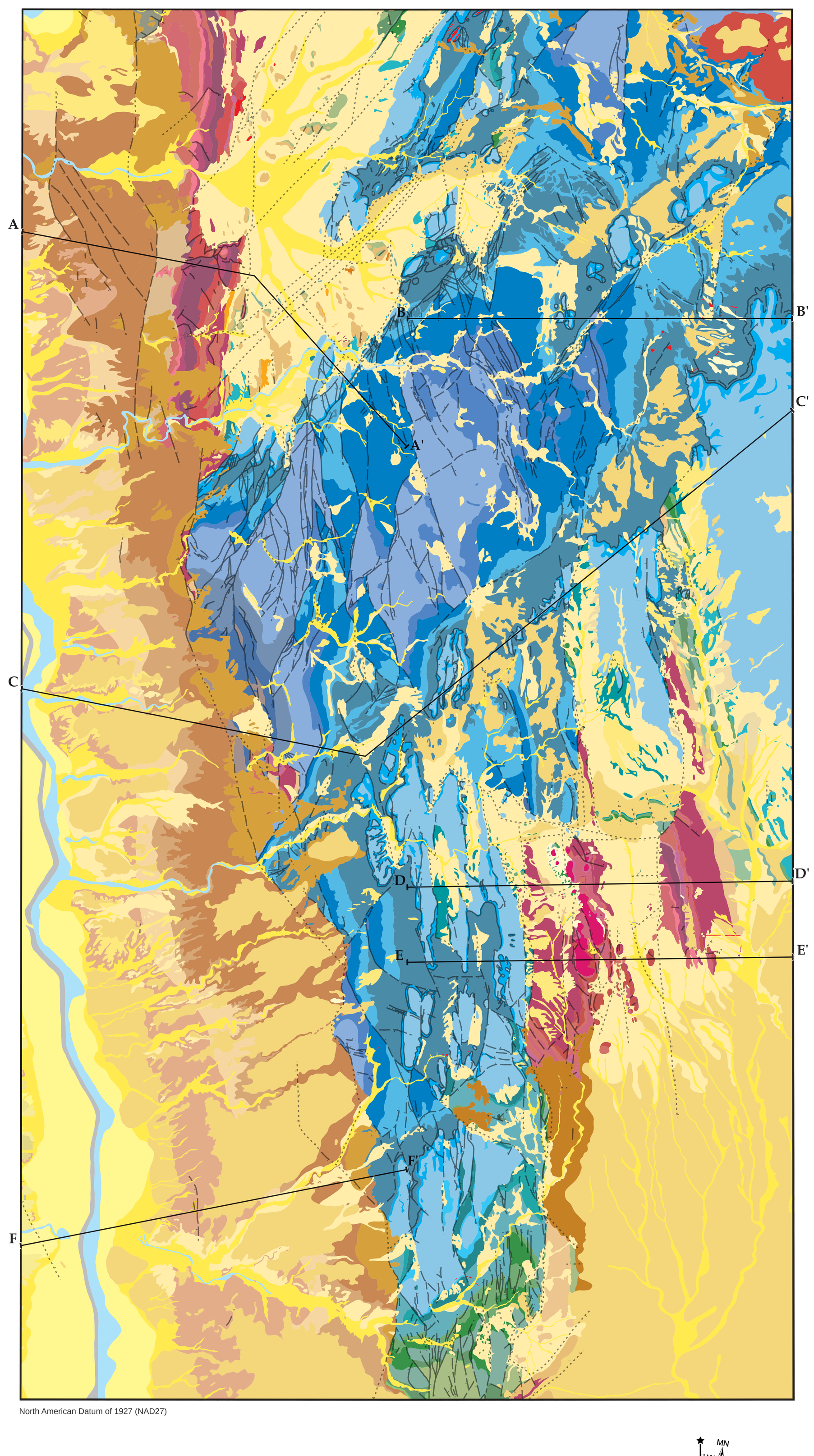
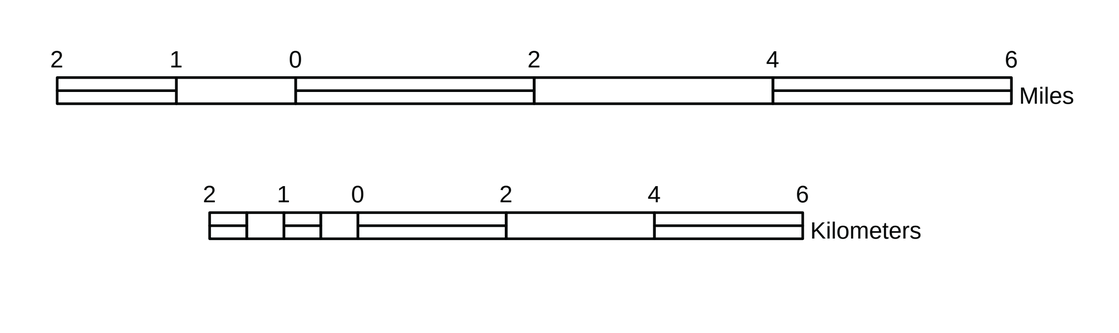


North American Datum of 1927 (NAD27)

1:100,000



Description of Map Units

CENOZOIC
Quaternary

af **Artificial fill (Holocene)**—Sand and gravel in human-made levees, berms, and dams. Unit is 0–5 m thick.

Qsg **Sand and gravel (Holocene)**—Sand, gravel, and minor mud in modern active arroyo channels and in the channel of the Rio Grande. Unit is 0–10 m thick.

Qf **Floodplain deposits (Holocene)**—Overbank sand, mud, and minor gravel of the Rio Grande. Includes local eolian deposits. Unit is 0–10 m thick.

Qal **Alluvium (Holocene)**—Sand, gravel, and minor mud in and adjacent to modern arroyo channels. Alluvium is typically at or near the grade of modern channels. Unit is 0–10 m thick.

Qls **Landslide deposits (late Pleistocene)**—Mass-wasting and landslide deposits consisting mostly of limestone boulders of San Andres Formation (**Psa**) in the southeastern part of the Loma de las Cañas quadrangle. Unit is 0–10 m thick.

Qc **Colluvium and talus (late Pleistocene to Holocene)**—Gravelly deposits of poorly sorted colluvium and talus blocks on, or adjacent to, steep slopes. Unit is 0–10 m thick.

Qae **Eolian deposits (late Pleistocene to Holocene)**—Eolian sand and loessic silt locally reworked by alluvial processes. Deposits are stabilized by vegetation in most areas. Includes intercalated alluvial deposits and thin, active, eolian veneers and dunes on stable upland surfaces. Unit is 0–5 m thick.

Qvy **Younger valley-fill and piedmont alluvium (late Pleistocene)**—Sand, gravel, and minor mud deposited at low elevations above modern stream grade. Elevation of alluvium above modern grade depends on location. Areas that drain to the Jornada del Muerto (i.e., most of the Bustos Well and Cañon Agua Buena quadrangles) are not deeply incised. There, **Qvy** is less than about 5 m above modern stream grade. In other areas that drain to the Rio Grande, **Qvy** is as much as 30 m above stream grade. In places, two or more aggradational episodes are represented by **Qvy**. Alluvium was deposited in a variety of piedmont environments, including paleovalleys and arroyos, alluvial fans, strath terraces, fill terraces, and pediments. Unit is 0–20 m thick.

Qvi **Intermediate-age valley-fill and piedmont alluvium (late? Pleistocene)**—Sand, gravel, and mud deposited at intermediate elevations (about 5–10 m) above modern stream grade. It is only present in the Bustos Well quadrangle. Range of depositional paleoenvironments is similar to **Qvy**. Unit is 0–10 m thick.

Qvo **Older valley-fill and piedmont alluvium (middle? Pleistocene)**—Sand, gravel, and mud deposited at higher elevations above modern stream grade. Height above modern grade depends on location. Areas that drain to the Jornada del Muerto (i.e., most of the Bustos Well and Cañon Agua Buena quadrangles) are not deeply incised. There, **Qvo** is more than 10 m above modern stream grade. In other areas that drain to the Rio Grande, **Qvo** is more than 30 m above stream grade. In places, two or more aggradational episodes are represented by **Qvo**. Range of depositional paleoenvironments is similar to **Qvy**. Unit is 0–30 m thick.

Qv2, Qv3, Qv4, Qv5 **Arroyo deposits and piedmont alluvium (late Pleistocene to Holocene)**—Volcaniclastic sand, gravel, and minor mud in serially inset deposits (**Qv5** is oldest) west of the Rio Grande. Correlation to alluvial sequences east of the Rio Grande is uncertain. Each unit is 0–20 m thick.

Neogene & Quaternary
Santa Fe Group

QTsp **Piedmont facies of the Sierra Ladrones Formation, undivided (Quaternary)**—Weakly consolidated sandstone, conglomerate, and minor mudstone. Conglomerate is typically poorly sorted and clast supported. Sandstone is typically medium- to very coarse-grained, and cross-bedded or horizontally stratified. Matrix-supported debris-flow deposits are rare. **QTsp** includes gravelly veneers on pediment surfaces. Clasts consist primarily of Permian sandstone and limestone. Thickness is unknown.

QTspc **Conglomeratic piedmont lithofacies of the Sierra Ladrones Formation (early Pliocene to middle Pleistocene)**—Characterized by a conglomerate to sandstone ratio greater than 2:1 (lithofacies subdivisions after Cather [1997]). Conglomerate is typically poorly sorted and clast supported. Sandstone is typically medium- to very coarse-grained, and cross-bedded or horizontally stratified. Matrix-supported debris-flow deposits are common. Mudstone is rare. Includes fills 0–30 m thick in topographically inverted paleovalleys in the northern part of the Sierra de la Cruz quadrangle. These fills are inset against, and younger than, the 3.7 Ma basalt flow at Black Mesa (**Tb**). Thickness in the Socorro Basin is poorly constrained.

QTspcs **Conglomerate and sandstone piedmont lithofacies of the Sierra Ladrones Formation (early Pliocene to middle Pleistocene)**—Characterized by conglomerate to sandstone ratio between 2:1 and 1:2; this is the volumetrically dominant piedmont facies within the Sierra Ladrones Formation. Conglomerate is mostly clast supported and poorly sorted. Sandstone is typically medium- to very coarse-grained, commonly pebbly, and exhibits cross-bedding or horizontal stratification. Mudstone is minor. The thickness in the Socorro Basin is unknown, but it thickens to the west.

QTsps **Sandstone-dominated piedmont lithofacies of the Sierra Ladrones Formation (early Pliocene to middle Pleistocene)**—Characterized by conglomerate to sandstone ratio of less than 1:2. Conglomerate is clast supported and occurs in tabular or lenticular units <2 m thick. Sandstone is very fine- to very coarse-grained and exhibits a dominance of horizontal stratification and trough cross-bedding. Mudstone is common and occurs as tabular units that locally constitute as much as 20% of the unit. Incipient calcareous paleosols occur locally. Thickness is unknown.

QTsap **Pumice and ash deposits of the Sierra Ladrones Formation (early Pleistocene)**—Flood and debris-flow deposits of ash and pumice derived from the 1.6 Ma lower Bandelier Tuff (Otowi Member; see Cather and McIntosh [2009]). Unit is 0–5 m thick.

QTsa **Axial-river lithofacies of the Sierra Ladrones Formation (early Pliocene to middle Pleistocene)**—Channel and floodplain deposits of the ancestral Rio Grande consisting of variable proportions of sandstone, pebbly sandstone, mudstone, and conglomerate. Sandstone is typically light-gray, cross-bedded, and poorly indurated. Clasts consist of well-rounded to subrounded pebbles of quartzite, chert, granite, gneiss, sandstone, volcanic lithics, siltstone, schist, phyllite, limestone, obsidian, and pumice. Mudstone ranges in color from reddish-brown to greenish-gray. Paleoflow was toward the south. Thickness is unknown.

QTst **Transitional axial-piedmont lithofacies of the Sierra Ladrones Formation (early Pliocene to middle Pleistocene)**—Intertongued axial-river deposits and piedmont deposits. Transitional deposits are defined as the zone of overlap between the basinward extent of piedmont sand and gravel and the mountainward extent of axial-river sand and gravel. Thickness is unknown.

QTsm **Lacustrine lithofacies of the Sierra Ladrones Formation (early Pliocene to middle Pleistocene)**—Laminated reddish-brown mudstone and minor sandstone that accumulated in local ponds and lakes. Exposed only in the hanging wall of Alamillo fault in the west-central part of the Mesa del Yeso quadrangle. Thickness is approximately 10 m.

Tb **Basalt flow at Black Mesa (early Pliocene)**—Dark-gray, locally vesicular, olivine-bearing basalt. Consists of two lava flows derived from vents just east of the Sierra de la Cruz quadrangle (Lucas et al., 2009a). An imprecise $^{40}Ar/^{39}Ar$ isochron age of 3.68 ± 0.34 Ma has been obtained from the upper flow. Unit is approximately 20–30 m thick.

Tppc **Conglomeratic piedmont lithofacies of the Popotosa Formation (late Oligocene to late Miocene?)**—Piedmont deposits characterized by conglomerate to sandstone ratio of greater than 2:1. Consists mostly of alluvial deposits, but matrix-supported debris-flow deposits are common. Conglomerate is mostly clast supported, crudely imbricated, and poorly sorted. Sandstone is medium- to very coarse-grained and commonly exhibits cross-bedding and horizontal laminations. Mudstone is rare, occurring mostly as thin, discontinuous drapes. Detritus was derived dominantly from Oligocene volcanic rocks. Paleoflow was generally westward. Thickness and age in the study area are unknown.

Paleogene

Mogollon Group—All $^{40}Ar/^{39}Ar$ ages for volcanic rocks reported here are by W.C. McIntosh and M.T. Heizler of the New Mexico Bureau of Geology and Mineral Resources. Ages are calculated (or recalculated) relative to Fish Canyon Tuff sanidine at 28.201 Ma (Kuiper et al., 2008). Errors are 1σ. Formation-rank nomenclature for volcanic rocks in the study area is after Osburn and Chapin (1983); group-rank terminology is from Cather et al. (1994).

Tsc **South Canyon Tuff (late Oligocene)**—Light-gray to light-purple, densely welded, crystal-poor to moderately crystal-rich rhyolitic ignimbrite. Crystals (approximately 10–20% of rock volume) are mostly sanidine and quartz; lithic fragments are common. The tuff is at least 375 m thick in the northern part of the Mesa del Yeso quadrangle but thins southward. It is about 150–250 m thick in the Blackington Hills area. The $^{40}Ar/^{39}Ar$ sanidine ages are 27.68 ± 0.02 and 27.67 ± 0.01 Ma in the Blackington Hills. In the southern Joyita Hills, samples yielded an $^{40}Ar/^{39}Ar$ sanidine age of 27.65 ± 0.01 Ma.

Tl **Lemitar Tuff (early Oligocene)**—Pink, densely welded, moderately crystal-rich rhyolitic ignimbrite. Crystals of sanidine, plagioclase, quartz, biotite, pyroxene, and opaque minerals constitute about 35% of the rock; lithics are minor. The tuff is about 110 m thick in the Blackington Hills area and about 75 m thick in the southern Joyita Hills. The $^{40}Ar/^{39}Ar$ sanidine age is 28.22 ± 0.01 Ma in the southern Joyita Hills and 28.25 ± 0.01 Ma in the Blackington Hills.

Tvp **Vicks Peak Tuff (early Oligocene)**—Light-gray, moderately welded, crystal-poor rhyolitic ignimbrite. Crystals (less than 5% of the rock) are mostly sanidine, with sparse quartz, biotite, plagioclase, and opaque minerals. Thickness is approximately 100–110 m. The $^{40}Ar/^{39}Ar$ sanidine age is 28.78 ± 0.01 Ma in the Joyita Hills and 28.77 ± 0.01 in the Blackington Hills.

Tlj **La Jencia Tuff (early Oligocene)**—Pink to gray, densely to moderately welded, crystal-poor, rhyolitic ignimbrite that exhibits compound cooling. The upper part of the unit is prominently flow banded. Crystals of sanidine and minor quartz, biotite, and opaque minerals constitute about 5–10% of the rock; lithics are typically sparse. Thickness is approximately 140 m in the Blackington Hills and approximately 315 m in the southern Joyita Hills. The $^{40}Ar/^{39}Ar$ sanidine age is 28.98 ± 0.01 Ma in the Joyita Hills, 29.00 ± 0.01 Ma in the Blackington Hills east of the Bustos fault, and 29.00 ± 0.01 Ma west of the Bustos fault.

Tll **Luis Lopez Formation (early Oligocene)**—Light-gray, poorly welded, moderately crystal-rich pyroclastic deposits. Crystals (approximately 10% of rock volume) are mostly sanidine, quartz, and plagioclase; lithic fragments range from sparse to abundant. Includes fallout tuffs and thin, poorly welded ignimbrites probably associated with pre-La Jencia Tuff domes to the west. Correlative with the upper part of the Luis Lopez Formation in areas to the west (e.g., Chamberlin et al. [2002]). Unit is about 0–60 m thick. The $^{40}Ar/^{39}Ar$ sanidine ages are 29.00 ± 0.01 Ma (fallout deposits in the Blackington Hills, east of Bustos fault), 29.02 ± 0.01 Ma (thin ignimbrite in the Blackington Hills, east of Bustos fault), and 29.01 ± 0.02 Ma (west of Bustos fault).

Tlp **La Jara Peak Basaltic Andesite (late Eocene to late Oligocene)**—Aphanitic to slightly porphyritic mafic flows and associated breccias of mostly basaltic andesite composition. Phenocrysts are mostly plagioclase, clinopyroxene, and opaque minerals. The unit occurs as several tongues, each 0–100 m thick, that fill paleovalleys within the stratigraphic interval between the lower Spears Formation (**Tsl**) and the South Canyon Tuff.

Datil Group

Thm **Hells Mesa Tuff (early Oligocene)**—Brownish-pink, crystal-rich, densely welded rhyolitic ignimbrite. Crystals of sanidine, plagioclase, quartz, biotite, and opaque minerals constitute 30–45% of the rock (Spradlin, 1976). Quartz becomes more abundant upsection (Spradlin, 1976; Osburn and Chapin, 1983). Lithic fragments are sparse to common. Exposed only in the southern Joyita Hills. Thickness is approximately 150–300 m. The $^{40}Ar/^{39}Ar$ sanidine age is 32.35 ± 0.01 Ma.

Tdl **Dacite lava (late Eocene)**—Medium-brownish-gray, plagioclase- and amphibole-bearing lava. It is composed of a single flow 0–90 m thick with an autobrecciated base. The flow yielded $^{40}Ar/^{39}Ar$ hornblende ages of 34.04 ± 0.02 Ma and 33.98 ± 0.05 Ma.

Tav **Tuff of Arroyo Veranito (late Eocene)**—Pink, crystal- and lithic-rich, moderately welded tuff. Crystals of plagioclase, sanidine, quartz, biotite, and hornblende constitute about 20–40% of the rock volume. The $^{40}Ar/^{39}Ar$ sanidine age is 34.37 ± 0.06 Ma (Chamberlin et al., 2022). Exposed locally only in the southern Joyita Hills, where it is approximately 20 m thick. Informal name from Chamberlin et al. (2022).

Tui **Unidentified ignimbrite (late Eocene)**—Brownish-pink, crystal- and lithic-rich, welded rhyolitic ignimbrite. Crystals are sanidine, quartz, and biotite. Crops out only in a fault-repeated paleovalley on both sides of the Bustos fault in the Blackington Hills area. Unit is 0–10 m thick. Overlies the 34.8 Ma Rock House Canyon Tuff (**Trh**) and is stratigraphically beneath a 34.0 Ma dacite lava (**Tdl**). The unidentified ignimbrite yielded $^{40}Ar/^{39}Ar$ sanidine and biotite ages near 35.3 Ma, similar to the age of the Datil Well Tuff (**Tdw**) and significantly older than the 34.8–34.0 Ma stratigraphic constraints. The dated crystals are probably xenocrysts derived from exposed surfaces of the Datil Well Tuff (**Tdw**) during transport of the unidentified ignimbrite.

Trh **Rock House Canyon Tuff (late Eocene)**—Light-gray, crystal-poor rhyolitic ignimbrite. Crystals (4–10% of rock volume) are mostly sanidine, with minor plagioclase, biotite, and trace quartz (Osburn and Chapin, 1983). It is poorly to moderately welded, with local zones of abundant flattened pumice. The tuff is about 90–150 m thick in the Blackington Hills but is not present in the southern Joyita Hills. The $^{40}Ar/^{39}Ar$ sanidine age is 34.78 ± 0.01 Ma east of the Bustos fault.

Ti **Andesite to basaltic andesite dikes and sills (late Eocene to late Oligocene)**—Mafic to intermediate-composition intrusives that commonly exhibit greenish propylitic alteration. Most are probably equivalents of the La Jara Peak Basaltic Andesite, which ranges in age from approximately 36 to 24 Ma regionally. A dike in NW 1/4 sec. 8, T2S, R3E yielded an $^{40}Ar/^{39}Ar$ integrated age on biotite of 34.68 ± 0.11 Ma (Green et al., 2013).

Tdw **Datil Well Tuff (late Eocene)**—Medium-brownish-gray, crystal-rich rhyolitic ignimbrite. Crystals constitute 15–25% of the ignimbrite and are mostly sanidine, with minor clinopyroxene and biotite and traces of quartz and plagioclase (Osburn and Chapin, 1983). Lithic-rich and pumice-poor. It is about 0–50 m thick in the Blackington Hills and is not present in the southern Joyita Hills. The $^{40}Ar/^{39}Ar$ sanidine ages are 35.38 ± 0.01 Ma (east of the Bustos fault) and 35.32 ± 0.02 Ma (west of the Bustos fault).

Spears Group

Tsu **Upper Spears Group (late Eocene to early Oligocene)**—Dark- to medium-gray volcaniclastic sandstone and conglomerate. Debris-flow breccias are locally present. Clast lithotypes are mostly dark-gray basaltic andesite (plagioclase- and clinopyroxene-bearing) but also andesite and dacite (plagioclase- and amphibole-bearing clasts similar to those of the lower Spears Group) and ignimbrite clasts. The unit is 0–120 m thick. Mapped as tongues within the Datil Group. Upper Spears Group deposits below the Datil Group are as much as approximately 100 m thick, but were mapped as part of the lower Spears Group due to poor exposure.

Tsl **Lower Spears Group (middle to late Eocene)**—Medium- to light-gray volcaniclastic sandstone, conglomerate, debris-flow breccia, and minor mudstone. Clasts are dominated by plagioclase- and amphibole-bearing andesite and dacite. Nonvolcanic clasts are locally present above the transition with the underlying Baca Formation. Thickness in the Blackington Hills area is approximately 760 m (this estimate includes approximately 100 m of poorly exposed upper Spears Group beneath the Datil Well Tuff). Thickness is approximately 200–400 m in the southern Joyita Hills. The age range is approximately 39–36 Ma regionally (Cather et al., 1987), but two andesite clasts from the lower and middle part of the lower Spears Group east of the Bustos fault near the Blackington Hills yielded imprecise $^{40}Ar/^{39}Ar$ hornblende ages of approximately 43 Ma.

Baca Formation

Tbps, Tbpg, Tbae, Tbpv **Baca Formation (middle Eocene)**—Fluvial and alluvial red-bed sandstone, conglomerate, and mudstone. Sandstone is commonly cross-bedded; conglomerate contains pebbles, cobbles, and boulders of Cretaceous, Paleozoic, and Proterozoic lithotypes. The sedimentary-clast-dominated piedmont lithofacies (**Tbps**) was derived mainly from the west (from the Sierra Uplift of Cather [1983]), but locally on the Mesa del Yeso quadrangle, it was derived from the south (from the Amado fault zone) and the northeast (from the Montosa Uplift of Cather [1992]). The basement-dominated piedmont lithofacies (**Tbpg**) was derived from granitic exposures mostly to the west (Sierra Uplift) but with a minor component from the east (Montosa Uplift). Sandstone and conglomerate containing clasts of well-rounded quartzite and metavolcanics (lithofacies **Tbae**) are exposed on the Mesa del Yeso quadrangle. This lithofacies is also present in the northern Bustos Well quadrangle but was included in map unit **Tbpg**. Quartzite and metavolcanic clasts resemble those present in the Mogollon Rim formation and Eagar Formation of eastern Arizona and western New Mexico, and represent exotic axial-river deposits derived from far to the west in the Mogollon Highland of central Arizona. Tongues of piedmont sandstone and conglomerate that contain 10– 50% volcanic detritus (lithofacies **Tbpv**) occur in the middle and upper Baca Formation in the Mesa del Yeso quadrangle. These deposits were derived from the west and mark the transition to the overlying Spears Group. The Baca Formation has yielded late Bridgerian (approximately 46 Ma) fossils in the Carthage area (Gardner, 1910; Morgan et al., 2009).

MESOZOIC
Late Cretaceous

Kuu **Undivided Late Cretaceous strata (Late Cretaceous)**—Map unit in the Bustos Well quadrangle consisting of the Gallup Sandstone (late Turonian to early Coniacian), the Mulatto Tongue of the Mancos Shale (early Coniacian), and the Crevasse Canyon Formation (Coniacian to Santonian?). The total thickness is as much as much as approximately 240 m. The Gallup Sandstone is fine-grained, gray to yellowish-gray, regressive coastal barrier-island sandstone mudstone approximately 6 m thick. The Mulatto Tongue of the and Mancos Shale is drab marine shale at least 10 m thick that is intercalated within the lower Crevasse Canyon Formation (Dilco Coal Member), about 29 m stratigraphically above the top of the Gallup Sandstone, and contains abundant *Flemingostrea elegans* Hook. The Dilco Coal Member consists of paralic carbonaceous mudstone, fine- to medium-grained sandstone, and coal. This member contains a coal bed 60 cm thick that has been mined locally in the northeastern Cañon Agua Buena quadrangle. Overlying the Mulatto Tongue, the upper Crevasse Canyon Formation (the Gibson Coal Member) is drab to gray sandstone, mudstone, and coal deposited in coastal plain and fluvial settings. The thickness of the upper Crevasse Canyon Formation near Carthage is as much as approximately 200 m (Gardner, 1910). Typically poorly exposed.

Kcc **Crevasse Canyon Formation of the Mesaverde Group (Coniacian to Santonian?)**—Heterogeneous map unit consisting of nonmarine sandstone, paralic and marine shale, and coal that has a sharp basal contact and an erosional upper contact. Thickness is approximately 260 m. The Crevasse Canyon Formation is well exposed near Carthage. Numerous isolated outcrops with no exposed basal contacts occur along the floor of Valle del Ojo de la Parida in the northeastern portion of Mesa del Yeso quadrangle. In both areas, an approximately 10- to 13-m-thick marine shale interval (the Coniacian Mulatto Tongue of the Mancos Shale) is included in the Crevasse Canyon Formation for the purpose of mapping. *Flemingostrea elegans* Hook is abundant in the Mulatto Tongue. At Carthage, the Mulatto Tongue is poorly exposed 46 m above the Gallup Sandstone. There, the Crevasse Canyon above the Mulatto Tongue is approximately 200 m thick (Gardner, 1910). In the lower part of the Crevasse Canyon Formation, below the Mulatto Tongue, paralic mudstone and sandstone of the Dilco Coal Member host the Carthage coal seam. This seam is up to 1.5 m thick and lies 8 m above the Gallup Sandstone. In the northeastern Mesa del Yeso quadrangle, the Mulatto Tongue is only exposed in the NW 1/4 sec. 32, T1S, R2E. About 2 km northeast of Puertecito of Bowling Green in the Mesa del Yeso quadrangle, lenses of pebble conglomerate occur in the uppermost Crevasse Canyon Formation. Derived from the southwest, these consist mostly of quartzite and chert pebbles recycled from Mesozoic strata but also contain sparse pebbles of Paleozoic limestone. These relationships indicate that the nearby Sierra Uplift was being unroofed late in Crevasse Canyon time.

Kg **Gallup Sandstone of the Mesaverde Group (late Turonian to early Coniacian)**—Fine-grained, marine, regressive, coastal-barrier sandstone unit 6–13 m thick. The Gallup Sandstone was mapped as a discrete unit on the Cañon Agua Buena and Mesa del Yeso quadrangles but was lumped within map unit **Kuu** on the Bustos Well quadrangle. The thickest sections are gray to yellowish-gray, poorly indurated, slope-forming units. Thinner sections are more indurated, commonly consisting of concretionary and fossiliferous sandstones that form ledges. Lower contact is gradational; upper is fairly sharp. The base of the Gallup contains *"Lopha" sannionis* (White). Concretionary sandstones about 1.5 km north of the Mesa del Yeso quadrangle have yielded abundant *Cremnoceramus erectus* (Meek) and thus are early Coniacian.

Kmd **D-Cross Tongue of the Mancos Shale (late-middle Turonian to latest? Turonian)**—Noncalcareous, medium-gray marine shale. About 85–110 m thick with a sharp basal contact (an unconformity) and a gradational upper contact. Fossils include *Prionocyclus wyomingensis* Meek near the base, *Mytiloides incertus* (Jimbo) near the middle, and *Placenticeras cumminsi* Cragin near the top. Calcarenites and sandstones of the Juana Lopez Beds occur 1.5–2.4 m above the base of the D-Cross Tongue and are up to 3.5 m thick. The Juana Lopez Beds are of differing thicknesses and ages in the study area. Near Carthage, they are 1.3 m thick and entirely in the *Prionocyclus novimexicanus* Zone; in the Bustos Well quadrangle, they are 3.1 m thick and entirely in the *P. novimexicanus* Zone; at the north end of the Mesa del Yeso quadrangle, they are 1.7 m thick and entirely in the *P. wyomingensis* Zone. Near the middle of the Mesa del Yeso quadrangle, they are 3.5 m thick and include fossils from the *P. wyomingensis* Zone at the base and the *P. novimexicanus* Zone at the top.

Kth **Tres Hermanos Formation (middle Turonian)**—Sandstone and mudstone that form a regressive to transgressive wedge of nearshore marine and nonmarine deposits about 73–84 m thick with a gradational base and a sharp top. Consists of three unmapped members, in ascending order: **Atarque Sandstone Member (middle Turonian)**—Regressive coastal barrier sandstones that weather light gray to dark brown or buff and are about 3–26 m thick. Lower sandstones are transitional with the underlying Tokay Tongue and have very fossiliferous lenses and concretionary sandstone bodies with *Collignoniceras woollgari woollgari* (Mantell). The upper contact is sharp, especially near Carthage. **Carthage Member (middle Turonian)**—Marine, marginal marine, and nonmarine sandstone and shale unit 35–63 m thick; lower two-thirds contains thin, fine-grained sandstone beds of paludal-lacustrine or crevasse splay origin and discontinuous, cross-bedded channel sandstones. The upper part of the Carthage Member contains marine shale with fossiliferous concretions containing *Cameleolopha bellaplicata* (Shumard) and *Prionocyclus* sp. **Fite Ranch Sandstone Member (middle Turonian)**—Highly bioturbated, coastal-barrier sandstone that coarsens upward from very fine-grained to fine-grained. Sandstones are light-gray weather light- to dark-brown and constitute a 9- to 23-m-thick, ridge-forming unit with a sharp top and gradational base. Contains *Cameleolopha bellaplicata* (Shumard) and *Prionocyclus macombi* Meek.

Kmt **Tokay Tongue of the Mancos Shale (middle Cenomanian to Turonian)**—Calcareous to noncalcareous gray marine shale with minor, thin sandstone beds near the base. Sharp basal contact and gradational upper contact. Concretions near the top contain *Collignoniceras woollgari woollgari* (Mantell). Thin sandstones in basal 5 m contain common *Ostrea beloiti* Logan and rare *Acanthoceras bellense* Adkins. Unit is about 165–190 m thick. The Bridge Creek Limestone Beds (22 m thick, 91 m above the base of the tongue) crop out near Carthage and contain the *Euomphaloceras septemseriatum* assemblage zone fauna at the base, including abundant *Pycnodonte newberryi* (Stanton). *Mytiloides mytiloides* (Mantell) occurs near the top of Bridge Creek.

Kdm **Dakota Sandstone and lower part of Tokay Tongue of Mancos Shale, undivided (middle Cenomanian)**—This unit was mapped only in a small exposure in NE 1/4 sec. 22, T4S, R2E of the Cañon Agua Buena quadrangle.

Kd **Dakota Sandstone (middle Cenomanian)**—Gray to yellow, fluvial to marine, medium- to coarse-grained sandstone and minor mudstone. Fossils include *Conlinoceras tarrantense* (Adkins), *Plesiacanthoceras muldoonense* (Cobban and Scott), and *Acanthoceras amphibolum* Morrow on the Bustos Well and Mesa del Yeso quadrangles. Unit is 20–23 m thick.

Jurassic

Jm **Morrison Formation (Late Jurassic)**—Light-gray to light-brown, kaolinitic, cross-bedded sandstone, pebbly sandstone, and greenish-gray mudstone that is 0–16 m thick. It appears to fill a shallow paleovalley about 300 m wide cut into the Chinle Formation in the northeastern part of the Mesa del Yeso quadrangle. Outcrops of thin (0–3 m) Morrison also occur on the southern part of the Cañon Agua Buena quadrangle but were mapped as part of the Chinle Formation.

Triassic

Ŧc, Ŧcp, Ŧcs **Chinle Formation (Late Triassic)**—Red, gray, and maroon fluvial mudstone with subordinate sandstone, limestone-pebble conglomerate, and limestone. Consists of two members. The basal Shinarump Member (mapped locally as **Ŧcs**) is mostly sandstone, pebbly sandstone, conglomerate, and minor mudstone 0–30 m thick. The overlying San Pedro Arroyo Member (mapped locally as **Ŧcp**) is mudstone, sandstone, and minor limestone approximately 165–210 m thick. Forms slopes and valleys. Unit mapped as Chinle Formation (**Ŧc**) where undivided.

Ŧm **Moenkopi Formation (Middle Triassic)**—Red-brown, brown, and buff continental mudstone, sandstone, and minor conglomerate. Unit is 0–40 m thick.

Ŧu **Triassic strata, undivided (Middle and Late Triassic)**—Consists of undifferentiated beds of the Moenkopi and Chinle Formations. This map unit was employed where exposures are poor or where the lower contact of the Chinle Formation is difficult to map because the basal Shinarump Member is thin or absent. About 200–250 m thick.

PALEOZOIC
Permian

Pag **Artesia Group (Guadalupian)**—Tabular-bedded, orange-red to pale-orange, calcareous and locally gypsiferous siltstones and very fine-grained quartzose sandstones. Thickness is 0–20 m.

Psa **San Andres Formation (Leonardian)**—Interbedded limestone, dolostone, gypsum, and minor sandstone and limestone breccia. Consists of two informal members: a lower limestone member and an upper gypsum member. Limestone is brownish-black, pale-yellowish-brown, and medium-gray, and ranges from wackestone to grainstone. Dolostone is brownish-gray to olive-gray and locally gypsiferous. Quartzose sandstone resembles the underlying Glorieta Sandstone and occurs as beds 1–2 m thick, mostly in the lower part of the formation. Breccias consist of brownish-black limestone and dolostone that grade laterally into thin-bedded, dark-gray limestones; these may be the result of evaporite dissolution. Bedded gypsum and gypsiferous siltstone are abundant in the middle and upper part of the San Andres Formation in the northeastern part of the Bustos Well quadrangle and north of Mesa del Yeso, where it is as much as approximately 70 m thick. Gypsum is white to light-gray and laminated to massively bedded. Locally includes, in the Bustos Well quadrangle, 5–15 m of orange gypsiferous siltstone at the top of the unit that is probably correlative with the Permian Artesia Group (**Pag**). Formation thickness is approximately 100–150 m. Uranium has been produced from vein-type deposits in the San Andres Formation in sec. 35, T2S, R2E (McLemore, 1983).

Pg **Glorieta Sandstone (Leonardian)**—White to very pale-orange, fine- to medium-grained, friable to well-indurated, cross-bedded quartz-arenite. Contains scattered, well-rounded, frosted, coarse quartz grains, especially in the lower half of the unit. Thickness is approximately 50–70 m.

Pyv **Los Vallos Formation (Leonardian)**—Interbedded siltstone, gypsum, dolomitic limestone, sandstone, and shale in the upper part of the Yeso Group. About 210–225 m thick. Consists of three unmapped members (in ascending order): the Torres, Cañas, and Joyita Members. The lower contact of the Los Vallos Formation is placed at the base of the lowermost, laterally continuous limestone of the Torres Member. One or both of the Cañas and Joyita Members are locally cut out by low-angle normal faults. Torres Member—Interbedded pale- to moderate-reddish-brown, grayish-pink, or grayish-red, fine- to medium-grained quartzose sandstone; white to light-gray gypsum; thin layers and lenses of dolomitized limestone; and pale-yellowish-brown to olive-black limestone that ranges from carbonate mudstone to peloidal or oolitic packstones and grainstones. They are locally fossiliferous, dolomitic, and argillaceous. Thickness is approximately 155 m. Cañas Member—Very light-gray to white, laminated to nodular-mosaic gypsum with minor, thin beds of very fine-grained sandstone and fetid, gypsiferous micrite. About 25–100 m thick. Joyita Member—Pale-reddish-brown to moderate-reddish-orange, friable and calcareous, fine- to very fine-grained quartzose sandstone with scattered halite casts and clay flakes on bedding surfaces. The upper beds commonly display low-angle cross-beds and ripple cross-laminations. Thickness is approximately 10–50 m.

Pym **Meseta Blanca Formation (Leonardian)**—The Meseta Blanca Formation constitutes the lower part of the Yeso Group. The Meseta Blanca is interbedded very pale-orange, pinkish-gray, and moderate-reddish-brown, very fine- to medium-grained quartzose sandstone; very light-gray to dark-reddish-brown siltstone; and dark-reddish-brown to grayish-red, slope-forming mudstones and shales. Thickness is approximately 70–110 m. Nomenclature after Cather et al. (2013).

Pa **Abo Formation (Wolfcampian to Leonardian)**—Interbedded dark-reddish-brown fluviatile mudstone, grayish-red to dark-reddish-brown lenticular sandstone, minor conglomerate, and rare limestone. Consists of the lower, mudstone-dominated Scholle Member and the upper Cañon de Espinoso Member, characterized by greater sandstone content (Lucas et al., 2005). Thickness is approximately 140–240 m.

Pennsylvanian

IPb **Bursum Formation of the Madera Group (early Wolfcampian)**—Interbedded medium- to dark-gray to grayish-red mudstone; medium-gray to brownish-black, fossiliferous, and locally dolomitic limestone; and grayish-orange-pink to purplish-red, fine- to very coarse-grained, lenticular and trough cross-bedded, commonly pebbly, subarkosic to arkosic sandstone. About 25–90 m thick.

IPma **Atrasado Formation of Madera Group (Desmoinesian, Missourian, and Virgilian)**—Interbedded marine, continental, and paralic brownish-gray subarkosic sandstone; greenish-gray to gray mudstone; and light-gray limestone. Includes Bartolo, Amado, Tinajas, Council Spring, Burrego, Story, Del Cuerto, and Moya Members of Lucas et al. (2009). Approximately 230–270 m thick.

IPmg **Gray Mesa Formation of the Madera Group (Desmoinesian)**—Medium-gray, fossiliferous, and commonly cherty marine limestone; greenish-gray mudstone; and minor quartzose sandstone. Includes Elephant Butte, Whiskey Canyon, and Garcia Members of Lucas et al. (2009). About 130–190 m thick.

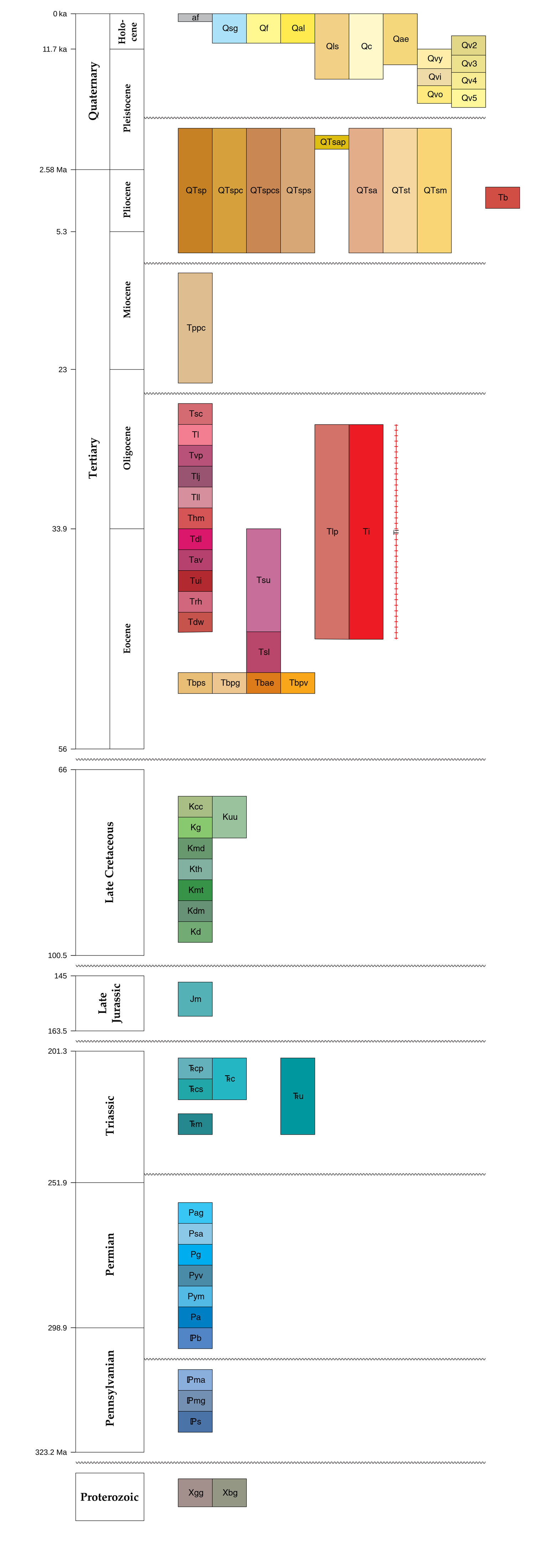
IPs **Sandia Formation (Atokan)**—Continental, shore-zone, and marine quartz-arenitic sandstone; greenish-gray mudstone; and subordinate medium-gray marine limestone. Unit is 90–175 m thick.

PROTEROZOIC

Xgg **Tajo Pluton (Proterozoic)**—Medium- to coarse-grained, weakly foliated granite (Tajo pluton) is exposed in the Loma de las Cañas quadrangle. Commonly highly fractured and jointed. Locally, it contains metamorphic xenoliths, rare pegmatites, and aplites. Barite and fluorite veins and uranium mineralization also occur locally (McLemore, 1983).

Xbg **Biotite gneiss (Proterozoic)**—Medium- to coarse-grained biotite gneiss with microcline porphyroblasts locally as long as 2 cm. Exposed only in the northern Mesa del Yeso quadrangle. Hosts sparse amphibolite units as much as 10 m thick and small granite intrusions.

Correlation of Map Units



Digital layout and cartography by the NMBGMR GIS Services Program:
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