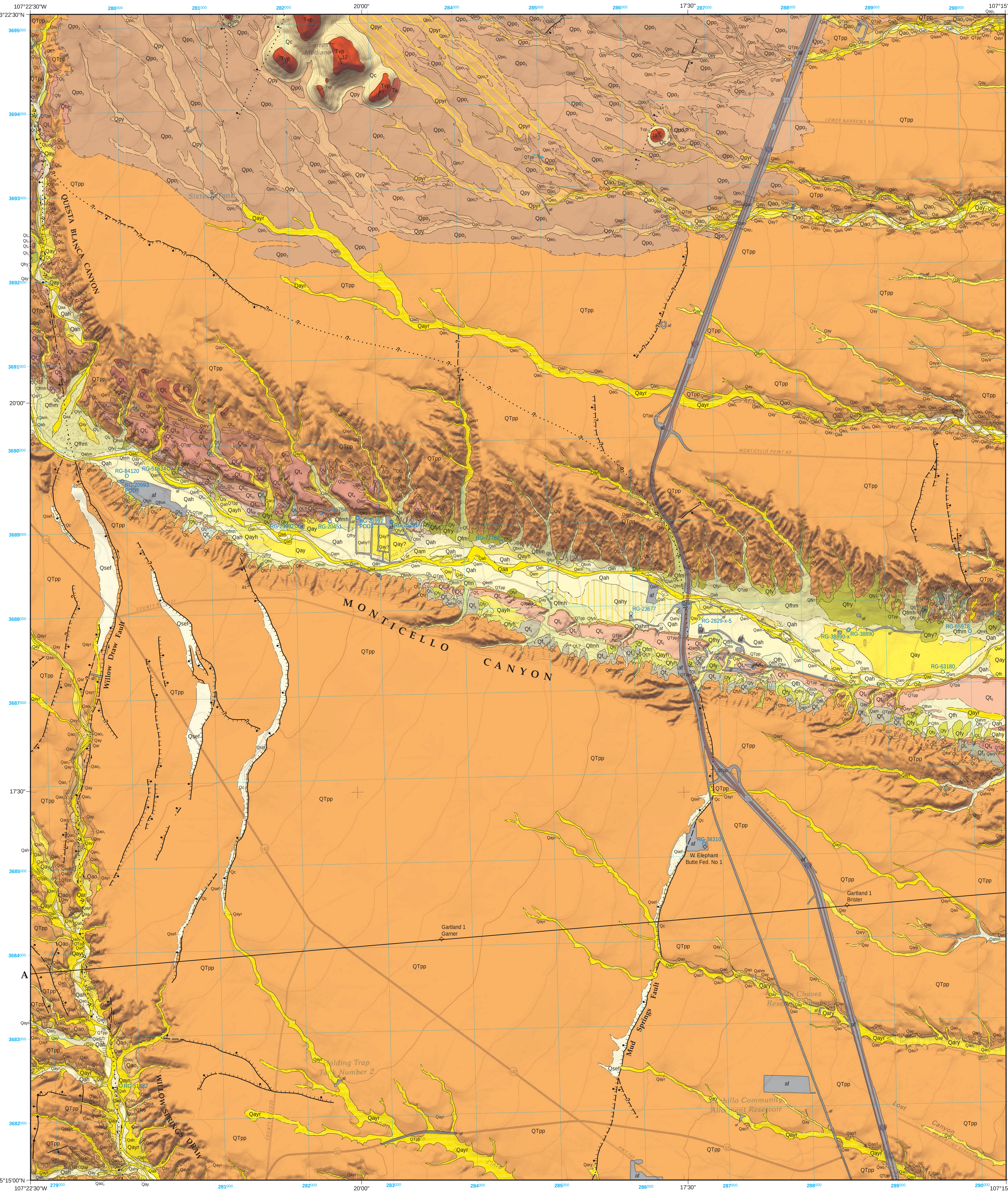
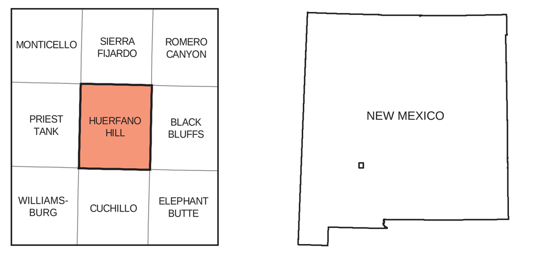
NMBGMR Open-file Geologic Map 243
Last Modified June 2013



Base map from U.S. Geological Survey 1961, photorevised 1979, edited in 1980. 1927 North American datum, Universal Transverse Mercator projection. 1000-meter grid, UTM zone 13, shown in blue.

1:24,000

CONTOUR INTERVAL 20 FEET
NATIONAL GEODETIC VERTICAL DATUM OF 1929



QUADRANGLE LOCATION

Magnetic Declination 1997 11.4° East At Map Center

New Mexico Bureau of Geology and Mineral Resources
Open-file Geologic Map 243

Mapping of this quadrangle was funded by a matching-funds grant from the STATEMAP program of the National Cooperative Geologic Mapping Act, administered by the U. S. Geological Survey, and by the New Mexico Bureau of Geology and Mineral Resources, (L. Greer Price, *Director and State Geologist*, Dr. J. Michael Timmons, *Associate Director for Mapping Programs*).

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

http://geoinfo.nmt.edu

Geologic map of the Huerfano Hill quadrangle, Sierra County, New Mexico

June, 2013

by

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MAP SYMBOLS

- Location of geologic cross section.
- Geologic contacts: Exposed or certain, location accurate; Exposed or certain, location approximate; Questionable, location accurate; Questionable, location approximate; Probable, location accurate; Probable, location approximate.
- Normal fault, bar-ball on downthrown side, tick gives attitude of fault plane, showing dip magnitude.
- Left lateral, oblique-slip fault, bar-ball on downthrown side, tick gives attitude of fault plane, showing dip magnitude.
- Scarp on normal fault, bar-ball on downthrown side.
- Scarp on left lateral, oblique-slip fault, bar-ball on downthrown side.
- Small, minor fault, showing strike and dip.
- Inclined foliation in igneous rocks, showing strike and dip.
- Paleocurrent vector determined by imbrication.
- Water well and NM Office of State Engineer permit number.
- Petroleum exploratory well.

COMMENTS TO MAP USERS

A geologic map displays information on the distribution, nature, orientation, and age relationships of rock and deposits and the occurrence of structural features. Geologic and fault contacts are irregular surfaces that form boundaries between different types or ages of units. [illegible]

The map has not been reviewed according to New Mexico Bureau of Geology and Mineral Resources standards. [illegible]

Cross-sections should be used as an aid to understanding the general geologic framework of the map area, and not be the sole source of information for use in locating or designing wells, buildings, roads, or other man-made structures.

MAP UNITS

(Partial description of units; complete descriptions found in the accompanying report.)

af — **Artificial fill (<80 years old)** — Sand and gravel reworked by humans into berms, levees, and road beds. Weakly to well consolidated and non-cemented. Locally includes minor excavations. Up to 15 m thick.

Quaternary Colluvium and Slopewash Deposits

Qc — **Colluvium (middle-upper Pleistocene and Holocene)** — Poorly sorted, angular to subangular, clayey-silty sand and gravel mantling middle-lower hillslopes of Huerfano Hill, the Sierras Mediano, and along the footslopes of fault scarps. <8 m thick.

Qsef — **Slopewash and sheetflood deposits associated with fault-related depressions (upper Pleistocene to Holocene)** — Yellowish brown (10YR5/4), massive, poorly sorted, clayey-silty very fine- to very coarse-grained sand. Minor (~10%), scattered, very fine to very coarse-grained pebbles eroded from the Palomas Formation. This sediment fills depressions created by hanging wall subsidence immediately adjacent to fault scarps. Thickness likely less than 6 m.

Quaternary Valley Bottom Deposits

Unless otherwise noted, gravel is composed of rhyolite and minor felsic tuffs (both mainly crystal-poor) along with 5-15% andesite. The latter is typically dark gray and contains plagioclase ± pyroxene phenocrysts. Clasts are subrounded (minor subangular). Sand is subrounded (minor subangular) and a volcanic litharenite.

Qaa — **Active alluvium in active channels (<5 years old)** — Sand and gravel underlying modern channel floors that are generally active on a yearly basis. Sediment similar to that described in unit *Qam*. No soil development. Generally <3 m thick, although greater thicknesses are possible locally along Alamosa Creek.

Qam — **Modern alluvium (0 to ~50 years old)** — Sand and gravel underlying very low surfaces astride active channels, probably active on a multi-year to decadal recurrence interval. Bar and swale topography and channel forms are sharp, with 30-80 cm of typical surface relief, and vegetation is sparse. Sediment is commonly in very thin to thin, tabular to lenticular beds; sand is typically horizontal-planar laminated to cross-laminated. Gravel are poorly sorted and consist of pebbles with subordinate cobbles and boulders. Sand is grayish brown to pale brown (10YR 5/2-6/3), fine- to very coarse-grained, and poorly to moderately sorted within a bed. Loose and no soil development. Generally <3 m thick, although greater thicknesses are possible locally along Alamosa Creek.

Qaam — **Active and modern alluvium, undivided (0 to ~50 years old)** — Active (*Qaa*) alluvium associated with channels and subordinate modern alluvium (*Qam*).

Qah — **Historical alluvium (50 to ~800 years old)** — Well-bedded sand and gravel in valley bottoms occurring in very thin to medium, tabular to lenticular beds. Sand is brown to light brownish gray (10YR 4-6/2, 5/3), locally silty, very fine- to very coarse-grained, and moderately to poorly sorted. Gravel are clast- to matrix-supported (matrix being sand), subrounded, and moderately to poorly sorted within a bed. Gravel sizes consist of pebbles with minor cobbles (~30%) and 5-10% boulders. Surface exhibits muted bar and swale topography and channel forms; generally less than 30 cm of surface relief. Sparsely to moderately vegetated and exhibits no obvious soil development. Tread is commonly less than 2 m above modern grade. Loose. Base not observed; possibly up to 3-4 m maximum thickness.

Qaha — **Historical alluvium and active alluvium, undivided (0 to ~800 years old)** — Historical alluvium (*Qah*) and subordinate active alluvium (*Qaa*).

Qamh, Qahm — **Modern and historical alluvium, undivided (0 to ~800 years old)** — A mixture of modern alluvium (*Qam*) and historical alluvium (*Qah*). Map label lettering order indicates relative abundances (primary - secondary) of individual alluvial components.

Qar — **Recent (active, modern, and historical) alluvium, undivided (0 to ~800 years old)** — Active alluvium (*Qaa*), historical alluvium (*Qah*), and modern alluvium (*Qam*) in various proportions, grouped together as a "recent" deposit.

Qay — **Younger alluvium, undivided (middle to upper Holocene)** — Sand and gravel underlying low-level terraces alongside modern arroyos. Generally consists of sandy gravel and pebbly sand. Clasts are dominated by pebbles with subordinate cobbles (30-40%) and lesser boulders (~10%). Sand is brown to light brownish gray (7.5-10YR 4-5/3; 10YR 6/2), very fine- to very coarse-grained, and poorly sorted. Gravel is clast-supported and poorly sorted. Except where eroded, the top of this unit typically exhibits a weak soil marked by calcium carbonate accumulation (stage I, locally stage II carbonate morphology) overlain locally by slightly darkened A horizons (where minor organic matter has accumulated). Surface exhibits a weak clast armor; clasts are non- to weakly varnished and subtle bar-and-swale topography may still be evident. Surface stands a little higher (by 0.2-1.0 m) than the surface of unit *Qah*. Loose to weakly consolidated. Typical thickness of at least 2 m estimated maximum thickness of 5-7 m. Locally, this unit is subdivided into two subunits:

Qay₂ → **Qay_2** — **Younger unit of younger alluvium (upper Holocene)** — Interbedded sand, pebbly sand, and sandy pebbles-cobbles underlying low-level terraces alongside modern arroyos. Locally overlies Qay_1 across a sharp, scoured disconformity. Sand is grayish brown to brown to light brown (7.5YR 5/3-6/4; 10YR 5/2-3), fine- to very coarse-grained, locally silty, and moderately to poorly sorted. Gravel is dominated by pebbles and cobbles, is clast- to matrix-supported, and may exhibit imbrication. This unit has weaker degrees of calcium carbonate accumulation (stage I carbonate morphology) than Qay_1, and commonly exhibits a slightly darkened A horizon (dark brown to brown, 7.5YR 3-4/3) at the top of its weak soil profile. Surface clast armor is weak to moderate; clasts are non- to weakly varnished. Surface lies 0.1-1.0 m above the modern channel and retains subdued evidence of bar and swale topography. 1-2 m thick.

Qay_1 — **Older unit of younger alluvium (middle to upper Holocene)** — Sand and gravel underlying low-level terraces alongside modern arroyos whose treads are slightly higher than those associated with Qay_2. Sand associated with the gravel is light brownish gray (10YR 6/2) to brown (7.5YR 4/3 to 10YR 5/3), locally silty, very fine- to very coarse-grained, loose, and poorly sorted. Gravel-dominated strata are typically clast-supported, variably imbricated and poorly sorted. Clasts include pebbles with subordinate cobbles (35-40% or less) and lesser boulders (~10%). This unit exhibits more visible evidence of calcium carbonate accumulation (stage I to II) than Qay_2, and sparse, thin clay films occur on clasts. Weakly consolidated. Surface is 1 to 3 m above that of modern stream grade. 1-5 m thick.

Qaya — **Active alluvium and younger alluvium, undivided (0 to 8,000 years old)** — Younger alluvium (*Qay*) and subordinate active alluvium (*Qaa*), the latter typically occupying a deeply incised channel.

Qary, Qayr — **Recent alluvium and younger alluvium, undivided (0 to 8,000 years old)** — A mixture of recent alluvium (*Qar*) and younger alluvium (*Qay*). Map label lettering order indicates relative abundances (primary - secondary) of individual alluvial components. Map unit *Qayr* is deposited on alluvial fans in Monticello Canyon. Up to ~10 m thick.

Qahy, Qayh — **Historical alluvium and younger alluvium, undivided (~50 to 8,000 years old)** — A mixture of historical alluvium (*Qah*) and younger alluvium (*Qay*). Map label lettering order indicates relative abundances (primary - secondary) of individual alluvial components.

Quaternary Terrace Deposits and Older Alluvium

Unless otherwise noted, gravel is composed of rhyolite and minor felsic tuffs (both mainly crystal-poor) along with 5-15% andesite. The latter is typically dark gray and contains plagioclase ± pyroxene phenocrysts. Clasts are subrounded (minor subangular). Sand is subrounded (minor subangular) and a volcanic litharenite.

Qtu — **Undifferentiated Alamosa terrace deposit (Pleistocene)** — Sandy gravel terrace deposit that was not correlated. 1-3 m thick.

Qt_6 — **Lowermost Alamosa terrace deposit (uppermost Pleistocene)** — Sandy gravel occurring as 2-3 m-thick strath terraces. Gravel consists of well-graded pebbles through fine boulders and is clast–supported. Sand is brown (10YR 5/3), very fine- to very coarse-grained (mostly coarse- to very coarse-grained), and poorly sorted. McCraw and Williams (2012) note reddish, illuviated clay (Bt) horizons 35-40 cm thick which overlie a 10 cm-thick calcic soil horizon manifesting a stage I carbonate morphology. 1-3 m thick. Locally, Qt_6 can be subdivided into two subunits:

Qt_{6b} — **Lower subunit of the lowermost terrace deposit along Alamosa Creek (uppermost Pleistocene)** — Sandy gravel similar to Qt_6. Tread lies about 5-7 m above the modern stream grade.

Qt_{6a} — **Upper subunit of the lowermost terrace deposit along Alamosa Creek (uppermost Pleistocene)** — Sandy gravel whose tread lies about 2 m above the tread of terrace Qt_{6b}. Probably 1-2 m thick.

Qt_5 — **Upper lower Alamosa terrace deposit (upper-middle to upper Pleistocene)** — Sandy gravel underlying an extensive terrace along Alamosa Creek. Gravel is clast-supported and imbricated to the east. Clast range from pebbles to boulders (mostly pebbles and cobbles, with 10-20% boulders), are subrounded to rounded, and poorly to very poorly sorted. The sand is brown (7.5YR 5/4; 10YR 5/3), mostly medium- to very coarse-grained, and moderately to poorly sorted. Less than 7% clay chips and argillans. Weakly consolidated and non-cemented. Surface is subjected to sheetflooding and the development of the preserved soil is variable (stage I to stage III carbonate morphology, but mostly stage II to II+). Surface typically exhibits moderate to weak reddening and varnishing of clasts, although near the western quadrangle boundary Qt_5 lacks a desert pavement and clasts are not varnished. This unit is a fill terrace in the vicinity of Interstate 25 and downstream of the highway, where it has a thickness of 4-12 m, but upstream the terrace diverges into four strath terraces whose deposits are relatively thin (1-2 m). To the east, the lower contact is highly scoured and exhibits meter-scale relief. To the west, the lower contact is scoured but more planar. Locally, Qt_5 can be subdivided into four subunits:

Qt_{5d} — **Lowest subunit of the upper lower terrace deposit along Alamosa Creek (upper-middle to upper Pleistocene)** — Sandy gravel whose sediment resembles that of units Qt_{5b} and Qt_{5a}. Not described in detail. Tread lies 2 m above the tread of Qt_{6a}. Likely 1-2 m thick.

Qt_{5c} — **Lower middle subunit of the upper lower terrace deposit along Alamosa Creek (upper-middle to upper Pleistocene)** — Sandy gravel whose sediment resembles that of units Qt_{5b} and Qt_{5a}. Not described in detail. Tread lies 1-2 m above the tread of Qt_{5d}. Likely 1-2 m thick.

Qt_{5b} — **Upper lower subunit of the upper lower terrace deposit along Alamosa Creek (upper-middle to upper Pleistocene)** — A coarse, very poorly sorted deposit composed of sandy gravel (est. 50-60% pebbles, 30-40% cobbles, and 10-20% boulders). Surface is similar to that described on unit Qt_{5a}. Tread lies ~3 m above the tread of Qt_{5c}. Deposit is 1-2 m thick.

Qt_{5a} — **Highest subunit of the upper lower terrace deposit along Alamosa Creek (upper-middle to upper Pleistocene)** — A relatively coarse deposit composed of very poorly sorted, sandy gravel (estimated 40-50% pebbles, 30-40% cobbles, and 15-30% boulders. Surface clasts have a weak-moderate desert pavement (weakly to moderately developed clast armor and Av peds) and a weak-moderate varnishing of clasts. Tread lies about 2 m above the tread of Qt_{5b}. Deposit is ~2 m thick.

Qt_4 — **Lower middle terrace deposit along Alamosa Creek (middle Pleistocene)** — A sandy gravel that consists of pebbles with 10-50% cobbles and 1-25% boulders. Generally less bouldery than lower terrace deposits (Qt_5 and Qt_6). Gravel are clast-supported, subrounded, and very poorly to moderately sorted. Sand is brown to strong brown to light brown (7.5YR 5/4-6, 6/4), very fine- to very coarse-grained (mostly medium- to very coarse-grained), subangular to rounded (mostly subrounded), and poorly to moderately sorted. <10% clay films and clay chips. Surface gravel is weakly to moderately varnished and moderately reddened; moderate desert pavement development. Soil marked by a thick (up to 150 cm) illuviated clay horizon underlain by a calcic horizon exhibiting stage I+ to IV carbonate morphology; the calcic horizon commonly coincides with the base of the terrace deposit. Generally no Holocene surface deposits on its upper surface. Weakly to moderately consolidated. Looser and browner than underlying Palomas Formation. Tread lies about 19-20 m above the Qt_{5a} tread and 36-39 m above modern stream grade. Thickness of 1.5 to 2.5 m.

Qt_3 — **Upper middle terrace deposit along Alamosa Creek (middle Pleistocene)** — Tread is 2.5 m above the tread of unit Qt_4. Qt_3 appears to be slightly thicker than Qt_4 and can be subdivided into two subunits:

Qt_{3b} — **Lower subunit of the upper middle terrace deposit along Alamosa Creek (middle Pleistocene)** — Sandy gravel that is poorly exposed. Gravel consists of pebbles with 30% cobbles and 5% boulders. Clasts are subrounded and poorly sorted. Top soil marked by significant clay accumulation and probably has what can be classified as an argillic horizon (Soil Survey Staff, 1992). Clay films are distinct to prominent and cover 30-60% of grains and clasts. Sand is fine- to very coarse-grained and poorly sorted. Clay films inhibit identification of grain composition, but based on adjoining terraces the sand is likely a volcanic litharenite. Weakly (mostly) to moderately consolidated. Near base of the deposit is a 40-50 cm-thick petrocalcic horizon (stage III+ carbonate morphology). Surface lies 3-8 m above the surface of Qt_4. 1-5 m thick.

Qt_{3a} — **Higher subunit of the upper middle terrace deposit along Alamosa Creek (middle Pleistocene)** — Sandy gravel roughly similar to that in the Qt_{3b} deposit. Not described in detail. Tread of Qt_{3a} typically lies 4-6 m above the tread of Qt_{3b}, increasing to ~8 m in a downstream direction. 1-2 m thick.

Qt_2 — **Lower upper terrace deposit along Alamosa Creek (middle Pleistocene)** — No exposure observed but deposit is probably less than or equal to 1 m thick. The tread exhibits a stage IV petrocalcic horizon which is buried by gravelly colluvium and slopewash.

Qt_1 — **Uppermost terrace deposit along Alamosa Creek (middle Pleistocene)** — No exposure observed but deposit is probably less than or equal to 1 m thick.

Older alluvium associated with streams other than Alamosa Creek

Qao — **Older alluvium, undivided (middle to upper Pleistocene)** — Relatively thin alluvium underlying terraces alongside drainages other than Alamosa Creek. Surfaces are typically moderately varnished, lack bar-and-swale topography, and exhibit topsoils with strong calcium carbonate accumulations (stage II+ to III carbonate morphology). <2 m thick. Typically three terrace levels are present in a given drainage, which are described below:

Qao_3 — **Lower unit of older alluvium (middle to upper Pleistocene)** — Sandy gravel not described in detail. Probably correlates to Qt_3 or possibly Qt_2. Tread is located 2-4 m below Qao_2 and 2-6 m above modern stream grade, with the vertical distance between Qao_2 and modern stream grade increasing in a downstream direction. Probably 1-3 m thick.

Qao_2 — **Middle unit of older alluvium (middle to upper Pleistocene)** — A prominent strath terrace found in most canyons. [illegible]

Qao_1 — **Upper unit of older alluvium (middle Pleistocene)** — [illegible]

Quaternary Alluvial Fan and Piedmont Deposits

Qfm — **Modern active alluvium in alluvial fans flanking Monticello Canyon (0 to ~50 years old)** — [illegible]

Qfh — **Historical alluvium in alluvial fans flanking Monticello Canyon (0 to ~50 years old)** — [illegible]

Qfmh, Qfhm — **Modern-active and historic alluvium in alluvial fans flanking Monticello Canyon, undivided (0 to ~800 years old)** — [illegible]

Qfy — **Younger alluvium in alluvial fans along the margins of Canada Alamosa (Holocene)** — [illegible]

Qfry, Qfyr — **Recent alluvium (historical and modern-active) and younger alluvium in alluvial fans flanking Monticello Canyon, undivided (0 to ~800 years old)** — [illegible]

Qfhy, Qfyh — **Historic and younger alluvium in alluvial fans flanking Monticello Canyon, undivided (0 to ~800 years old)** — [illegible]

Qfo — **Older alluvium in alluvial fans flanking Monticello Canyon, undivided (upper-middle Pleistocene to lower Holocene)** — [illegible]

Qf_6 — **Alluvial fans graded to the lowermost terrace tread of Alamosa Creek (uppermost Pleistocene to lower Holocene)** — [illegible]

Qf_5 — **Alluvial fans graded to the upper-lower terrace tread of Alamosa Creek (upper-middle(?) to upper Pleistocene)** — [illegible]

Qf_4 — **Alluvial fans graded to the lower-middle terrace tread of Alamosa Creek (middle Pleistocene)** — Sandy gravel to sand. Gravel consist of pebbles and minor cobbles, is clast-supported, subrounded, poorly to moderately sorted, and commonly imbricated parallel to local side-stream arroyos. Sand associated with the gravel is brown (7.5YR 5/4), very fine- to very coarse-grained, subrounded to subangular, and poorly sorted. Also locally present is massive, clayey-silty, very fine- to fine-grained sand with minor, scattered, medium- to very coarse-grained sand and 20-25% scattered pebbles. It has common colors of light brown to strong brown (7.5YR 6/4-5/6). This finer-grained sediment is intercalated with 15-30%, very thin to medium, lenticular beds of very fine-very coarse pebbles and minor (1-5%) fine cobbles. Local medium to thick beds composed of sandy pebbles to fine boulders. Top soil consists of a stage I+ to II calcic horizon that is locally >30 cm thick. Desert pavement is similar to that developed on Qt_4. Approximately 2 m thick.

Qf_3 — **Alluvial fans graded to the upper-middle terrace tread of Alamosa Creek (middle Pleistocene)** — Sandy gravel and sand that was not described in detail. The associated alluvial fan progrades onto the Qt_{3b} terrace tread tread. Surface is roughly similar to that on Qt_{3b} but surface varnishing is slightly less. About 2 m thick.

Post-Palomas Formation piedmont alluvium, northwest corner of quadrangle

Unless otherwise noted, gravel is composed of rhyolite and minor felsic tuffs (both mainly crystal-poor) along with 1-10% andesite (commonly plagioclase-phyric) that are angular to subrounded; andesites are typically more rounded than felsic clasts. Sand is a volcanic litharenite.

Qpy — **Younger piedmont sediment (Holocene)** — Pebbly sand. Brown (7.5YR 5/3) and bioturbated. Very fine petrocalcic nodules locally common but typically sparse. Pebbles are composed of rhyolite and commonly matrix-supported. Surface is non- to poorly varnished. 1-5(?) m thick.

Qpyr — **Younger piedmont and recent sediment, undivided (Holocene)** — Unit *Qpy* and subordinate *Qar* occupying the floors of drainages near the Sierras Medianos. Surface is non- to poorly varnished. 1-5(?) m thick.

Qpo — **Older piedmont sediment (middle to upper Pleistocene)** — undifferentiated.

Qpo_2 — **Younger subunit of older piedmont sediment (middle to upper Pleistocene)** — Clayey-silty, very fine- to medium-grained sand that is subangular to rounded, poorly sorted, and lithic-rich; contains very sparse coarse to very coarse sand grains and pebbles. This finer sediment is interbedded with pebbly beds that are moderately imbricated and bioturbated. Channel-fill sand is brown (7.5YR 5/3) and contains very fine to fine pebbles, with minor (<15%) medium to very coarse pebbles. Massive. Near the surface the sediment is overprinted by a weak to strong calcic horizon (stage I to III) that is moderately indurated and soft to moderately hard; color of light brown (7.5YR 6/4). Overlying the calcic horizon is illuviated clay horizon(s). Surface contains more fine-grained sediment than that associated with Qpo_1 (commonly 20-60% gravel on the surface) and exhibits a browner color on aerial imageryy; clast size does not change significantly between Qpo_2 and Qpo_1. Qpo_2 is commonly inset into Qpo_1, although this relation is not ubiquitous. Based on inset relations, Qpo_2 is older than Qao_2 and younger than or concomitant with Qao_1. Up to 2 m thick.

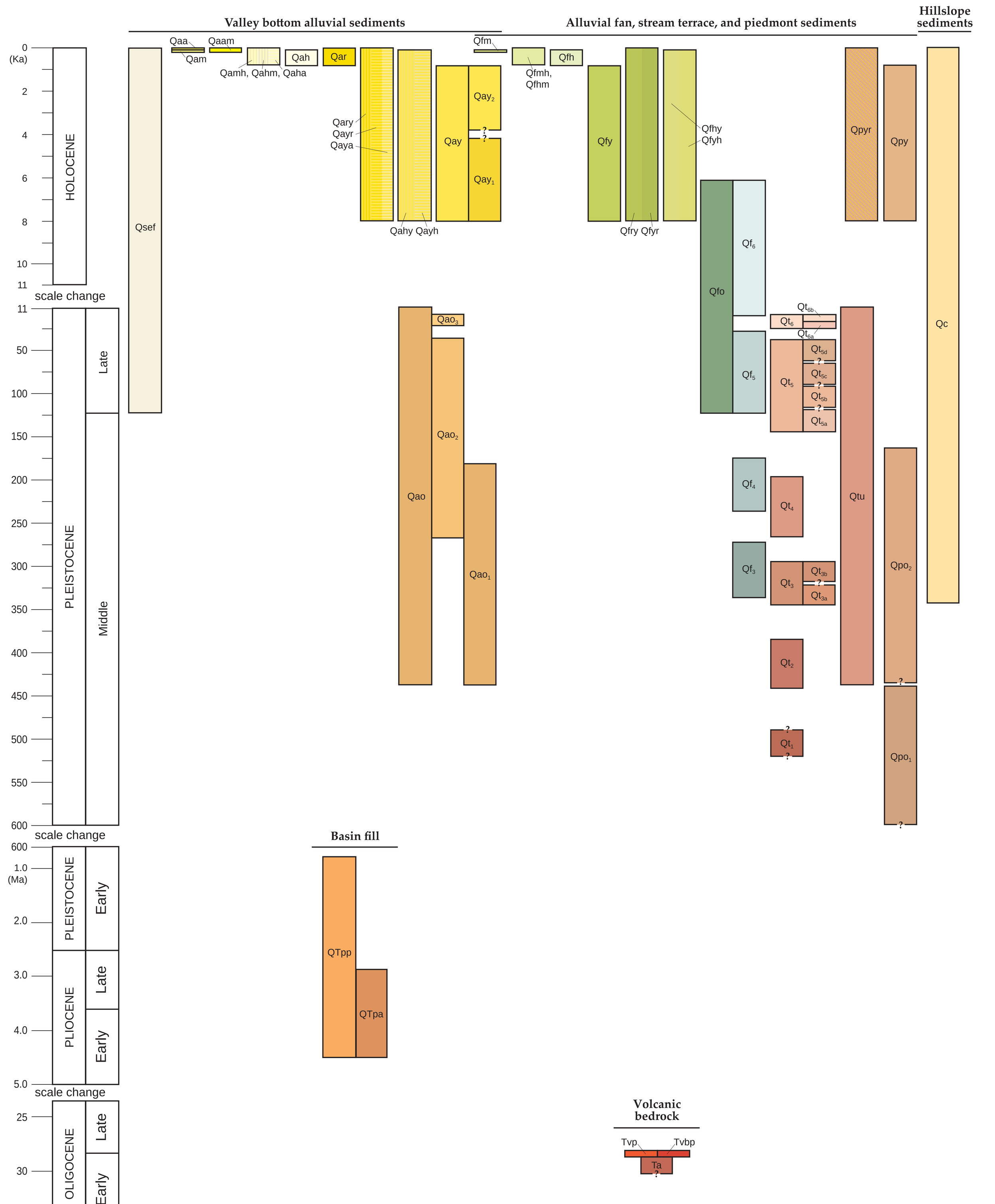
Qpo_1 — **Older subunit of older piedmont sediment (middle Pleistocene)** — Sandy gravel. Gravel consists mainly of pebbles with minor (<10%) cobbles and very sparse (<1%) boulders. Locally cross-bedded. Gravel are imbricated and moderately to poorly sorted. Sand is reddish brown (5YR 5/4), slightly silty, fine- to very coarse-grained sand (mostly medium- to very coarse-grained). Sand is angular to subangular and poorly sorted. Wavy, erosional base. Top soil is marked by mixed illuviated clay-calcic horizon(s) overlying calcic horizon(s) exhibiting stage III carbonate morphology. Surface is more gravelly than that associated with Qpo_2 (60-90% pebbles) and exhibits a lighter color on aerial imagery. Based on inset relations, Qpo_1 is older than Qao_1. Up to 2 m thick.

Neogene - Quaternary Basin-fill

QTpp — **Palomas Formation, piedmont facies (lower Pliocene to lower Pleistocene)** — Sandy gravel channel-fills interbedded with extra-channel deposits composed of clayey sand with minor, scattered pebbles. Upper 10-30 m of the Palomas Formation is typically dominated by gravel. Distinguished from younger terrace deposits by less distinct bedding and the presence of 5-20% clay chips (up to 1 mm long) and clay films on sand grains and clasts (argillans), with local clay bridging (very faint to distinct and 25-50% surface coverage). The sandy gravel tends to be in 1-5 m thick, amalgamated complexes displaying very thin to very thick (mostly very thin to medium), tabular to lenticular beds; local (~10%) planar- to trough-cross stratification (very thinly to thinly bedded) where foresets are up to 60 cm thick. Gravel is generally clast-supported, subrounded (mostly) to subangular, poorly to moderately sorted, and composed of felsic volcanic clasts (rhyolite and rhyolitc tuffs, mainly crystal poor with 1-2% of gravel being moderately crystal-rich) and minor (5-15%), dark gray (mostly) to brown andesite clasts (with phenocrysts of plagioclase ± pyroxene). Gravel consists primarily of well-graded pebbles, minor to subordinate cobbles, and 1-10% boulders. Clast imbrication indicates an east-southeast flow direction. Channel-fills also include minor pebbly sand in beds that are medium to thick and tabular to lenticular (internally laminated or in thin, tabular beds), with local cross-stratification up to 30 cm thick. Channel-fill sand is relatively minor (<25%) and reddish brown to light reddish brown (2.5YR 4/4; 5YR 5-6/4) to yellowish red (5YR 5/6) to reddish yellow (5YR 6/6) to brown (7.5YR 5/4; 10YR 5/3)), very fine- to very coarse-grained (mostly fine to very coarse-grained), subrounded to subangular (mostly subrounded), moderately to poorly sorted, and a volcanic litharenite with 1-5% plagioclase grains. Extra-channel sediment is massive and dominated by very fine- to lower-medium sand and clayey-silty fine sand, with minor medium-upper to very coarse sand and pebbles that are scattered; minor very thin to thick, pebbly channel-fills; and minor silt beds near the eastern quadrangle border. Clay-rich sediment is light reddish brown to reddish brown (5YR 5-6/3-4); sandy sediment is light brown (7.5YR 6/3-4). Up to 5% accumulation of calcium carbonate (as nodules or along fractures). Weakly to well consolidated and non- to weakly cemented by clays (which also facilitate consolidation); the extra-channel sediment is commonly well consolidated. Surface soil is marked by a petrocalcic horizon that is 1-2 m thick and generally exhibits a stage IV carbonate morphology. Lower part of the petrocalcic horizon is gradational. The degree of clast varnishing on the Cuchillo surface is variable, depending on the degree of reworking by sheetflooding; near the south-central quadrangle border the clasts are strongly varnished. Fossil data (summarized by Morgan and Lucas, 2012), basalt radiometric dates (Bachman and Mehnert, 1978; Seager *et al.*, 1984), together with magnetostratigraphic data (Repenning and May, 1986; Mack *et al.*, 1993; 1998; Leeder *et al.*, 1996; Seager and Mack, 2003), indicate an age range of 4.5-0.78 Ma for the Palomas Formation. 100-131 m thick according to Lozinsky and Hawley (1986).

QTpa — **Palomas Formation, axial facies (lower Pliocene to lower Pleistocene)** — Thick intervals (≥ 10 m) of amalgamated channel-fill sands interbedded with floodplain sediment of similar thicknesses. Lozinsky (1985) reports that the sand is generally arkosic and pebbles consist of quartz, chert, granite, sandstone, and a variety of volcanic rock types. Floodplain sediment is light reddish brown (5YR 6/3) and consists of clay-silt in medium to thick, tabular beds. Some zones in the floodplain facies have abundant calcium carbonate nodules (up to 5 mm thick), some of which appear to be associated with paleo-burrows. This unit grades laterally westward into unit *QTpp*. Fossils collected from this general stratigraphic interval suggest a 3.0-3.3 Ma age (Morgan and Lucas, 2012, Elephant Butte Lake fauna) or 3.0-5.0 Ma (if extended into the subsurface). The maximum age (5.0 Ma) is constrained by magnetostratigraphic data (Mack *et al.*, 1993; 1998; Leeder *et al.*, 1996; Seager and Mack, 2003). >12 m thick.

CORRELATION OF MAP UNITS



Volcanic bedrock

Tvp — **Vicks Peak Tuff (upper Oligocene)** — Light to medium gray (5YR-7.5YR 7/2), fine-grained (3-10% visible crystals) ignimbrite exhibiting flattened pumice (fiamme; 10-15%). Crystals include sanidine and <1% quartz. ~5% ferromagnesium minerals. $^{40}Ar/^{39}Ar$ dating indicates an age of 28.75 ± 0.04 Ma (former age of 28.56 Ma of McIntosh *et al.*, 1991, corrected using the revised Fish Canyon sanidine age of 28.02 Ma from Renne *et al.*, 1998). At least 60 m thick.

Tvbp — **Brecciated Vicks Peak Tuff (upper Oligocene)** — A crystal poor tuff interpreted as Vicks Peak Tuff but brecciated. At least 60 m thick.

Ta — **Andesite (upper Oligocene)** — Gray andesite. 25-40% visible crystals in hand sample, with phenocryst assemblage consisting of plagioclase and subordinate pyroxene or amphibole. Locally exhibits vesicular textures. Underlies the Vicks Peak Tuff. Generally identified using float. >15 m thick.

Subsurface Units

Tsf — **Santa Fe Group below the Palomas Formation (upper Oligocene to Miocene)** — Coarse channel-fills interbedded with tan-brown mudstones and clayey-silty, very fine- to fine-grained sandstones. Consolidated and variably cemented. Tilted 2-4° E (apparent dip) and overlies older strata across an angular unconformity apparently dipping 5° E (see cross section A-A'). East of the Mud Springs fault, this unit is subdivided according to gross texture. Greater than 1880 m thick on the hanging wall of the Mud Springs fault.

Tvs — **Volcaniclastic sediment interbedded with volcanic flows (upper Eocene to upper Oligocene)** — Includes volcaniclastic sandstone and conglomerate eroded from surrounding volcanic highlands. Likely interbedded with andesite to rhyolite volcanic flows that increase in abundance to the west. Correlative to the Datil and Spears Groups as well as the Thurman Formation. Thickness is poorly constrained but speculated to be 600 m on the hanging wall of the Mud Springs fault. Unit was eroded off of the footwall of the Mud Springs fault prior to deposition of *Tsf*.

Kmc — **McRae Formation (Upper Cretaceous)** — Lower 120 m consists of dark brown to olive-green sandstone interbedded with volcaniclastic conglomerates and olive-green to purple shales. Upper part is composed of maroon to brown shales interbedded with sandstone and minor conglomerate. Preserved thickness on the quadrangle is 530 m (description from Lozinsky, 1985).

Ku — **Undivided Cretaceous rocks (Upper Cretaceous)** — Includes (in ascending order): 1) the Dakota Sandstone (24-75 m thick), 2) Mancos Shale divided by the Tres Hermanos Formation (sandstone and mudstone)(~80 m thick), and 3) Crevasse Canyon Formation (1005-1010 m thick). 400 m thick in the Gartland 1 Brister exploratory well, corrected for dip, which means that much of the Crevasse Canyon Formation was eroded prior to McRae deposition.

Psa — **San Andres Formation (Upper Permian)** — Gray limestone with minor interbeds of shale and sandstone. Rare chert nodules and lenses. 210-230 m thick (description from Lozinsky, 1985).

Py — **Yeso Formation (Lower Permian)** — Sandstone and siltstone exhibiting yellowish, orange, greenish, and reddish to reddish brown colors. Abundant gray limestone in middle and upper parts. Local beds of gypsum and gypsiferous siltstone found in upper part (description from Jahns *et al.*, 1978, and Lozinsky, 1985). 270-280 m thick, corrected for dip. The unit thickens to the east and is as much as 533 m thick in the vicinity of the Gartland 1 Brister exploration well; this thickening is attributed to dioritic(?) sills and other intrusives (Lozinsky, 1987).

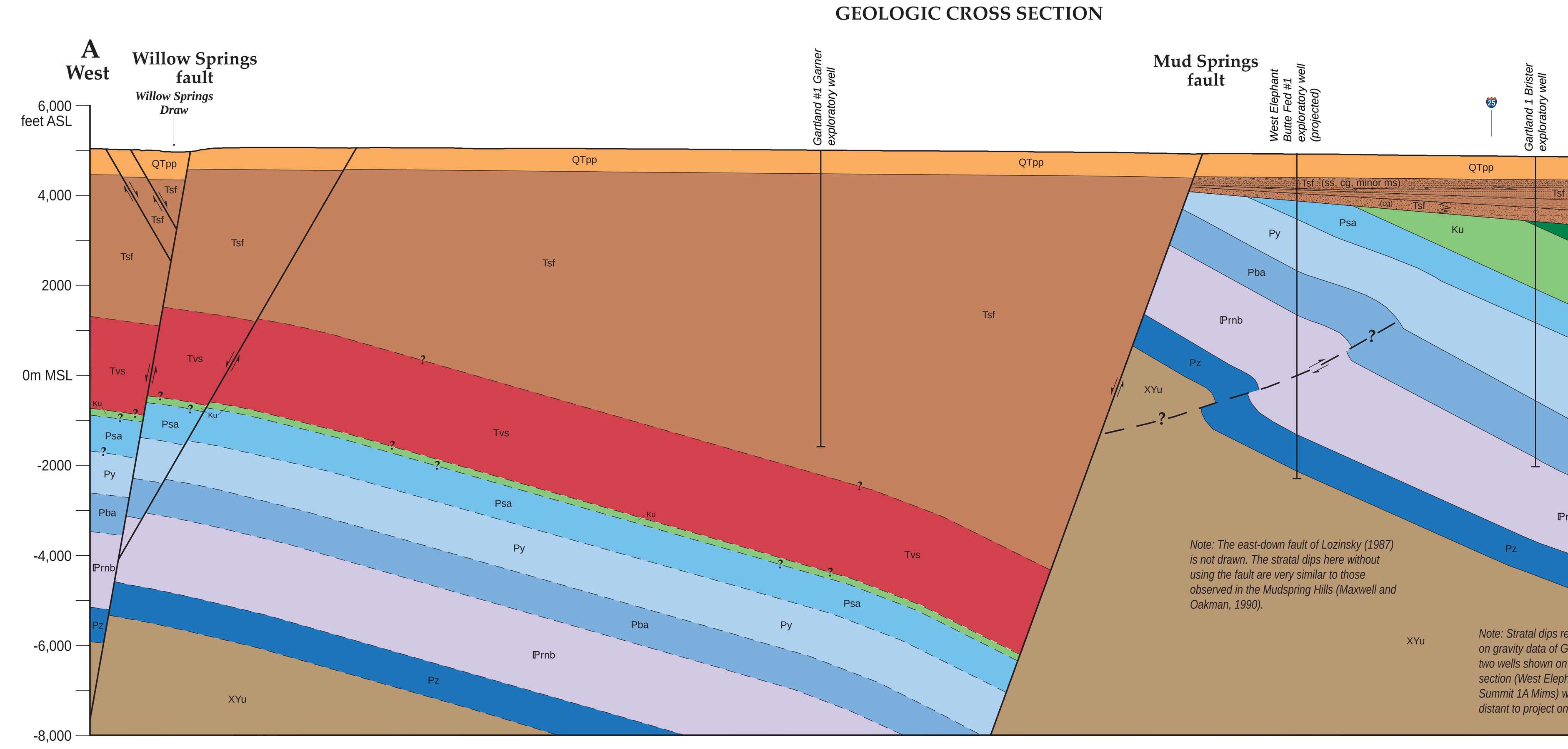
Pba — **Abo and Bursum Formations (Lower Permian)** — The Bursum Formation is composed of reddish-purple siliclastic beds interbedded with limestone and is conformably overlain by the Abo Formation (~150 m thick according to Maxwell and Oakman, 1990). The latter is composed of dark red shale and sandstone; there is minor orange-red arkosic sandstone and conglomerate as well as purplish-gray, nodular calcareous mudstone (Maxwell and Oakman, 1990). Well data on cross section A-A' indicate a thickness of 250-260 m, corrected for dip.

IPrnb — **Red House, Nakaye, and Bar B Formations (Pennsylvanian)** — Largely grayish, cherty limestone interbedded with shale; very minor sandstone and pebble conglomerate. 540-550 m thick according to Lucas *et al.* (2012).

Pz — **Lower to middle Paleozoic, undivided (Cambrian through Devonian)** — Sedimentary strata that includes the Bliss Sandstone at the base (Upper Cambrian-Lower Ordovician and 40-55 m thick). Overlying the Bliss Sandstone is a thick sequence dominated by limestones and dolomites, including (from bottom to top): 1) the El Paso Group (Lower Ordovician) represented by the Hitt Canyon Formation (~120 m thick) and overlying McKelligon Limestone (~36 m thick)(nomenclature following Hayes, 1975a,b), and 2) the Montoya Formation (Upper Ordovician and ~110 m thick). Overlying these carbonate-dominated strata is a shaly-siltstone-domianted interval that includes the Percha Shale, Sly Gap, and Oñate Formations (Devonian and 30-40 m thick) -- which Lucas *et al.* (2012) advocates lumping into the Percha Formation. Devonian strata are missing in the northern Mud Spring Mountains (Maxwell and Oakman, 1990) and may not be present in cross-section A-A'. Total thickness of 375-380 m in the Mud Spring Hills (Lucas *et al.*, 2012), but we used a thickness of ~230 m based on thicknesses from the West Elephant Butte Federal No. 1 well.

XYu — **Proterozoic, undivided (Paleo- to Neoproterozoic)** — Reddish gray quartzite, dark gray and brown quartz schist, quartz-biotite schist, foliated amphibolite, and porphyritic, reddish granitic gneiss. Possible metarhyolite and granite. Rocks are complexly interlayered and contorted (Maxwell and Oakman, 1990; Jahns *et al.*, 1978; Nelson *et al.*, 2012).

GEOLOGIC CROSS SECTION



References
(see accompanying report).