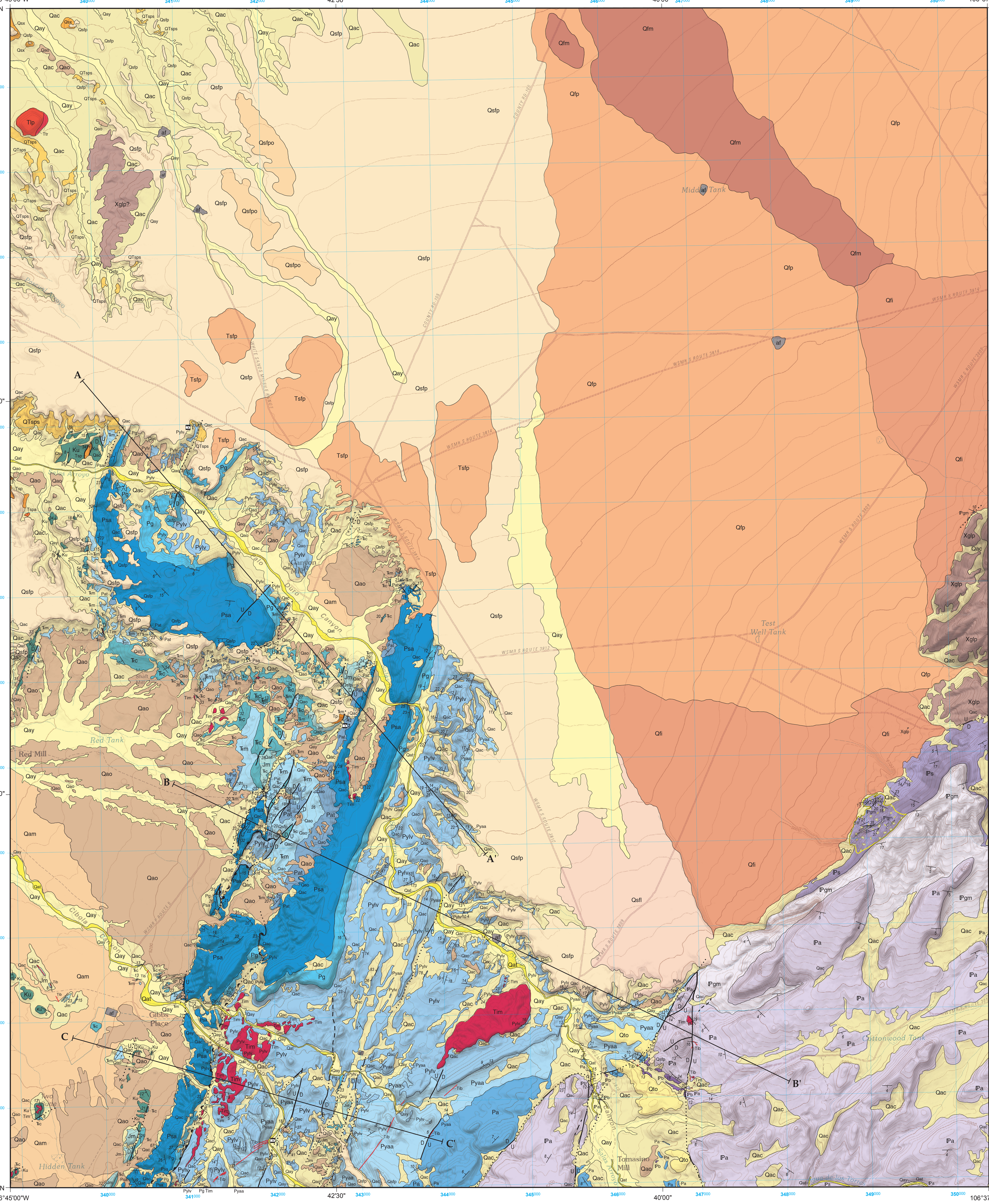
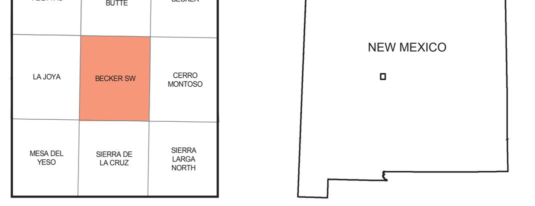
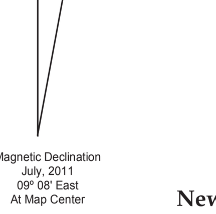


Base map compiled from US Topo, U.S. Geological Survey, 2010.
1983 North American datum reprojected to 1927 North American datum.
UTM projection -- zone 13. 1000-meter UTM grid shown in blue.



QUADRANGLE LOCATION



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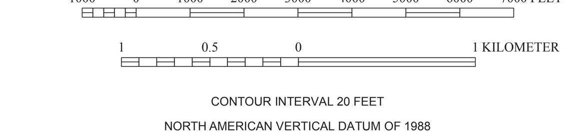

CONTOUR INTERVAL 20 FEET

NORTH AMERICAN VERTICAL DATUM OF 1988

New Mexico Bureau of Geology and Mineral Resources
Open-file Geologic Map 233

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, *Assoc. 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 Becker SW quadrangle, Socorro County, New Mexico

June, 2013

by

Bruce D. Allen, David W. Love, David J. McCraw, and Alex J. Rinehart

New Mexico Bureau of Geology and Mineral Resources, 801 Leroy Place, Socorro, NM 87801

MAP SYMBOLS

A ⊢—⊣ A' Location of geologic cross section.

Geologic contact, solid where exposed or known.

Fault with local normal offset, ball-and-bar or letter "D" on downthrown side; "U" on upthrown side. Solid where exposed or known, dashed where inferred, and dotted where concealed.

Low-angle normal fault, half-circles on upper block. Solid where exposed or known, dotted where concealed.

Tib — Basaltic dike, unit Tib.

Rockslide.

4 — Strike and dip of inclined bedding.

1 — Photo location and number.

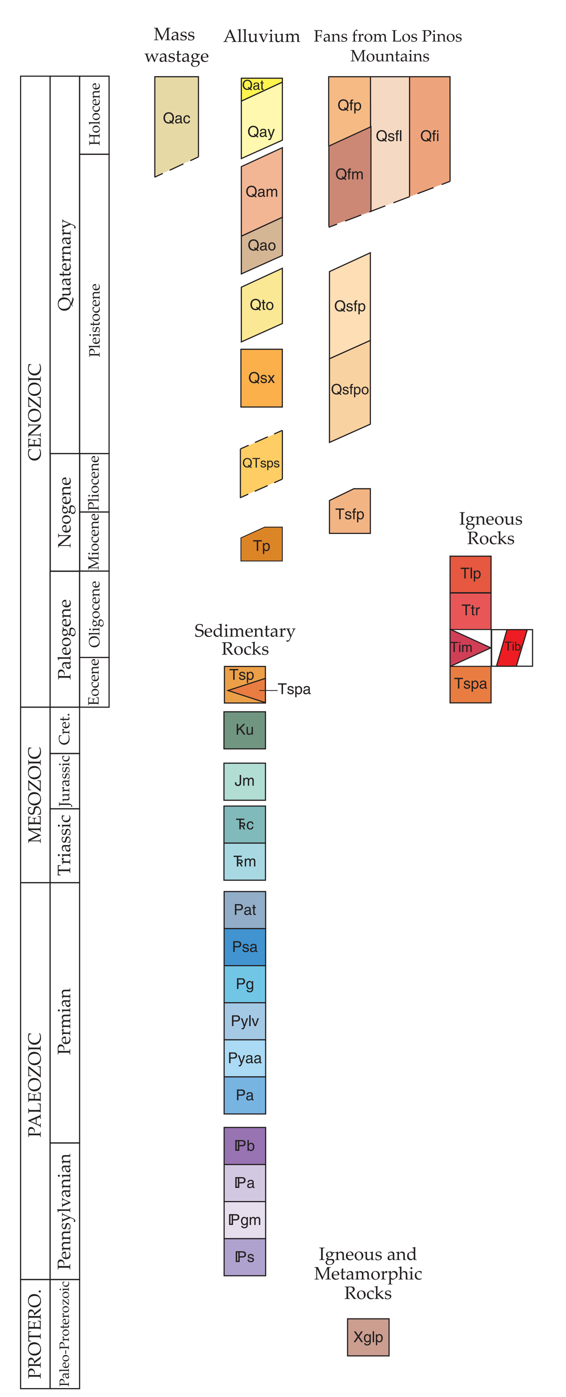
COMMENTS TO MAP USERS

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. Data depicted on this geologic quadrangle map may be based on any of the following: reconnaissance field geologic mapping, compilation of published and unpublished work, and photogeologic interpretation. Locations of contacts are not surveyed, but are plotted by interpretation of the position of a given contact onto a topographic base map; therefore, the accuracy of contact locations depends on the scale of mapping and the interpretation of the geologist(s). Any enlargement of this map could cause misunderstanding in the detail of mapping and may result in erroneous interpretations. Site-specific conditions should be verified by detailed surface mapping or subsurface exploration. Topographic and cultural changes associated with recent development may not be shown.

Cross sections are constructed based upon the interpretations of the author made from geologic mapping, and available geophysical, and subsurface (drillhole) data. 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.

The map has not been reviewed according to New Mexico Bureau of Geology and Mineral Resources standards. The contents of the report and map should not be considered final and complete until reviewed and published by the New Mexico Bureau of Geology and Mineral Resources. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the State of New Mexico, or the U.S. Government.

CORRELATION OF MAP UNITS



DESCRIPTION OF MAP UNITS

CENOZOIC

Quaternary and Neogene

Alluvium

af — **Artificial fill (historic)** — Reworked, compacted sand, gravel, and mud associated with roadfill, stock tanks, levees, and berms.

Qat — **Modern channel deposits in thalwegs of large drainages (historic)** — Poorly to moderately sorted, unconsolidated coarse-grained sand with local accumulations of cobbles and small boulders in channels, and silt and clay in backwaters and low point bars and floodplains. Commonly exhibits waning-flow bedforms such as ripples, dunes, and longitudinal bars. Underlies narrow- to broad streams; channels are inset against low terrace (*Qay*) and abandoned slightly higher deposits under plains in southwest part of quadrangle (*Qam*). Includes active alluvium of Palo Duro (*a.k.a.*, Agua Torres and Salas) Arroyo and Cibola Canyons. Deposits are generally ephemeral and thin, ranging from less than 1 m to more than 2 m thick. Channel position based on 2005 aerial photographs. Includes unmapped exposures of bedrock in scoured reaches and adjacent, very low overbank areas.

Qay — **Valley bottom alluvium, undivided (upper Holocene to historic)** — Poorly to moderately sorted, poorly consolidated pebble-to- cobble alluvium and fine- to coarse-grained sand with local accumulations of cobbles and small boulders in buried channels, and silt and clay in backwaters of floodplains. Incipient soils poorly expressed in darker horizons lacking sedimentary structures. Mapped adjacent to incised active channels (*Qat*) and in unincised valleys. Deposits range from at least 1.5 m to more than 7 m thick.

Qam — **Alluvium, undivided deposits at low-intermediate valley-border levels (Holocene to upper Pleistocene)** — Poorly consolidated sand and gravel adjacent to and beyond modern drainages. These less active, slightly higher deposits are primarily under plains in the southwest part of quadrangle. Inset against older alluvium; younger alluvium is inset against *Qam*. At least two levels noted adjacent to some drainages, but not mapped separately. Exposed thicknesses less than 10 m.

Qao — **Alluvium, undivided older deposits (upper to middle Pleistocene)** — Moderately consolidated and unconsolidated sand and gravel associated with sloping valley borders. Gravels are subangular to subrounded pebbles and cobbles of locally derived limestone and sandstone, along with granitic, metamorphic, and sparse volcanic rock types derived from reworked deposits from Los Pinos Mountain headwaters. Includes elevated local piedmont-alluvial areas capped by gypsum crust and incised by more recent drainages north of Gibbs Place. Also includes higher aggraded medial-distal fans elevated above valley alluvium (*Qay* and *Qam*).

Qto — **Alluvium, undivided older terrace deposits (middle Pleistocene)** — Moderately consolidated sand and gravel associated with stream terraces along valley borders. Gravels are subangular to subrounded pebbles and cobbles of limestone, sandstone, granitic, metamorphic, and sparse volcanic rock types indicating derivation from Los Pinos Mountain headwaters. Inset against the Sierra Ladrones formation and along bedrock buttresses of valley borders. Thickness ranges from less than 1 to 10 m.

Colluvial deposits

Qac — **Colluvium and alluvium, undivided (Holocene to upper Pleistocene)** — Poorly consolidated, poorly sorted and stratified, fine-to coarse-grained, clast- and matrix-supported deposits derived from a variety of mass-movement hill-slope processes, including debris flow, shallow slump and creep, overlying and interfingering with tributary alluvium at intermediate inset terrace levels. Clasts are typically rounded to subangular pebbles and cobbles reworked from bedrock and older Quaternary units. Colluvium is common on hillslopes and grades downslope to alluvium; both are dissected; thickness ranges from less than 1 m to 5 m.

Alluvial aprons and fans from the Los Pinos Mountains

Qfp — **Alluvium deposited on fans debouching from the Los Pinos Mountains, undivided (upper Holocene to upper Pleistocene)** — Poorly to moderately sorted, unconsolidated pebble to cobble alluvium and fine- to coarse-grained sand with local accumulations of cobbles and small boulders in longitudinal bars, and silt and clay in longitudinal areas of low slope. Includes both active broad shallow channels and interchannel areas. Also includes "whalebacks" of elevated alluvium of older fan remnants. Historic channels lack soils, while inter-channel highs exhibit incipient soils. Higher interfluves exhibit stage I-II pedogenic carbonate horizons. Deposits range from at least 1.5 m to more than 7 m thick and may be hundreds of meters thick in the subsurface. The large fans of Sepultura and Bootleg Canyons are delineated separately to illustrate their elongate shapes extending into the southern Albuquerque basin.

Qfi — **Interfan small alluvial aprons from small drainages along the Los Pinos Mountain front (upper Holocene to upper Pleistocene)** — Poorly to moderately sorted, unconsolidated pebble to cobble alluvium and fine- to coarse-grained sand with local accumulations of cobbles and small boulders in longitudinal bars, and silt and clay in longitudinal areas of low slope. Includes both active broad shallow channels and interchannel areas. Also includes "whalebacks" of elevated older Pleistocene alluvium of older fan remnants jutting a few meters above Holocene channels and inter-channel alluvium and eolian deposits. Thicknesses similar to *Qfp*.

Qfm — **Elevated alluvium and eolian sand and silt previously deposited on medial to distal fan positions debouching from the Los Pinos Mountains, undivided (upper Pleistocene)** — Poorly to moderately sorted, unconsolidated pebble to cobble alluvium and fine- to coarse-grained sand with local accumulations of pebbles and cobbles in longitudinal bars, and silt and clay in longitudinal areas of low slope. Includes low-gradient, broad shallow swales and inter-swale uplands. Also includes "whalebacks" of elevated alluvium of even older fan remnants. Higher interfluves exhibit stage I-II pedogenic carbonate horizons. Deposits range from at least 1.5 m to more than 7 m thick and may be hundreds of meters thick in the subsurface.

Santa Fe Group

Qsx — **Sierra Ladrones Formation, axial-fluvial deposits (upper Santa Fe Group, lower Pleistocene)** — Gravels contain abundant volcanic rocks (~40%), granite (25%), rounded orthoquartzite (20%) and polished rounded chert (15%) and differ in composition from the subangular, locally derived clasts of the distal Palo Duro fan facies. The most distinctive clasts are obsidians from Rabbit Mountain (Jemez Mountains; 1.4 Ma) and Grants (East Grants Ridge, 3 Ma). The unit is poorly exposed. Unit is 0-4 m thick.

Qsfl — **Sierra Ladrones Formation, fan deposits from drainage off limestone cuestas of SW Los Pinos Mountains (upper Santa Fe Group, lower Pleistocene)** — Pale gray (10YR 7/1 to 8/1) poorly consolidated, uncemented, poorly sorted proximal to moderately sorted distal fan deposits. Overlies and interfingers with *Qsfp* deposits to west. Clasts are all limestone and chert from the Gray Mesa Formation. Pedogenic carbonate horizon reaches Stage II. Fan is deeply incised by drainage to Palo Duro Canyon on the southwest side, and is moderately incised by drainages to the northeast. Includes more than one surface level in proximal part of fan and base is on gray limestone of cuesta. Distal parts of fan are largely eolian sand with clasts of limestone. Thickness reaches 10 m exposed in canyon.

Qsfp — **Sierra Ladrones Formation, coarse-grained fan deposits spread by ancestral Palo Duro drainage (upper Santa Fe Group, lower Pleistocene)** — Pink to reddish-yellow (7.5YR 6/6-7/3), poorly consolidated, uncemented to locally well cemented, poorly to moderately sorted conglomerate and pebbly sand. Bedding follows planar, west and northwestward sloping upper surfaces with extensive desert pavement; clasts include subangular to subrounded pebbles to boulders of rocks from the southern Los Pinos Mountains, including granite, granite gneiss, amphibolite, metarhyolite, quartzite, sandstone, limestone, basalt, basaltic andesite, and rhyolite; scoured basal contact with underlying finer-grained deposits and older bedrock. Basalt clasts from Black Mesa basalt flow to southeast (K-Ar age of 3.54 ± 0.17 Ma; Meyers *et al.* 1986) range in diameter to more than 1 m. Map unit is inset below older fan deposits (*Tsfp* and *Qsfpo*), and locally exhibits terrace-like benches. At distal edges of fan, overlies top of axial fluvial deposits of ancestral Rio Grande locally. Thickness ranges up to 10 m.

Photo 1. Exposure of Sierra Ladrones Formation, Palo Duro fan deposits (*Qsfp*) along northern edge of Palo Duro Canyon. Note stack of two cobble-gravel channels within finer-grained deposits, buried well-developed stage III soil, and stage III-IV calcic soil horizon at the surface. Shovel on upper left surface is 1 m long for scale. View is to north-northeast from 341162E 3799990N (all UTM coordinates are NAD27 13S).

Qsfpo — **Sierra Ladrones Formation, elevated remnants of coarse-grained fan deposits spread by ancestral Palo Duro drainage (upper Santa Fe Group, lower Pleistocene)** — Pink to reddish-yellow (7.5YR 6/6-7/3), poorly consolidated, uncemented to locally well cemented, poorly to moderately sorted conglomerate and pebbly sand. Surfaces exhibit degraded and brecciated petrocalcic blocks with local desert pavement; clasts include subangular to subrounded pebbles to boulders of rocks from the southern Los Pinos Mountains, including granite, granite gneiss, amphibolite, metarhyolite, quartzite, sandstone, limestone, basalt, basaltic andesite, and rhyolite; basal contact with underlying finer-grained deposits and older bedrock is not exposed. Map unit is inset below older fan deposits (*Tsfp*). Thickness estimated from elevations above surrounding *Qsfp* on the order of a few meters.

QTsps — **Sierra Ladrones Formation, sandstone- and mudstone-dominated piedmont deposits (upper Santa Fe Group, lower Pleistocene to Pliocene)** — Reddish-yellow (5YR 6/6), unconsolidated to poorly consolidated, uncemented to cemented, mudstones and sandstones with moderately sorted tabular sandstone with scattered, irregular pebbly sandstone and conglomeratic sandstone lenses exposed along Palo Duro Canyon west of "Five Points." Beds commonly form upward-fining sequences with a basal conglomerate that fines upward into sand and mud that is locally capped by calcic paleosols, thin rhizoconcretionary beds, and cemented tufa-like spring-groundwater-precipitated deposits. Sandstone beds tend to comprise less than 30% of the unit. Thickness ranges from 0 to more than 20 m.

Tsfp — **Sierra Ladrones Formation, elevated remnants of coarse-grained fan deposits spread by ancestral Palo Duro drainage (upper Santa Fe Group, lower Pliocene)** — Pink to reddish-yellow (7.5YR 6/6-7/3), poorly consolidated, locally well cemented, poorly to moderately sorted conglomerate and pebbly sand. Surfaces exhibit degraded but thick brecciated petrocalcic blocks with local desert pavement; surface called the "Pino Surface" by Treadwell (1996) and Bryan-Ricketts (2011); clasts include subangular to subrounded pebbles to boulders of rocks from the southern Los Pinos Mountains, including granite, granite gneiss, amphibolite, metarhyolite, quartzite, red Permian sandstones, and gray limestones, but NO basalt, basaltic andesite, or rhyolite. The lack of 3.51-Ma basalt clasts and the stage V-VI petrocalcic horizon at the surface suggest that this deposit is older than 3.5 Ma. Basal contact with underlying older bedrock is exposed along the north side of Palo Duro Canyon near "Five Points" where the thickness estimated to be approximately 10 m. Small exposures of Miocene Popotosa Formation with clasts of basaltic andesite and ash-flow tuffs exposed on divides between Palo Duro and Cibola Canyons are lumped into this unit.

Tp — **Popotosa Formation, faulted conglomerate and pebbly sandstone as paleovalley-fill trending south-southwest (Santa Fe Group, Miocene)** — Gray to pale tan conglomerate containing boulder-cobble-sized clasts of ashflow tuffs, basaltic andesite, granite, and Paleozoic-Mesozoic sandstones and limestones. Upper surface exhibits degraded but thick brecciated petrocalcic blocks with partially dissolved boulders and cobbles of limestone. West side of paleovalley is cut through 15 m of Morrison Formation; east side is a normal fault against Triassic Moenkopi Formation. Ashflow-tuff clasts indicate a source not from the southern Los Pinos Mountains, but perhaps from outliers similar to Turututu to the north. The thickness estimated to be approximately 15 m.

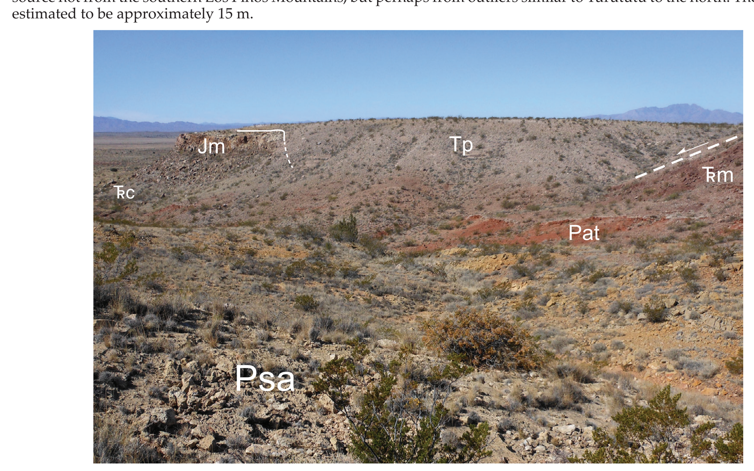


Photo 2. Stratigraphic sequence of lower Permian San Andres Formation (*Psa*) and Artesia Group (*Pat*), overlain by Triassic Moenkopi Formation (*Ꞧm*). West of a fault buried in the valley, the lower part of the Triassic Chinle Formation (*Ꞧc*) overlies the Moenkopi Formation, and is overlain by sandstones and mudstones of the Morrison Formation (*Jm*). The sandstone cliff of Morrison Formation forms the west side of a paleovalley approximately 15 m deep backfilled by Miocene Popotosa Formation (*Tp*). The upper surface of the Popotosa Formation developed a thick petrocalcic horizon with deeply corroded limestone cobbles and boulders. View to west-northwest from 342975E 3796392N.

Paleogene

Tlp — **La Jara Peak Basaltic Andesite, (probably tongue 5, upper Oligocene)** — Mostly medium gray to purplish gray, massive and platy to vesicular basaltic andesite lavas characterized by moderately abundant (5–10%) fine- to medium-grained phenocrysts of olivine, usually altered to reddish brown iddingsite. Phenocrystic plagioclase is typically absent. Thin flows (3-6 m) commonly exhibit vesicular tops and reddish basal breccia zones. *Tlp* at the top of Turututu (Black Butte, 4 km north of the quadrangle) rests on three tuffs in stratigraphic order and has a K-Ar age of 24.3 ±1.3 Ma (Bachman and Mehnert, 1978). Maximum thickness is 13 m.

Ttr — **Rhyolitic tuffs beneath Tlp (Oligocene)** — Poorly exposed beneath *Tlp* on butte in northwest corner of quadrangle; where exposed north and west of quadrangle, tuffs includeVicks Peak Tuff (17-20 m), La Jencia Tuff (13 m) and Hells Mesa Tuff (> 12 m) (28.4, 28.7, and 32 Ma $^{40}Ar/^{39}Ar$ ages respectively; Chapin *et al.*, 2004) — Vicks Peak Tuff: densely welded, brown to light brownish gray and light gray, phenocryst poor, pumiceous, rhyolite ignimbrite. Pervasive well developed compaction foliation, and large "sandy" (vapor phase) pumice lapilli up to 30 cm long. La Jencia Tuff: densely welded light gray, pale red and grayish red, phenocryst poor, rhyolite ignimbrite. Contains sparse (3–5%) phenocrysts of sanidine and quartz with rare plagioclase and biotite. Hells Mesa Tuff: Pale reddish gray to light gray, mostly densely welded, phenocryst-rich (40–50%), quartz-rich, rhyolite ignimbrite. Typically contains abundant medium grained (1–3 mm) phenocrysts of sanidine, plagioclase, quartz and minor biotite. Quartz is minor component (1-2%) in thin basal zone (not exposed here). [Description modified from William McIntosh, written communication, 1 April 2013]

Tib — **Basaltic andesite dikes (Oligocene)** — Medium to dark gray, olive gray, or dusky yellow basaltic andesite dikes; commonly aphyric (lack phenocrysts) or contain sparse (2-5%) micro-phenocrysts (< 1mm) of greenish olivine. Olivine is often altered to reddish-brown iddingsite. Some mafic dikes contain sparse small crystals of black pyroxene and traces of plagioclase.

Tim — **Mafic sills and dikes (Oligocene)** — Medium gray, locally mottled to light gray, greenish gray, or purplish gray mafic sills and dikes. Contain ~ 5% fine-grained (0.5-1 mm) black pyroxene in a felted matrix of plagioclase microlites. Sills range in thickness from 1 m to 100 m.

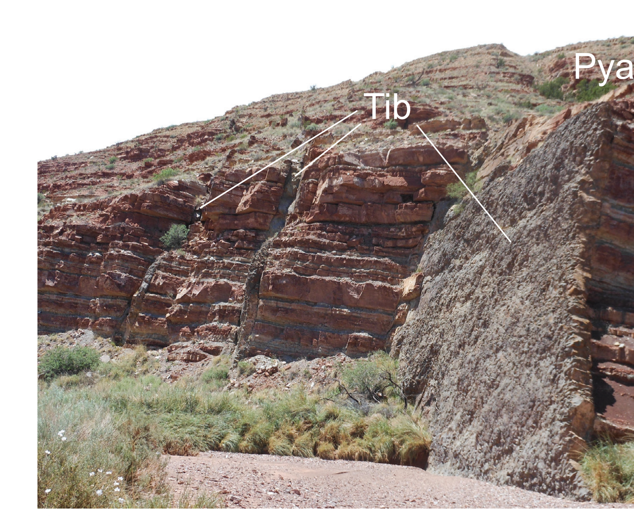


Photo 3. Mid-Cenozoic mafic dikes intruding Permian Arroyo de Alamillo Formation (*Pyaa*); view to southwest from Cibola Canyon drainage (341905E 3791576N). Note that dikes are resistant to erosion at stream level but weather more than enclosing sandstones higher on slopes.

Tsp — **Spears Formation (upper Eocene)** — Light gray and light brownish gray volcaniclastic conglomerates, sandstones, siltstones and reddish mudstones derived from intermediate-composition volcanic highlands, primarily to southwest of Joyita Hills, with auxiliary local sources. Subrounded to subangular dacite and andestite porphyry clasts range from boulders to pebbles; they are common in lenticular to tabular 1-3m thick conglomeratic beds. Dacitic clasts are characterized by sparse to abundant phenocrysts of plagioclase, hornblende and biotite; andesitic clasts are typically plagioclase-pyroxene porphyries. Matrix-supported clasts are common and indicate deposition as debris flows or hyper-concentrated mud flows. Sparse cobbles and pebbles of gray limestone and red siltstone locally occur in basal conglomerates (lowest 30 m), particularly where they overlie Permian San Andres outcrops on the La Joya quadrangle to the west (de Moor *et al.*, 2005).

Tspa — **Andesitic lava within Spears Formation** — Medium gray and purplish gray andesite exposed in small area within *Tsp*.

MESOZOIC

Cretaceous

Ku — **Cretaceous (undivided) (Upper Cretaceous)** — Because of the small size of surface exposures in the map area and possible structural complications, Cretaceous rocks are not subdivided on the map. The Cretaceous rocks were deposited within and in proximity to the Western Interior Seaway of North America during three major transgressive-regressive cycles (see Hook, 1983; Hook *et al.*, 2012, for summary papers). Strata include fossiliferous marine sandstone, shale and minor limestone, as well as non-marine clastic deposits. Shale units are poorly exposed in the Becker SW quadrangle; sandstones are generally fine grained and weather pale gray to yellowish and brownish gray, commonly with iron-oxide staining. The Cretaceous System in the area includes, in ascending order, the main body of the Dakota Sandstone (~20 m thick just to the south of the quadrangle; see also Hook and Cobban, 2007), lower part of the Mancos Shale (~ 160 m), Tres Hermanos Formation (~ 73 m), D-Cross Tongue of the Mancos Shale (~ 61 m), Gallup Sandstone (~ 42 m), and the Crevasse Canyon Formation (~ 28 m) (thickness of units are from a composite section for Sevilleta National Wildlife Refuge by Hook *et al.*, 2012, Fig. 6). Thus, the Cretaceous System in the area is on the order of 403 m thick. The small exposures of Cretaceous sandstone that are present in the map area are Dakota Sandstone, Tres Hermanos Formation, Gallup Sandstone, and sands within the Mulatto Tongue of the Mancos Formation, which together bracket the three major Late Cretaceous transgressive-regressive eustatic cycles in the region.

Jurassic

Jm — **Morrison Formation (Upper Jurassic)** — Fine- to medium-grained litharenite and intercalated greenish mudstone to sandy siltstone. Sandstones (some multi-story) generally weather dark brown to yellowish brown in blocky ledges, are typically planar-laminated or cross-bedded, and locally include pebble conglomerate in channels, and silicified fossil wood. Conglomerates locally contain an abundance of limestone clasts. Mudstone intervals are typically greenish-gray and covered. Hayden *et al.* (1990) suggested that the Morrison Formation is probably present in the map area; based on the lithology, stratigraphic position, and overall appearance of the deposits in comparison with other Morrison outcrops in central New Mexico, assignment to the Morrison Formation for these rocks is reasonable. Exposures in cuestas south of Gibbs Place suggest thicknesses of at least 60 m.

Triassic

Ꞧc — **Chinle Group (undivided; Upper Triassic)** — Upper Triassic rocks in the region include the basal Shinarump and the overlying San Pedro Arroyo formations of the Chinle Group (see Lucas [1991] for a summary of Triassic stratigraphy in south-central New Mexico). Only two small outcrops of probable Shinarump strata, less than 2 m thick, were encountered during mapping; therefore, the Chinle Group is not subdivided on the map. The small outcrops of Shinarump that were encountered include fine- to coarse-grained, pale yellowish gray conglomeratic sandstone with a preponderance of well-rounded, silica (chert, quartzite) pebbles up to a few centimeters in diameter. The San Pedro Arroyo Formation consists of reddish-brown to purplish-gray and greenish mudstone and shale (with some bentonitic layers), lesser siltstone, limestone, and minor reddish-brown sandstone. Pebble-conglomerate sands containing an abundance of limestone clasts were observed in a few small outcrops. The distinctive Ojo Huelos Member of the San Pedro Arroyo Formation, characterized by a vertical succession of brown weathering limestone beds up to a few meters thick, and intervening meter-scale intervals of siliciclastic muds that are commonly yellowish to greenish in color, is well represented in the map area. Finer-grained siliciclastic muds in the San Pedro Arroyo formation are generally poorly exposed, whereas limestone beds in the Ojo Huelos Member are resistant and form cuestas and flat outcrops where dips are shallow. In the areas where it is present on the quadrangle, the Chinle Group (except for the limestone beds) is poorly exposed and pervasively folded and faulted, making it difficult to ascertain thicknesses and stratigraphic relations to overlying Jurassic strata. In some areas, it appears that the Morrison Formation is present within a few meters of the top of the highest limestone bed in the Chinle. In other areas it seems possible that a greater thickness of Chinle muds may be present above the Ojo Huelos member. Lucas (1991) measured a total Chinle thickness of about 37 m on the Becker SW quadrangle, but indicates that the top of the section is a fault contact. At the type locality of the San Pedro Arroyo Formation approximately 40 km to the south of the map area, the formation is approximately 120 m thick (Lucas, 1991; Spielmann and Lucas, 2009).

Ꞧm — **Moenkopi Formation (Middle Triassic)** — Ledge-forming deep to pale grayish red crossbedded fine litharenitic sandstone, pebbly sandstone, and mudstone. Fluvial low-angle crossbeds and trough crossbeds are well expressed in cliffs. Hayden *et al*. (1990) measured approximately 60 m of sandstone exposed on the Becker SW quadrangle.

PALEOZOIC

Permian

Pat — **Artesia Group (Middle Permian)** — Yellowish, red, gray, and reddish brown siltstone, gypsiferous quartz-arenitic sandstone, and yellowish brown dolomite. Sandstone beds commonly exhibit ripple-laminated and planar-laminated bedforms. Estimated thickness is 10 to 25 m.

Psa — **San Andres Limestone (Lower Permian)** — The bulk of the San Andres is light-gray, brown-gray to pale orange limestone, with sandy lower beds. Pinkish-gray to grayish orange well sorted fine- to medium-grained quartz sandstone and reddish-brown siltstone near middle. Upper beds are cyclic gypsum and thin black limestone beds approximately 40 m thick. Unit thickness ranges from 70 to 160 m according to Myers *et al.* (1986).

Pg — **Glorieta Sandstone (Lower Permian)** — Cliff forming reddish-brown, grayish-orange, and yellowish-orange, fine- to medium-grained, well cemented, well sorted quartz sandstone. Thickness is about 55 m.

Py — **Yeso Group (Lower Permian)** — Ledge-forming orange sandstone and siltstone; white gypsum; and yellowish-gray dolomite, limestone and gypsiferous sandstone. Subdivided into two formations after Lucas *et al.* (2005).

Pylv — **Los Vallos Formation (combines Joyita, Cañas, and Torres Members)** — Interbedded dolomite, gypsiferous siltstone, gypsum and red-bed siltstone to fine-grained sandstone. Unit is approximately 215 m thick in the vicinity of Palo Duro Canyon (Wilpolt *et al.*, 1946).

Pyaa — **Arroyo de Alamillo Formation (equivalent to Meseta Blanca Member)** — Pinkish red, to pale orange and yellowish siltstone and fine grained sandstone, often gypsiferous and mostly thinly laminated or ripple laminated. Siltstone (mostly massive) is much less common, and there are a few beds of dolomite and gypsum present. Gradationally overlies the Abo Formation. Unit is approximately 65 m thick on the quadrangle (Wilpolt *et al.*, 1946).

Pa — **Abo Formation (Lower Permian)** — Distinctive-brick-red mudstone, fine-grained sandstone and siltstone with minor shale and intraformational conglomerate. Contains some greenish- and reddish-gray fine grained sandstones and characteristic greenish-gray reduction spots and mottling in some beds. Upper part of unit contains numerous sheet-like sandstone bodies. Lower beds are mudstone with lenticular and cross-bedded fine-grained sandstone. The unit is about 125 m thick on the Cerro Montoso quadrangle just the east of the map area (Myers *et al.*,1986).

Pennsylvanian

ℙb — **Bursum Formation (Upper Pennsylvanian to Lower Permian)** — Interstratified red to maroon and greenish gray mudstone and shale, reddish- to yellowish-brown sandstone, gray limestone, and minor intraformational (limestone-clast) conglomerate beds. Unit represents the transition from dominantly marine (Atrasado Fm.) to terrestrial (Abo Fm.) depositional environments. Limestone beds are commonly fossiliferous, and locally contain an abundance of fusulinid foraminifera and red silicified macro-invertebrate remains (*e.g.*, crinoid stems and bivalves). Allen *et al.* (2013) measured approximately 40 m of Bursum Formation just south of the map area.

ℙa — **Atrasado Formation (Upper Pennsylvanian)** — Gray, fossiliferous (normal marine) cliff-forming thin- to thick-bedded limestone and intervening intervals dominated by slope-forming greenish gray to reddish brown siliciclastic mudstone, siltstone, and calcareous shale. Crossbedded and planar laminated silty sandstone to conglomeratic sandstone including thick channel fills several meters thick and extending laterally for hundreds of meters are also common. A few distinctive yellowish-brown dolomitized limestone beds are present. Ongoing work on the Atrasado in central New Mexico by Lucas and others (e.g., Lucas *et al.*, 2009, Fig. 2) identifies 8 stratigraphic members that can be recognized over a widespread area of the state, the lower 6 of which are readily assigned in the map area. Thick algal bioherms and silicified breccia zones in the upper part of the unit locally make the distinction between the upper two limestone-dominated members (Story and Moya members) less certain in the map area. About 240 m thick in the southeastern part of the quadrangle.

ℙgm — **Gray Mesa Formation (Middle Pennsylvanian)** — Cliff-forming cherty, fossiliferous medium- to thick-bedded limestone with minor siliciclastic (calcareous shale and sandstone) interbeds. About 50 m thick on the east edge of the map area, which is relatively thin compared with exposures to the north in the southern Manzano Mountains (Nelson *et al.*, 2013) where the unit is approximately 190 m thick.

ℙs — **Sandia Formation (Middle Pennsylvanian)** — Ledges of gray, reddish brown to greenish gray, and yellowish brown planar laminated and crossbedded sandstone to pebble conglomerate and minor fossiliferous gray to brownish-gray-weathering limestone, and intervening covered slopes of greenish gray, reddish brown, and yellowish mudstone to silty sandy shale. Some sandstone beds contain abundant hematitic fossil woody debris. The deposits are of mixed terrestrial, marginal marine, and marine origin. About 140 m are exposed on the east edge of the map area at the mouth of Sepultura Canyon, which may be close to the maximum thickness of the Sandia Formation in the area.

PROTEROZOIC

Xglp — **Los Pinos Granite (Paleo-proterozoic)** — Rounded exfoliated knobs to steep, cliff and slope-forming pale reddish gray to pink and intense red, massive, medium- to coarse-grained, microcline + orthoclase + quartz + albite granite in Los Pinos Mountains and in western outlier (*Xglp?* - unkown if derived from same pluton). Simple pegmatite dikes of similar composition are common, but pale aplite dikes are uncommon. The south end of the outlier in the NW corner of the quadrangle consists of breccia of granite, granite gneiss, and amphibolite in blocks up to one meter in diameter. Present top of this exposure contains "cupolas" 3-25 m across and up to 6 m high of intensely metasomatized red granite and pegmatite. Cut by siliceous veins with barite, fluorite, and copper-carbonate mineralization, and later cut by iron-manganese oxide veins and partially filled fissures. In cross-sections, all Proterozoic labeled as "X." Los Pinos Mountains granite yielded radiometric ages of 1653 to 1658 million years (Karlstrom *et al.*, 2004).

GEOLOGIC CROSS SECTIONS