Geologic Map of the Becker SW Quadrangle, Socorro County, New Mexico

By

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

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Open-file Digital Geologic Map OF-GM 233

Scale 1:24,000

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New Mexico Bureau of Geology and Mineral Resources
801 Leroy Place, Socorro, New Mexico, 87801-4796

SUMMARY OF GEOLOGY OF BECKER SW 7.5 MINUTE QUADRANGLE, SOCORRO COUNTY, NEW MEXICO

Bruce D. Allen[1], David W. Love[1], David J. McCraw[1], and Alex J. Rinehart[2]

[1]New Mexico Bureau of Geology and Mineral Resources, New Mexico Institute of Mining and Technology, Socorro. June 2012.

[2]Earth and Environmental Science Department, New Mexico Institute of Mining and Technology, Socorro, NM 87801

The Becker SW 7.5-minute quadrangle straddles the southeastern edge of the Albuquerque Basin of the Rio Grande rift. The southeastern corner of the quadrangle includes the tilted uplift of the Los Pinos Mountains with Mesoproterozoic Los Pinos granite overlain by south-dipping cuestas of Pennsylvanian and Permian rocks. The Palo Duro and Cibola drainages have cut across faulted and deformed Paleozoic and Mesozoic sedimentary rocks in the southern and west-central parts of the quadrangle. The northern half of the map is dominated by north-directed fans from the Los Pinos Mountains and from the Palo Duro drainage debouching from the southern Los Pinos Mountains. The southwestern corner of the map is planar Quaternary alluvium covering eroded Cretaceous and other Mesozoic sedimentary rocks. The Paleozoic and Mesozoic sedimentary rocks are cut by dikes and sills of mid-Cenozoic basaltic and andesitic rocks. The northwestern corner of the map includes an outlier of Los Pinos granite and another small outlier of Oligocene ashflow tuffs capped by La Jara Peak basaltic andesite, both surrounded by Santa Fe Group distal-fan sediments and a thin wedge of ancestral Rio Grande pebbly sand.

The Paleozoic section consists of Pennsylvanian Sandia, Gray Mesa, Atrasado, and Bursum formations, and Permian Abo, Yeso, Glorieta, San Andres, and Artesia strata. Good exposures of each of these rock units invite further research on stratigraphy, depositional environments, and paleontology. The type section of the Torres Member of the Los Vallos Formation in the Yeso Group is in this quadrangle. The top of the San Andres Formation includes an extensive unit of cyclic gypsum and dark limestone-dolostone carbonates. The overlying Artesia Formation locally includes red and yellow dolostones, mudstones, and sandstones, and gypsum.

The Mesozoic section consists of Triassic Moenkopi Formation and Chinle Group, the Jurassic Morrison Formation (probably Salt Wash Member), and several Cretaceous formations. In most exposures, the Chinle Group was eroded down to the Ojo Huelos Member (limestone and chert) before the overlying Morrison Formation was deposited, but in at least one local area, thicker exposures of Chinle Cañon Agua Buena Member include channels of pedogenic-limestone-clast conglomerate in red mudstone. Although exposures of Cretaceous strata are small, rocks representing all three major Late Cretaceous transgressive-regressive eustatic sea-level cycles are present.

Mid-Cenozoic strata include Eocene-Oligocene volcaniclastic Spears Formation and an interbedded andesitic lava flow, welded ashflow tuffs from calderas to the southwest, and La Jara Peak basaltic andesite. Related to the mid-Cenozoic volcanic rocks are intrusive sills and dikes. Small, unmapped exposures of easternmost Popotosa Formation volcaniclastic conglomerates fill a paleocanyon and form a topographically high landscape position on a stream divide.

Neogene Santa Fe Group deposits consist of several levels of basin fill and alluvium as fans from the east. At least four levels of fans debouch northward from the Palo Duro drainage. The oldest coarse gravel deposit contains no 3.51-Ma basalt (the age for the Black Mesa basalt reported by Myers et al. 1986) and has a thick and degraded Stage V-VI petrocalcic horizon at the surface, suggesting an early Pliocene age (Treadwell 1996). Inset below that are fan levels that include basalt from the southeast (Black Mesa basalt), and terrace levels within Palo Duro and Cibola Canyons. Ancestral Rio Grande gravels reached the northwestern part of the quadrangle and interfingered with fans from the Palo Duro drainage before it incised. Clasts of obsidian from Rabbit Mountain (Jemez Mountains) show that the river deposits are younger than 1.4 Ma and predate incision of the modern Rio Grande valley 10 km to the west. The valley bottoms of both major drainages and many minor drainages and swales consist of mostly fine-grained (sand, silt, clay) Holocene-Late Pleistocene alluvium.

Despite the quadrangle's position on the rift flank, only one fault appears to offset early Quaternary deposits. The rest of the faults and other deformation appear to be related to earlier episodes of tectonic history, including early rifting, Laramide folding and faulting, and Ancestral Rockies faulting, uplift, and subsidence. As noted by earlier workers, Ancestral Rocky Mountain deformation is evident within Pennsylvanian units. One episode appears to have included silicification and barite-fluorite mineralization of the Atrasado limestone before Bursum deposition. Many of the faults deform the thick gypsum sections of the Yeso, San Andres, and Artesia units. The resistant limestones of the Atrasado and San Andres Formations make faulted, monoclinal cuestas as en echelon steps from southeast to northwest across the area. North-south grabens preserve younger strata west of each moncline. Sills within the faulted Paleozoic strata complicate the deformation pattern. As indicated above, the two bedrock outliers in the northwestern part of the quadrangle are the basaltic andesite/tuffs and the Proterozoic granite.

Although faulted boundaries must exist at depth, faults do not cut the overlying Santa Fe and post-Santa Fe Group sediments. Previous workers have suggested that these outliers belong to the repeatedly deformed Joyita Hills tectonic block(s) to the southwest. Laramide and rift-related faults cut the Mesozoic and mid-Cenozoic units, commonly in narrow north-trending grabens between broader folds. For example, in the west-central edge of the map in Palo Duro Canyon, a small graben contains a sliver of Spears volcaniclastic rocks sandwiched between two Cretaceous outcrops, and overlain by a Quaternary valley-border colluvial wedge.

Rather than being cut by young normal faults of the Albuquerque structural basin, the Becker SW area appears to have been uplifted and eroded in the southern part of the quadrangle, and tilted northward via subsidence to the north and northeast. Tilting via uplift (south) and subsidence (northwest) explains the paucity of preserved early Quaternary fan deposits south of Palo Duro Canyon, versus extensive northwest-directed fans north of the canyon, including those fans from the central Los Pinos Mountains. Subsidence to the northwest also could explain the northwestward paths of all drainages from this area to the Rio Grande. Off-quadrangle, they all approach the modern Rio Grande valley in an upstream orientation, rather than the typical downstream-directed orientation of most stream junctions.

Becker SW 7.5' Quadrangle Description of Map Units

NEOGENE

QUATERNARY

Alluvium
Qat Modern channel deposits in thalwegs of large drainages — 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 m 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.

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.

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 (3-6m) 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.

Tims 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.

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 CRETACEOUS

K 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

TRc 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).

TRm 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.

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 Mbrs) –** 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 Mbr) –** 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 Montosa quadrangle just the east of the map area (Myers et al.1986).

PENNSYLVANIAN

lPb 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.

lPa 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.

lPgm 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.

lPs 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 (Paleoproterozoic) – 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. 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 "Y." Los Pinos Mountains granite yielded radiometric ages of 1653 to 1658 million years (Karlstrom et al. 2004).

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