Preliminary Geologic Map of the Alamogordo North Quadrangle, Otero County, New Mexico

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Scale 1:24,000

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

PRELIMINARY GEOLOGIC MAP OF THE ALAMOGORDO NORTH 7.5-MINUTE QUADRANGLE, OTERO COUNTY, NEW MEXICO

BY

DANIEL J. KONING[1], BEN HALLETT[2], AND COLIN SHAW[3]

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[1] New Mexico Bureau of Geology and Mineral Resources, New Mexico Tech, 801 Leroy Place, Socorro, NM 87801-4796; dkoning@nmt.edu

[2] 4801 San Mateo Lane, NE, Apt. 178, Albuquerque, NM 87109

[3] Department of Earth Sciences, Montana State University, Bozeman, MT 59717

INTRODUCTION

The Alamogordo North 7.5-minute quadrangle encompasses the western front of the Sacramento Mountains in its eastern half and gravelly alluvial fans in its western half. The alluvial fans slope less than 1.4° to the west and grade westward into basin floor deposits composed largely of fine sand, silt, and clay. The mountains on this quadrangle are less than 7,000 ft (~2100 m) in elevation. Prominent canyons that drain the western flanks of the mountains and which feed sediment to the alluvial fans include (from south to north): Marble Canyon, Beeman Canyon, Dry Canyon, La Luz Canyon (Fresnal Canyon branches southward from the latter), and Cottonwood Canyon. With the exception of La Luz Canyon and local springs in Cottonwood Canyon, these drainages lack surface water flow for most of the year.

Alamogordo is located in the southern part of the quadrangle, where the mountain front curves eastward 2-3 km to form a reentrant. This city of approximately 35,000 people (Alamogordo Chamber of Commerce web page, May-2007) overlies relatively small alluvial fan deposits located between the larger alluvial fans associated with Alamo Canyon (off the quadrangle to the south) and Dry Canyon. The charming town of La Luz lies immediately south of La Luz Creek at the mouth of La Luz Canyon. Outside of these towns, there are low-density dwellings scattered across the basin floor and alluvial fans. In the mountains are residences in Burro Flats (northeast quadrangle corner) and along Fresnal Canyon.

The climate is relatively dry, particularly on the basin floor where annual precipitation averages about 20-28 cm per year (8-11 inches) (Houghton, 1981). Up to 64 cm (25 inches) can be expected in the higher parts of the Sacramento Mountains (Mclean, 1970), with values steadily decreasing towards the basin floor. Most of the precipitation occurs in the late summer and early fall via convective storms. Most days from mid-May to mid-September are hot (32 degrees C (90 degree F) or higher); the average number of days with freezing temperature ranges from 80-100 per year (Houghton, 1981). Mean temperature is 14-17 degrees C (58-62 degrees F) (Houghton, 1981). The wind generally blows from the west or southwest. In late winter and spring, these winds may carry considerable dust due to relatively dry conditions (Houghton, 1981).

Chihuahuan Desert vegetation thrives on the quadrangle. Above 5500-6000 ft (1670-1800 m) elevation are sparse stands of juniper and pinon trees. Below this elevation is largely creosote and grasses. On the proximal alluvial fans, mesquite and creosote may be quite dense, particularly near Alamogordo. The vegetation density of these shrubs decreases from the proximal to the distal alluvial fans and basin floor deposits.

After a brief discussion of previous work done in the area, we present the unit descriptions for the Alamogordo North 7.5-minute quadrangle, New Mexico. The area mapped by the respective authors is shown in Figure 1. Figure 2 depicts the age relations of the units described below.

PREVIOUS WORK

Lloyd Pray (1961) conducted what many consider to be the definitive study of Sacramento Mountain geology. Much of our mapping in the mountain block consisted of field-checking his line work and mapping his contacts at a more detailed scale. To the north, Otte (1959) studied Late Pennsylvania and Early Permian strata. Studies of the dikes and sills on this quadrangle include Asquith (1974) and McManus and McMillan (2002). Relative to overall basin structure, Howell et al. (2002) concluded that transpression occurred along major north-south faults in the area during Ancestral Rocky Mountain tectonic events. Herrick (1904) was the first to hypothesize that the Tularosa Basin was a down-dropped fault block. Concurring, Meinzer and Hare (1915) noted that the top of the Paleozoic bedrock was buried to great depths between the Tres Hermanos Hills southwest of Alamogordo and the Sacramento Mountains. Both Pray (1961) and Otte (1950) recognized that the Sacramento Mountains were uplifted along a range-bounding fault zone (i.e., the Alamogordo fault). Significant studies that interpret depth-to-bedrock under basin fill include Mclean (1970), Healy et al. (1978), Orr and Myers (1986), and Lanka (1995). Kelley and Chapin (1997) concluded that significant uplift of the Sacramento Mountains during the late Cenozoic was consistent with apatite-fission track data. Machette (1987), Koning (1999), and Koning and Pazzaglia (2002) conducted detailed studies of the Alamogordo fault.

DESCRIPTION OF MAP UNITS

QUATERNARY UNIT DESCRIPTIONS

The Quaternary units on this quadrangle are found in three topographic positions: on the flat basin floor in the southwestern part of the quadrangle, on alluvial fans flanking the Sacramento Mountains in the center of the quadrangle, and in canyons that have incised into the Sacramento Mountains in the eastern part of the quadrangle. Colluvial deposits were mapped where recognized along the Alamogordo fault scarp and in the mountains where it is extensive, greater than 1 m-thick, and obscures underlying bedrock units.

Observations in extensive and deep arroyo exposures (Figures 3-4) on this quadrangle justify refinement of the initial Quaternary alluvial fan stratigraphic nomenclature of Koning (1999) and Koning et al. (2002). **Qf1** remains as it was originally defined by these earlier works (Table 1). **Qfi** is applied to a buried, generally fine-grained alluvium about 1 m-thick overprinted by significant buried soils marked by illuviated clay (Bt soil horizons); this unit is not exposed sufficiently to depict on this scale of mapping. Coarse alluvial fan aggradation seems to have occurred from 9 ka through approximately 4 ka; we correlate deposits associated with this coarse aggradation to unit **Qf2**. **Qf2** can locally be differentiated into two subunits: **Qf2a** and **Qf2b**. **Qf2a** is interpreted as the approximate initial top of the coarse-grained aggradation (early to middle Holocene). Subsequently, net erosion over much of the alluvial fans has resulted in broad, younger erosional surfaces developed on the older Qf2 deposit. Qf2 is differentiated as **Qf2b** under these erosional surfaces. **Qf3** is assigned to relatively younger fill deposits that have aggraded in slightly lower areas on the medial to proximal alluvial fans. **Qf3** becomes more extensive on the distal parts of the alluvial fan, where it grades westward with fine-grained basin-floor deposits (**Qbf**). **Qah** is probable historical alluvium (50-200? years) and **Qam** is designated for alluvium interpreted to have been fluvially reworked over the past 50 years.

These units were mapped by field traverses and aerial photography (photos taken by BLM in 1975 and by the U.S. Forest Service in 1975). Initial work consisted of mapping representative parts of the alluvial fans with a hand-held GPS unit and using the 20-ft contours on the published topographic map. This preliminary map was then utilized in identifying and mapping units using aerial photography. Mapping from aerial photographs using the PG-2 plotter at the U.S. Geological Survey in Denver has resulted in a higher quality of precision compared to earlier mapping of Koning (1999). Linework from the aerial photographic-based mapping was then field-checked during subsequent field visits to the quadrangle. However, time and fiduciary constraints mean that we could only field-check perhaps two-thirds of the map polygons on the alluvial fans. We were able to field-check most of the terrace deposits in the mountains (except for those along Cottonwood Wash and those in La Luz Canyon upstream from Fresnal Canyon). In the field-checking process, we found there was an approximate 10-20% error in map unit identification using the aerial photographs between units **Qf1** and **Qf2** and between units **Qf2** and **Qf3**. Unit **Qf1** was not misidentified as **Qf3**. Consequently, the user should assume that there is a potential 10-20% error in the identification of the Quaternary map units. Some areas of the alluvial fan have two or more units that cannot be practically differentiated at a scale of 1:24000. In such cases, we use nomenclature reflecting a combination of units (e.g., Qf2-Qf3). Otherwise, we interpret ≤10% of other units present within a single-named unit. For example, in a map unit labeled “**Qf1**” we interpret ≤10% of other map units, such as **Qf2** or **Qf3**, within that mapped polygon.

A brief discussion is warranted on the difference between lithostratigraphic and allostratigraphic units. Unit **Qbf** is a lithostratigraphic map unit. That is, this unit can be identified solely by its sedimentologic and other physical characteristics. However, the rest of the Quaternary map units are more aptly described as allostratigraphic units with some lithostratigraphic differences. Allostratigraphic units are separated and defined by unconformities (i.e., there are significant time gaps in the deposition of the various units). Although there are lithostratigraphic differences present between the alluvial fan units (**Qf1**, **Qf2**, and **Qf3**), which are noted below, in places one would be hard-pressed to identify one of these units based solely on their sedimentologic characteristics (particularly units Qf2 versus Qf3 near the mountain-front). Rather, features relating to the unconformities between the units are generally needed to identify them, such as soil development properties and surface characteristics.

Grain sizes follow the Udden-Wentworth scale for clastic sediments (Udden, 1914; Wentworth, 1922) and are based on field estimates. Pebbles are subdivided as shown in Compton (1985). The term “clast(s)” refers to the grain size fraction greater than 2 mm in diameter. Descriptions of bedding thickness follow Ingram (1954). Colors of sediment are based on visual comparison of dry samples to the Munsell Soil Color Charts (Munsell Color, 1994). Surficial units are only delineated on the map if estimated to be at least 0.5 m thick. Soil horizon designations and descriptive terms follow those of the Soil Survey Staff (1992), Birkeland et al. (1991), and Birkeland (1999). Stages of pedogenic calcium carbonate morphology follow those of Gile et al. (1966) and Birkeland (1999). Because both calcic and gypsum often accumulate together in a given soil horizon on this quadrangle, we use the term “apparent carbonate morphology” to indicate that gypsum accumulation is influencing the determination of the carbonate stage. Discussion of a unit's age control is presented in the accompanying report.

Unless otherwise noted below, Quaternary gravel on this quadrangle consists of limestone and possible dolomite with 1-10% sandstone and siltstone clasts, 1-5% Tertiary igneous rocks (unit Ti), and trace-3% chert. Sand is subrounded to subangular. Medium to very coarse sand has a composition consistent with a litharenite, whereas very fine- to fine-grained sand is more arkosic (as inferred using a hand lens).

COLLUVIUM, SLOPEWASH, AND LANDSLIDES

Qce **Colluvium incorporating reworked eolian sediment (Holocene) –** Angular, locally derived pebbles and minor cobbles in a pink to very pale brown (7.5-10YR 7-8/4) silt and very fine- to fine-grained sand matrix that is highly gypsiferous. Minor medium to very coarse sand. Sand is subrounded to subangular and composed of gypsum, calcite, and limestone; coarse to very coarse sand fraction is all limestone. Estimated 1-5 m-thick.

Qc **Colluvium (upper Pleistocene to Holocene) –** Pink to light brown (7.5YR 7/3-6/4) to gray, massive, matrix-supported, gypsiferous silty-clayey very fine- to fine-grained sand mixed with medium to very coarse sand and gravel in various proportions. Sand is subrounded to angular. Gravel includes pebbles, cobbles, and boulders that are angular to subangular and poorly to very poorly sorted. Unit includes colluvium where recognized below fault scarps (probably more common than shown on the map). Holocene to upper Pleistocene age is inferred based on the position of this colluvium relative to the mountain terrace deposits. Thickness generally 1-5 m.

Qswg **Gyspiferous slopewash (Pleistocene to Holocene) –** Pink to light brown (7.5YR 7/3-6/4) to white to grayish brown (2.5Y 5/2), gypsiferous silt and very fine- to lower-medium-grained sand. Estimate 1-5% upper-medium to very coarse sand and very fine to fine pebbles. Deposit is massive, weakly consolidated, and locally underlain by sandy pebbles to cobbles. Gypsum precipitate, 20-30 cm-thick, may lie on top of the unit. There may be strong, buried gypsic horizons about 10-30 cm-thick. No tight constraints on the age of this unit. Estimated thickness of 2-5 m.

Qc-sw **Both Qc and Qswg deposits are present in broad swales (Holocene) –** See descriptions of these two deposits above.

Qls **Landslide deposits (Pleistocene to possibly Holocene) –** Chaotic, jumbled assemblage of angular gravel (with abundant boulders) in a clayey-silty sand matrix. Color is variable. Moderately consolidated and non-cemented. Age is not known with certainty.

Thickness is highly variable; landslides in lower Dry Canyon appear to attain thicknesses as great as ~ 30 m.

STREAM TERRACE DEPOSITS IN MOUNTAIN CANYONS

Qt3 **Lower stream terrace deposit (late Holocene) –** Sandy gravel terrace deposits inset below the terrace deposits of **Qt2** and **Qt1**. The sandy gravel is clast-supported, commonly imbricated, and in very thin to medium beds. Debris-flows are minor and matrix-supported. Gravel is subrounded to subangular, poorly sorted, and consist of pebbles with 1/3 cobbles and minor boulders of predominately carbonate clasts. Sand is very pale brown to pale brown (10YR 6-7/3), very fine to very coarse-grained, and poorly sorted. Surface has bar and swale topography and a stage I calcic-gypsic soil horizon up to ~ 50 cm-thick. Debris-flow deposits are less common in this unit than in **Qt2**, and the unit does not generally coarsen upwards. Correlates with unit **Qf3** on the alluvial fans and interpreted to have a similar age (see below). Locally, it is possible that this deposit may be a Qt2a or Qt2b deposit with an eroded upper surface. Loose to weakly consolidated and 2 m-thick

Qt2 **Intermediate stream terrace deposit (early to middle Holocene) –** Sandy gravel that generally coarsens upwards. Inset below the **Qt1** terrace deposit. Lower and middle parts of this unit are characterized by stream-flow deposits of clast-supported, imbricated, sandy pebbles and 20% cobbles. Beds are in U-shaped channel-fills or very thin to medium, lenticular to broadly lenticular beds. Gravel are subrounded to subangular and poorly sorted. Sand is pale brown (10YR 6/3), poorly sorted, and fine- to very coarse-grained. Debris-flow beds (typically matrix-supported) are more common in the upper part of the deposit; these contain abundant cobbles and boulders. Like on the alluvial fans, locally two surfaces have developed on this deposit, described below. This deposit is generally coarser-grained than **Qt1**. 2-3 m-thick.

Qt2a **Intermediate stream terrace deposit where approximate original aggradational surface is preserved –**Surface lacks bar and swale topography, has a desert pavement, and its topsoil has a calcic-gypsic horizon possessing an apparent stage I+ to II carbonate morphology. Correlates with unit **Qf2a** on the alluvial fans and inferred to have a similar age (see below). 2-3 m thick.

Qt2b **Intermediate stream terrace deposit with a significantly eroded surface –** Same deposit as unit **Qt2a**, but commonly has a lag of boulders on its surface due to erosion of the upper sediment of the initial **Qt2** deposit. Surface is marked by these boulders, bar and swale topography, and the presence of an apparent stage I+ calcic-gypsic soil horizon. Correlates with unit **Qf2b** on the alluvial fans and inferred to have a similar age (see below). About 2 m-thick.

Qt1: **Higher stream terrace deposit (middle to late Pleistocene) –** Sandy gravel in thick terrace deposits. Sediment is generally clast-supported and consists of pebbles, cobbles, and minor boulders. Beds are medium to thick and lenticular to broadly lenticular to tabular. About 10% of the beds have abundant silty-clayey fine sand mixed with gravel that includes boulders (both clast- and matrix-supported); these are probably debris-flow deposits. Gravel is subrounded to subangular and poorly sorted. Sand is light gray to light yellowish brown (2.5Y 6/3-7/2) to light brown to pink (7.5YR 6/3-4 and 7/4), very fine- to very coarse-grained (mostly coarse- to very coarse-grained), and poorly sorted. Locally, the sand is mostly a clayey-silty, very fine- to fine-grained sand with minor coarser sand and very minor pebbles. Buried soils locally are observed. Surface generally lacks original bar and swale topography. Correlates with Qf1 on the alluvial fans and inferred to have a similar age (see below). Up to ~15 m-thick.

Qto **Highest and oldest stream terrace deposit (middle to late Pleistocene) –** Only mapped in Marble Canyon, this deposit is similar to that of **Qt1** (described above) and may possibly represent the highest level of aggradation of **Qt1** prior to erosion of that unit to the level of the present tread of **Qt1**. Sediment has a reddish hue and several buried Bt and/or Bw soil horizons and less common Bk and Bky horizons. Deposit is generally a sandy gravel in thin to thick, lenticular beds. Gravel consists of clast-supported pebbles with 30-40% cobbles and minor boulders; gravel are subrounded to subangular and poorly sorted. Sand is very pale brown (10YR 7/3), very fine- to very coarse-grained, and poorly sorted. Age is poorly constrained. Weakly to well consolidated and approximately 15-20 m-thick. Tread lies 5-10 m above the **Qt1** tread in Marble Canyon.

QTgh **High-level sandy gravel that caps ridges in the Sacramento Mountains (Pliocene to early Pleistocene) –** Sandy gravel that caps ridges in the northern part of the quadrangle (i.e., north of Dry Canyon). These deposits are in very thin to thick, lenticular to tabular, vague beds. Gravel are imbricated, clast-supported, composed primarily of limestone, and consist of very fine to very coarse pebbles with subordinate cobbles and lesser boulders. Gravel are poorly sorted and subrounded. Matrix is a gypsiferous, pink (7.5YR 7/4), very fine to very coarse, poorly sorted sand. Age is poorly constrained. Thickness of 1-20 m.

Qtu **Undifferentiated terrace deposit (late Pleistocene to Holocene) –** Sandy gravel in terrace deposits that likely correlate to Qt1, Qt2, or Qt3; however, correlation to a specific terrace deposit is uncertain.

Qlfay **Younger alluvium mapped in La Luz and Fresnal canyons (Holocene) –** This unit either forms low terraces or occupies the valley floor. It consists of yellowish red to brown, silty-clayey, very fine- to very coarse-grained, subangular, poorly sorted arkosic(?) sand. Top soil is marked by gypsum accumulation in the upper 60-70 cm of the unit. 25-60% of the sediment consists of sandy gravel in very thin to medium, lenticular beds. Gravel generally consists of very fine to very coarse pebbles with minor fine cobbles. The gravel are subrounded to subangular, moderately to poorly sorted, and composed of Paleozoic carbonate clasts with minor quartzite, chert, sandstone, and siltstone clasts. Approximately 10-20% of sediment is silty-clay and very fine- to lower-fine-grained sand in thin, lentiuclar beds. Moderately to well consolidated. Unit probably correlates with **Qt3**, **Qt2**, or both **Qt3** and **Qt2**.

Qlfao **Older alluvium mapped in La Luz and Fresnal canyons (Pleistocene) –** Sandy gravel consists of pebbles and cobbles. Clasts are subrounded to subangular, poorly sorted, and composed of Paleozoic carbonates with subordinate chert, sandstone, and quartzite. Generally not well-exposed. Tread of this unit is approximately 2 m above the tread of unit **Qlfay**. Probably correlates to unit **Qt1** but this is somewhat uncertain. Generally 1-3 m-thick.

Qt3-Qt2 **Both Qt3 and Qt2 deposits are present in broad swales; Qt3 deposits are more common and Qt2 deposits exceed 10% by area (Holocene) –** See descriptions of these two deposits above.

ARTIFICIAL FILL AND EXCAVATIONS

afe **Artificial fill and excavations (modern) –** Used to designate excavations and fill associated with gravel and sand quarries, of which there are many on the quadrangle. Some abandoned quarries have been converted to parks.

BASIN FLOOR DEPOSITS

Qbf **Sheetwash and eolian deposits (Holocene; buried deposits are as old as Oligocene?) –** Silty-clayey, very fine- to fine-grained sand with 1-5% thin lenses of sandy pebbles. Color ranges from pale brown (10YR 6/3) to light brownish gray (2.5-10YR 6/2) to light yellowish brown (10YR 6/4) to light brown (7.5YR 6/3-4). Beds are vague, medium to thick, tabular, and either internally massive and bioturbated or else planar- to ripple-laminated. Locally, there is minor medium- to very coarse-grained sand. Common buried soils having minor gypsum accumulation, weak to moderate ped development, and weak clay illuviation (as films on ped faces or bridges between grains). Weakly to moderately consolidated. Deposit underlies gentle slopes west of the steeper alluvial fans. A sparse cover of lag gravel may be present. A stratigraphic section of this unit is presented in Romero and Koning (2006). Inferred thickness of 300-600(?) meters under the basin floor.

ALLUVIAL FAN DEPOSITS

Qam **Sandy gravel associated with modern drainages on the alluvial fans (0-50 yrs old) –** Sandy gravel in recent bars and swales having up to 0.5 m of relief. Gravel includes pebbles, cobbles, and boulders. Clasts are subrounded to subangular, commonly clast-supported, and very poorly sorted. Sand is grayish brown to light brownish gray (2.5Y 5-6/2) and pale brown (10YR 6/3). Sand is mostly upper-fine- to upper-very coarse-grained. Relatively sparsely vegetated. No soil development, desert pavement, or clast varnish. Generally less than 2 m-thick.

Qah **Historical deposition of sandy gravel along modern drainages of alluvial fans (50-200 yrs) –** Deposits similar to those of Qam but whose surfaces support moderate vegetation. There is no evidence on its surface of significant fluvial aggradation in recent time. No observable soil development, desert pavement or clast varnish.

Qf3 **Sand, gravelly sand, and subordinate sandy gravel (late Holocene) –** This unit is designated for thin, relatively sandy deposits that appear slightly inset into **Qf2b** in the proximal alluvial fans. Unit generally consists of thin to thick, vague beds of silty very fine- to lower-medium-grained sand, and minor upper-medium to very coarse sand. At the mountain front, this unit is gravelly (pebbles and cobbles). Sediment is pale brown to very pale brown (10YR 6-7/3) to light yellowish brown (10YR 6/4) to yellowish brown (10YR 5/4) and moderately to poorly sorted. Within this finer sand may locally be scattered very fine to medium pebbles of Paleozoic sedimentary clasts. There is subordinate thin to thick, lenticular beds of sandy gravel. The gravel are typically clast-supported, subrounded to subangular, poorly sorted, and consist of very fine to very coarse pebbles with up to 25-30% fine to coarse cobbles. Sand in the coarse channel-fills is typically pale brown to very pale brown (10YR 6-7/3), fine- to very coarse-grained, and poorly sorted. The relatively charcoal-rich, grungy “G-unit” depicted in the stratigraphic sections of Figure 3 is useful in identifying this unit in the northern part of the quadrangle. The lack of a coarsening-upward trend and its more sandy texture helps in differentiating this unit from **Qf2** deposits. The surface is generally not as bouldery and cobbly as that associated with **Qf2b**, but yet commonly has a pebble to fine cobble gravel lag indicating erosion of the surface. The surface has slight bar and swale relief of 10-30 cm. Its desert pavement has weak clast armor and no to slight varnish. Soil development is characterized by a stage I calcic soil horizon. In the medial to proximal parts of the alluvial fan, the surface is moderately dissected by gullies about 2 m-deep. In the distal parts of the alluvial fan, this unit forms an extensive, albeit relatively thin, deposit. Unit generally corresponds to Qf3m and Qf3L of Koning (1999) and Koning et al. (2002). Unit correlates to the inset terraces noted within the Organ alluvium of the Desert Project (those under the Organ II and III surfaces, which have a maximum age of ~2200 yrs according to table 8 of Gile et al., 1981) A Qf3 deposit on the Mule Canyon alluvial fan south of Alamogordo consisting of an in-filled swale returned a C-14 age of 1980 ± 50 yrs (Koning, 1999, and Koning et al., 2002). Generally less than 2 m-thick.

Qf3gh **Gravel-capped, slightly high-standing ridges of Qf3 (late Holocene) –** This is a subunit of **Qf3** mapped in the distal to medial parts of the La Luz Creek alluvial fan in the northern part of the quadrangle. It consists of a varnished, poor to moderate, surface clast armor of very fine to very coarse pebbles overlying a 20-70 cm-thick layer of gypsiferous, silty, very fine to fine sand (minor medium sand and locally 1-25% coarse to very coarse sand and scattered pebbles). The silty fine sand is reddish yellow (5YR 7/6). The clast armor allows preservation of broad but yet elongated, relatively flat surfaces that stand 20-100 cm above surrounding, eroded low areas. Surface supports a moderate cover of creosote (mostly) and other shrubs (about 3 plants per 5 m^2). The topsoil is characterized by 10-20 cm of a Bw horizon that overlies gypsic horizon(s). The Bw soil horizon has a light brown to reddish yellow color (7.5YR 6/4-6) and moderate, medium to very coarse, subrounded blocky peds; vesicular peds in the overlying A horizon (Av peds) were not observed. In gypsic horizons below the Bw horizon, gypsum may cover 20-50% of clast surfaces in coats 1-2 mm-thick. Gypsum is also well-distributed in the topsoil, giving it a whitish appearance but not forming individual gypsum crystals. Locally, gypsum cements sand to form moderate, coarse, subangular blocky peds. Under the gypsiferous, silty, very fine to fine sand generally lies sediment containing relatively abundant (20-25% estimated sediment volume) gravelly channel-fills like those in unit **Qf3**; these are up to 70 m wide and commonly more than 30 cm-thick. The fine sediment overlying the gravelly channel-fill may be due to aggradation of gypsiferous, eolian fine sediment that has been incorporated into a soil. Unit is probably less than ~2200 years (see discussion of **Qf3** above). Unit is approximately1-2 m-thick and includes the lower, gravelly channel-fills immediately under the silty fine sand.

Qfgh-Qfn3-2 **A composite unit containing >10% each of Qfgh and Qfn3-2 (Holocene) –** See **Qfgh** and **Qfn3-2** entries for their respective detailed descriptions.

Qf2 **Sandy gravel and gravelly sand (early to middle Holocene) –** Representing a period of relatively coarse, Holocene-age, alluvial fan aggradation, this map unit is the most aerially extensive of the mapped alluvial fan units. It includes the Qf2, Qf3u, and part of the Qf3m units of Koning (1999) and Koning et al. (2002) and probably correlates with the Organ I alluvium of the Desert Project (although near Alamogordo its age extends to 9-10 ka, according to Koning et al., 2002). Near the mountain front on alluvial fans that experience debris-flow deposition, this unit commonly coarsens-upwards from a clast-supported, imbricated sandy gravel to bouldery debris-flows intercalated with sandy gravel. On the La Luz and Cottonwood alluvial fans, alluvium is generally sand, clayey-silty sand, and pebbly sand that has a reddish color and a somewhat higher arkosic component due to having a source area with Abo Formation. After the culmination of aggradation in the middle(?) Holocene, this deposit experienced net erosion until the present. Below, we have differentiated this unit into two subunits marked by different surface characteristics and geomorphic position; these are called Qf2a and Qf2b. Note that these denote the same deposit overlain by different surfaces. In the proximal to medial parts of the alluvial fans, the Qf2 unit consists mostly of a sandy gravel laid down by stream-flow, with local clast imbrication. Most of the sandy gravel is clast-supported. Matrix-supported, poorly sorted, cobbly-bouldery debris-flows typically become more common up-section (particularly in the upper 2 m, where debris-flows may be about subequal to stream-flow sediment). Debris-flows are in medium to thick, tabular to broadly lenticular beds; these typically have a matrix of slightly clayey-silty, very fine- to very coarse-grained sand (mostly very fine- to medium-grained) that is poorly sorted. Boulders are more common in the debris-flow sediment than stream-flow sediment. Stream-flow beds are thin to thick and lenticular to broadly lenticular. Stream-flow gravel are clast-supported, commonly imbricated, subrounded to subangular, poorly sorted, and generally consists of pebbles, 15-40% cobbles, and 1-15% boulders. Sand is very pale brown (10YR 7/3-4) to pale yellow (2.5Y 7/3-4) to pale brown to light yellowish brown (10YR 6/3-4), very fine to very coarse grained (mostly medium- to very coarse grained), and poorly to moderately sorted. Unit becomes more sandy and less gravelly westward away from the mountain front. Radiocarbon analyses of charcoal collected from the upper debris flows of this deposit returned a radiocarbon age of 8750 ± 70 yrs. However, this deposit probably correlates at least in part with the Organ alluvium in the Desert Project, and we suspect its age may extend to 4-6 ka based on the age control there (Gile et al., 1981). Thus, we assign an age range of 4-9 ka for this deposit. Unit is generally 2-5 m thick and weakly consolidated, but locally exceeds 8 m in thickness (such as at the mouth of Marble Canyon).

Qf2a This is applied to the deposit under the highest aggradational surface associated with unit **Qf2**. Its topsoil is characterized by having calcic-gypsic horizons up to 50 cm-thick with an apparent stage I+ to II morphology, and no (locally very weak) illuviated clay horizons (Bt soil horizons). Generally, the surface has a desert pavement marked by a varnished and moderate to dense clast armor. Bar and swale topography has less than 30 cm of relief.

Qf2b This is applied to the deposit under a relatively extensive erosional surface developed on the **Qf2** unit. Erosion of the upper sediment has left a bouldery to cobbly lag gravel with significant bar and swale topography (30-70 cm of relief). Soil development is marked by a stage I+ calcic soil horizon and no noticeable illuviated clay. Its desert pavement has only a moderate clast armor and relatively weak clast varnish. Ocotillo and yucca appear to prefer growing on this surface compared to surfaces on **Qf2a** and **Qf1**. This was mapped as Qf3u, Qf3m, and Qf2 by Koning (1999) and Koning et al. (2002). The age of this erosional surface will lie between the ages assigned to the Qf2 and Qf3 deposits, probably 2-4 ka.

Qf2-c **Both Qf2 and Qc deposits are present; Qf2 deposits are more common and Qc deposits exceed 10% by area.**

Qfn3-2 **Northern alluvial fan sediment consisting of unit Qf3 with subordinate Qf2 sediment (Holocene) –** This unit is applied to most of the La Luz Creek alluvial fan because incised arroyos there indicate that locally **Qf3** is less than 0.5 m-thick and unit **Qf2** is relatively near the surface. Sediment of this fan has a remarkably red color (pink to reddish yellow; 7.5YR 7/4-6) due to erosion of Abo Formation upstream. Unit **Qf2** in the distal part of this fan commonly consists of very fine- to fine sand, with local medium to very coarse-grained sand and pebbly sand (1-3% pebbles) that is horizontal-laminated to planar- to lenticular-very thinly bedded, cross-laminated, or massive. Sand is moderately sorted (see description of lower Ritas Draw stratigraphic section). Locally, **Qf2** may consist of silty-clayey very fine- to fine-grained sand overprinted by Bty soil development (see description of upper Ritas Draw stratigraphic section). Based on the ages interpreted for units **Qf2** and **Qf3**, this deposit spans most of the Holocene. 1.5-3 m-thick.

Qfi **Clayey-silty very fine- to medium-grained sand, and subordinate gravelly sand and sandy gravel (latest Pleistocene to early Holocene; 25? to 9-10 ka) –** This is generally a fine-grained deposit that overlies the prominent soil developed on top of Qf1. However, near the mountain-front this unit has subordinate pebbles, and locally near the mountain front it may be a sandy gravel. A noteworthy feature of this unit is the development of soils marked by illuviated clay (Bt soil horizons). Although this soil development imparts a relatively dark brown color to the unit, the degree of soil development is generally less than that developed on the immediately underlying argillic horizon associated with the top of unit Qf1. **Note: this unit is buried by Qf3 and Qf2 deposition, and thus is not delineated on the map (just in stratigraphic sections).** Correlates to the Isaack's Ranch alluvium in the Desert Project, inferred to be 8-25 ka (Gile et al., 1981). Approximately 1 m thick.

Qf1 **Sandy gravel, gravelly sand, and subordinate silty-clayey fine sand (late middle(?) to late Pleistocene) –** Alluvium generally characterized by a slightly reddish color, multiple buried soils consisting of reddish horizons possessing illuviated clay and/or ped structure that overlie whitish calcic-gypsic horizons, a well-developed topsoil, and a relatively smooth surface having varnished desert pavement. On the La Luz alluvial fan in the northern quadrangle, this unt is typically exposed in the lower 1-2 m of recently incised arroyos, where it is a relatively clean sandy gravel overlain by fine sediment overprinted by soil development. Exposures of **Qf1** are most common immediately east of the Alamogordo fault, and indicate a clast-supported, sandy pebble-cobble gravel with minor debris-flows. Debris-flows are matrix-supported, have coarser (i.e., more bouldery) gravel sizes, and generally occupy thick beds. In the more common stream-flow deposits, beds are generally very thin to thick and lenticular to broadly lenticular, and clast imbrication is common; sandy sediment may be laminated or in very thin, horizontal-planar to broadly lenticular beds. Gravel is dominated by pebbles and cobbles, is subangular to subrounded, and poorly sorted. Sand is light brown to light yellowish brown (7.5-10YR 6/4) to light brownish gray (2.5Y 6/2) to light yellowish brown (2.5Y 6/3), very fine- to very coarse-grained (mostly medium- to very coarse-grained), and poorly sorted. Multiple buried soils are generally observed; these consist of pink to light brown to reddish yellow to brownish yellow (7.5YR 6- 7/4; 7.5-10YR 6/6) Bw or Btk horizons, 10-50 cm-thick, that overlie whiter Bky horizons, 10-50 cm-thick, possessing apparent stage I to II carbonate morphology. Surface is marked by no original bar and swale relief and desert pavement with a dense, varnished clast armor. Surface soil is marked by calcic-gypsic soil horizons having an apparent of stage II+ or greater carbonate morphology. On the La Luz alluvial fan, this unit is characterized by light brown (7.5YR 6/4), clast-supported, imbricated, subrounded to rounded, sandy pebbles and cobbles in thin to thick, lenticular, vague beds. Locally, this unit is subdivided into two subunits based on the recognition of a younger cut-and-fill deposit (**Qf1b**) incised into older and higher sediment (**Qf1a**). Away from areas where one can see these two separate deposits, this is mapped as an undivided unit (**Qf1**) which probably corresponds to the locally differentiated **Qf1a**. Correlates to the Jornada II alluvium in the Desert Project, which is inferred to be upper middle to upper Pleistocene in age (Gile et al., 1981, table 9). This age range is consistent with a possibly finite radiocarbon age of 41,320 ±1000 ka from charcoal collected from fine-grained sediment correlated to **Qf1** located 1.5 km southeast of the International Space Hall of Fame (UTM coordinates of 414,580 ± 60 m E, 3,641,500 ± 60 m N; fig. 9 of Koning et al., 2002). Greater than 8 m-thick.

Qf1a **Sandy gravel and gravelly sand underlying the approximate aggradational surface marking the end of the main period of Qf1 deposition (late to late middle(?) Pleistocene –** Surface is characterized by no bar and swale relief and desert pavement with a dense, varnished clast armor. Only differentiated where inset deposits of **Qf1b** are locally present. Deposit is as described above.

Qf1b **Cut-fill deposits below Qf1 composed of sandy gravel and gravelly sand that have probably been uplifted along the Alamogordo fault (late to latest Pleistocene) –** An exposure approximately 2 km south-southeast of the Space Museum reveals a buttress unconformity of this unit against an older Qf1 deposit. Here, the inset deposit is 3 m-thick and is similar to Qf2 except for the development of a 1.5-2.0 m-thick Bky calcic horizon having a stage II+ carbonate morphology. The lower 1 meter of this deposit is a clast-supported, imbricated, stream-flow sandy gravel (imbrication indicates a 215-250° transport direction). Gravel are subrounded to subangular, poorly sorted, and comprised of subequal cobbles and pebbles and 10-15% boulders. Sand is pale yellow (2.5Y 7/3), very fine- to very coarse-grained, and poorly sorted. The upper 2 m of this deposit consists of matrix-supported and bouldery debris-flows. Boulders are as large as 1.5 m. Surface is gravelly and supports relatively abundant yucca and ocotillo. Tread of deposit is inset 1.5-2.0 m below the top of the adjoining Qf1a deposit, and appears to have been uplifted along the Alamogordo fault during its major displacement events of 12.6-15 ka (see Koning and Pazzaglia, 2002 and Koning, 1999, for discussion of tectonic activity along the Alamogordo fault). Deposit is 3 m-thick.

Qf1e **Sandy gravel, gravelly sand, and subordinate silty-clayey sand (late to late middle(?) Pleistocene) –** This unit was mapped where a Qf1 deposit was subjected to extensive erosion. Even though eroded, this deposit is typically redder than younger alluvial fan deposits.

Qfo **Older alluvial fan alluvium (middle to upper Pleistocene) –**No exposures were available to describe this unit. It is distinguished by its higher geomorphic position, abundant cobbles and boulders on its surface, and an eroded and steep surface. Like unit Qto, this unit may represent the highest level of aggradation of Qf1 before subsequent erosion lowered much of its tread and re-graded the tread to a lower slope. The age of this unit is uncertain.

Qf3-Qam **Both Qf3c and Qam deposits are present; Qf3c deposits are more common and Qam deposits exceed 10% by area.**

Qah-Qam **Both Qah and Qam deposits are present; Qa deposits are more common and Qam deposits exceed 10% by area.**

Qf3-Qf2b **Both Qf3 and Qf2b deposits are present; Qf3 deposits are more common and Qf3b deposits exceed 10% by area.**

Qf2b-Qf3 **Both Qf3b and Qf3 deposits are present; Qf3b deposits are more common and Qf3c deposits exceed 10% by area.**

QTa **Undivided basin floor and alluvial fan alluvium (shown only in the cross-section (Oligocene(?) to Holocene) –** Probably similar to unit Qf1 based on well data.

TERTIARY IGNEOUS ROCKS IN SACRAMENTO MOUNTAINS

Ti **Igneous intrusive rocks (middle to late Eocene) –** Igneous intrusive rocks that intrude Paleozoic strata. These rocks are predominantly grayish green and porphyritic, with phenocrysts of plagioclase, hornblende, and diopsidic augite (plagioclase seems to be the most prevalent on this quadrangle). The groundmass consists of plagioclase laths, interstitial chlorite, magnetite, minor orthoclase, and apatite (Asquith, 1974). These rocks have been characterized as nepheline normative trachybasalts, basaltic trachyandesites, trachyandesites, and dacites by McManus and McMillan (2002), and as diorite (minor camptonite) by Asquith (1974). Where exposed, igneous rocks are hydrothermally altered to common secondary minerals. Small intrusive sheets, on the scale of 10s to 100s of meters, along with thinner dikes, occur in the northern and eastern parts of the quadrangle. Widespread sills and minor dikes, 1-10 meters thick, occur in the southern part of the quadrangle, mainly within the lower part of the Pennsylvanian Gobbler formation. $^{40}Ar/^{39}Ar$ ages of 44-36 Ma (McManus and McMillan, 2002).

SEDIMENTARY ROCKS IN SACRAMENTO MOUNTAINS

Pa **Abo Formation (Permian) –** Medium to dark reddish brown mudstones with minor coarse, arkosic sandstone lenses. Sandstones are commonly cross-bedded and individual grains are subangular to angular. The basal part of the Abo Formation contains thick conglomeratic beds that are composed of predominantly subrounded quartzite clasts. These conglomerates are interbedded with reddish-brown mudstone. ~100-120 m thick (330-400 ft).

Pbm **Bursum Formation** (Permian) – The Bursum Formation, as defined by Pray (1961), is composed of silty and sandy limestone interbedded with red mudstone together with minor fine quartz sandstone and limestone- to chert-bearing conglomerate. The amount of red mudstones in the Bursum Formation increases to the southeast on the Alamogordo North quadrangle. Limestone conglomerates in the southeastern part of the quadrangle contain Pennsylvanian lithologies, suggesting a syn-tectonic deposition with respect to movement along the Fresnal fault to the east in the High Rolls quadrangle. The Bursum Formation terminology is used here because its upper contact with the Abo Formation, as defined by Pray (1961), is better defined in the map area than the upper contact of the Laborcita formation, as defined by Otte (1959). ~90-110 m thick (300-350 ft).

/Ph **Holder Formation (Pennsylvanian) –** A heterogeneous unit of dark and reddish shale, sandstone, nodular limestone, and limestone conglomerate. Well-developed algal bioherms are evident in the basal part of the formation, forming massive cliffs 17-23 meters thick (50-75 feet), as in Dry Canyon. The lower contact is best defined by the presence of such bioherms. The lower part of the Holder Formation is dominated by marine carbonates and dark shales. The upper Holder Formation is marked by an increase in the amount of reddish shale, sandstone, nodular limestone, and limestone conglomerate. The upper contact is an abrupt change to quartz sandstone and pebble conglomerates of the Permian Bursum Formation. ~180-275 m thick (600-900 ft).

/Pb **Beeman Formation (Pennsylvanian) –** Thin beds of argillaceous limestone interbedded with calcareous shale. Locally sporadic, olive gray, feldspathic sandstones are found towards the base. A yellowish dolomitic unit and an upward transition to more feldspathic sandstones marks the base of the Beeman Formation, in contrast to the quartz sandstones of the underlying Gobbler Formation. ~110-150 m thick (350-500 ft). Description taken in part form Romero and Koning (2006).

/Pg **Gobbler Formation (Pennsylvanian) –** The lower few hundred meters of this formation exhibits minor coarse-grained sandstone, fine pebbly sandstone, and chert-bearing cobble conglomerate with a sandstone matrix that are interbedded with abundant dark gray to black shale and dark gray cherty limestone. The middle part (Bug scuffle Member) consists almost entirely of calcarenitas and calcilutitas. This member also forms the highest and steepest cliff of the western escarpment of the Sacramento Mountains, though it is thickest to the south of the Alamogordo North quadrangle. Shales and quartz sandstones predominate towards the top of the unit, and these lithologies are gradational with the Bug Scuffle limestone. ~400-500 m thick (1000-1200 ft). Description taken in part from Romero and Koning (2006).

Mlv **Lake Valley Formation (Mississippian) –** The lower interval (Andrecito Member) consists of calcareous shale, mudstones to wackestones, thin-bedded argillaceous limestone, some well sorted, crinoidal grainstones, and minor quartzose siltstone. The middle part of the Lake Valley Formation is characterized by a prevalence of crinoid-bearing bioherm mounds. The biohermal interval includes the Alamogordo, Nunn, and Tierra Blanca Members (Laudon and Bowsher, 1949). The lower part of this interval consists of a ledge of medium-gray, cherty calcareous siltstones and shales developed in massive beds 8-300 cm in thickness (Alamogordo Member). Above these ledges are interbedded, friable or poorly cemented, crinoidal grainstones, and minor amounts of crinoidal wackestones (Nunn Member). Crinoidal grainstones and wackestones with large nodules of light colored chert are abundant in the upper part of this formation and characterize the Arcente Member. Here, the grainstones and packstones are normally well-cemented. Lateral changes in thickness and facies as well as poor exposures posed a challenge in mapping the members of this formation. The Lake Valley Formation was therefore mapped as a single unit unless the upper, post-biohermal strata (Arcente and Dona Ana members, see below) were recognized. Thickness varies from a maximum of nearly 80 m (250 ft) to a more prevalent 50 m (160 ft) in areas where it is near mounds, and becomes considerably thinner(15-20 m, 48-65 ft) away from the bioherm mounds.

Mlvd **Dona Ana Member of Lake Valley Formation (Mississippian) –** The upper 45 meters (150 feet) of the Lake Valley Formation above the Arcente Member is the Dona Ana Member. It consists of cherty, light gray, irregularly bedded crinoidal grainstones to packstones. This unit also thins and pinches out near biohermal mounds, and north of Marble Canyon was removed by pre-Pennsylvanian erosion or is indistinguishable from the underlying Lake Valley Formation strata. Thus it is not exposed across much of the map area. ~0-18 m thick (0-55 ft).

Mlva **Arcente Member of Lake Valley Formation (Mississippian) –** Dark calcareous shale and thin- to medium-bedded (<30 cm-thick), medium-gray, argillaceous limestone. The Arcente Member seems to level out some of the topographic relief caused by mound development in underlying strata. Approaching the mounds, this member shows abrupt thinning and locally pinches out. This unit is only recognizable on the south side of Marble canyon, and it thins out towards the north where it was probably removed by pre-Pennsylvanian erosion. ~0-25 m in thickness (0-80 ft).

D **Onate, Sly Gap and Percha Shale Formations (Devonian) –** Dark gray to brownish gray silty dolomite, dolomitic siltstones, and very fine-grained quartz sandstones. Light gray calcareous shales are common towards the base and black, non-calcareous shales are common at the top of the section. Pebbly sandstones occur locally in basal levels. Gray calcareous shale and nodular, medium gray limestone are interbedded with minor black shale layers in the middle part of this unit. Limestone beds increase towards the upper part of the unit and is interbedded with layers of black shales. Locally, the black shales contain pyrite. Some beds present a distinctive reddish and yellowish color of alteration. Mostly medium bedded, shales are in layers not very resistant to erosion. It is poorly exposed and commonly covered by colluvium. 15-30 meters (50-100 feet) thick (mostly ~ 30 m-thick). The upper contact is a disconformity.

S **Fusselman Formation (Silurian) –** Dark-colored, cherty dolomite and very minor siliciclastics. Fresh samples vary in color from light gray to dark gray or are olive to brownish gray. Fine to medium crystalline. Bedding is obscure. Chert is abundant and it is present as irregular nodules. Locally medium- to thick-bedded (10-100 cm thick), sandy to conglomeratic units are found close to the basal contact (Pray, 1961). These units contain phosphatic nodules, dolomite, quartz and chert particles that vary in size from sand to pebbles. The Fusselman formation is very resistant to erosion which has allowed for the formation of steep cliffs, wide ledges and dip slopes that are laterally continuous and easily recognizable along the mountain front and canyons of the escarpment. Both, the lower and upper contacts are sharp disconformities. The nature of the contacts is reflected in the variation of thickness of the unit. ~22-30 m thick (70-100 ft). Description taken in part from Romero and Koning (2006).

Ov **Valmont Dolomite (Ordovician) –** Sharply defined, thin to medium (3 to 60 cm-thick) beds of light to very light gray, finely crystalline, sublithographic dolomite and minor chert. Its typically very light-colored dolomite is consistent throughout the area. The lower contact with the cherty member of the Montoya formation is lithologically transitional. However, the Montoya formation is darker in color, coarser in texture, and its bedding more obscure compared to the Valmont Dolomite. The Valmont Dolomite is divided into an upper and lower member. Two argillaceous and shaly zones 60-150 cm-thick can be traced along the area about 25 m above the base of the unit, and represent the basal part of the upper member. Chert is more common in the lower member, where it is present in large nodules up to 10-15 cm thick and is light gray in color. In the upper part of the upper member, chert is also present in light brown masses 8 to 25 cm-thick. Formation is 45-58 m thick (150-190 ft). Description slightly modified from Romero and Koning (2006).

Om **Montoya formation (Ordovician) –** Almost entirely crystalline dolomite and cherty dolomite. About a meter of thick and massive beds of quartz sandstone and sandy dolomite marks the base of the section. Thick beds of chert (30-100 cm) mark the upper part of the unit. The dolomite ranges in color from medium dark gray to light olive gray. Formation is 57 to 69 m thick (190-225 ft). Description slightly modified from Romero and Koning (2006).

Oe **El Paso Formation (Ordovician) –** Dolomites, sporadic sandy dolomites, and dolomitic quartz sandstones in thin to medium beds. Mostly light olive gray to light gray, very fine to medium crystalline dolomite. Dolomitic quartz sandstone is common in the upper half of the lower third of the section, as well as in the upper 30 meters of the section. Thin beds of sandy dolomites and dolomitic quartz sandstones are sporadically present in other parts of the section. Thin to medium, light- to medium-gray chert lenses, seams and nodules are common in the middle part. 131 m thick (430 ft). Description slightly modified from Romero and Koning (2006).

Ob **Bliss Sandstone (Ordovician) –** Quartz sandstone that does not appear on the Alamogordo North quadrangle, but was used in the cross section. ~34 meters thick (110 feet).

STRUCTURE

Fold-related deformation constitutes the main structural feature of the mountain block on this quadrangle. The most prominent fold is the north-plunging, north- to northwest-trending, La Luz anticline northwest of Alamogordo. A northeast-down monocline parallels this anticline between Mill Ridge and Fresnal Canyon. Southwest of the La Luz anticline is a smaller, northwest-trending anticline in Beeman Canyon. A north-trending, north-plunging syncline is present near the mountain front in the southern quadrangle, whose west limb may be flexure related to footwall uplift of the Alamogordo fault zone (Pray, 1961). Although as a whole the Sacramento Mountains may be thought of as an east-tilted fault block (Pray, 1961), the attitudes in this quadrangle largely reflect folding and other localized deformation.

The sequence and timing of deformation affecting the Sacramento Mountain block was reconstructed by Pray (1961), and his interpretations are summarized in the following. Pre-

Permian strata are more intensely deformed than Permian or post-Permian strata, owing to folding and normal faulting that occurred during Pennsylvanian and earliest Permian time associated with Ancestral Rocky Mountain tectonism. In addition, some epeirogenic tilting and warping occurred during pre-Pennsylvanian time, and gentle folding and some faulting persisted during deposition of the Abo Formation (and possibly the later Permian strata). Minor disconformities occur at the base of the Montoya, Fusselman, and Onate Formations and may be present at the base of the El Paso and Sly Gap Formations. Disconformities are also present at the base of the Percha and Lake Valley Formations. The unconformity at the base of the Pennsylvanian deposits is probably a tectonic signal. Structural features indicate increasing tectonic activity through the Pennsylvanian, culminating in a major period of deformation in latest Pennsylvanian and earliest Permian (Wolfcampian) time. Strata which experienced folding in this area and which host high-angle faults (primarily normal motion) lie under an angular unconformity at the base of the Abo Formation.

Normal faults are scattered in the mountain block throughout the quadrangle. The longest of these is a west-down fault that strikes parallel to lower Fresnal Canyon (see map and cross-section). This fault may have moved during Ancestral Rocky Mountain tectonism or during late Cenozoic extension. The most significant normal fault is the Alamogordo fault zone, along which the Tularosa Basin may have dropped ~600 m (2000 ft) in this quadrangle relative to the Sacramento Mountains. This fault formed during late Cenozoic extension (Pray, 1961) associated with the Rio Grande rift. Analysis of well data of the Alamogordo well field between Beeman and La Luz Canyon indicates that the Alamogordo fault zone consists of multiple, west-down strands. The common north- to northeast-striking faults in the bedrock at the mountain front near the mouth of Marble Canyon probably are an extension of the Alamogordo fault zone. It is likely that the northeast-striking faults in the mountain block are early rift-related because they are parallel to northeast-striking dikes filled with magma whose composition is interpreted to reflect early rifting (44-36 Ma; McManus and McMillan, 2002).

SUMMARY OF GEOLOGIC HISTORY

Paleozoic strata in the mountain front record a long history of relative sea level transgressions and regressions interspersed with tectonic events. The next three paragraphs summarize a synopsis of the stratigraphic history of the Tularosa Basin area by Raatz (2002), who in turn drew heavily from Pray (1961), Kottlowski (1963 and 1965), and Wilson (1967, 1975, and 1989).

Ordivician through Devonian strata record a series of marine transgressions and regressions on a large, low-angle, south-dipping ramp. These created unconformity-bounded stratal wedges that generally thin to the north. Sea levels were relatively high at this time. Lower Paleozoic strata were deposited in restricted to open-marine conditions in a stable shelf environment, with open-marine conditions increasing upwards that culminate in deep-water facies (Pray, 1961; Kottlowski et al., 1956). The Mississippian system records more active tectonism, as evidenced by numerous angular unconformities, karsted surfaces, and disconformities (Pray, 1961; Bachtel and Doroek, 1994, 1998). The growth of particularly large and abundant bioherms in the Early and Middle Mississippian may also have been structurally controlled (Bowsher, 1991; Jeferry, 1997).

As noted above, Ancestral Rocky Mountain tectonism occurred during the Pennsylvanian through earliest Permian. During this time, the north-trending Orogrande basin experienced sedimentation from adjacent uplifts. The Orogrande basin was an asymmetric, intracratonic trough with a narrow, high-relief eastern shelf and a broader, low- relief eastern shelf. The depocenter of the basin moved northward with time so that it lay northwest to west of Alamogordo in the middle to late Pennsylvanian (Myer, 1966).

In the early Permian, the Orogrande basin experienced rapid subsidence and basin in-filling with mixed marine and terrestrial carbonates and clastics (Raatz, 2002). Deposits are terrestrial-dominated to the north and marine-dominated to the south (Kottlowski et al., 1956; Otte, 1959; Pray, 1961; Jordan, 1971). The Abo Formation, which overlies older strata with angular unconformity (Pray, 1961), post-dates the most intense Ancestral Rocky Deformation and grades southward into marine limestone south of the map area.

Evidence for the Laramide orogeny is cryptic on this quadrangle. McManus and McMillan (2002) interpret that the 36-44 Ma magmas filling northeast-striking fissures (unit **Ti** dikes) are related to earliest Rio Grande rift tectonic activity. Northeast-striking faults may possibly have been active at this time. Activity along the Alamogordo fault during Oligocene(?) through Holocene time has progressively down-dropped the Tularosa Basin relative to the Paleozoic strata of the mountain block. During this time, possibly during the Pliocene, gravelly sediment was deposited in Fresnal and La Luz Canyons. Continued uplift of the Sacramento Mountain block and accompanying stream incision left remnants of this sediment as high-level terrace deposits. Minor, localized flexure associated with footwall uplift has been interpreted to form the synclines at the mountain front, including the syncline south of Marble Canyon (Pray, 1961).

During the middle to late Pleistocene, there appears to have been relatively little activity on the Alamogordo fault because alluvium backfilled mountain-front canyons as much as 15-20 m thick (units **Qto**, **Qt1**, **Qfo**, and **Qf1**). If the fault was relatively active, the mountain-front canyons would probably be eroding rather than aggrading due to the local base level drop at the location of the fault line. These backfilled deposits generally contain many paleosols having reddish horizons marked by alteration (Bw horizons) and containing illuviated clay accompanying precipitated calcium carbonate (Btk horizons); these reddish horizons commonly overlie whitish horizons of precipitated calcium carbonate and/or gypsum (Bky horizons). Reddish Bw or Bt horizons are not characteristic of soils that formed over the last 10,000 years -- an interglacial, relatively warm and dry time period. So one may infer that the reddening of these paleosols may be due to wetter conditions present during Pleistocene glacial times (associated with oxygen isotope stages 2, 4, 6, 8, etc).

Detailed study of the Alamogordo fault indicates that it moved 1-3 m in a poorly constrained event sometime in the late Pleistocene. Between 12.5-15 ka (radiocarbon years), two ruptures are interpreted in close succession. The first possibly resulted in 1-3 m of throw and the second may have produced 3-6 m of throw. North of Alamogordo, a rupture event on the fault produced 1-3 m of throw. This rupture does not appear to have extended south of Alamogordo. The last rupture south of Alamogordo was relatively small (up to 1.5? m) and occurred while Qf2 was being deposited in the early to middle Holocene. Data and discussion pertaining to these rupture events are found in Koning (1999) and Koning and Pazzaglia (2002).

Significant alluvial fan aggradation occurred in the early to middle Holocene following the scarp-forming, latest Pleistocene ruptures. This aggradation was initially marked by stream-flow depositional processes, but later debris flows became more common. Drier conditions were conducive to precipitation of calcium carbonate and gypsum in soils; formation of Bt or Bw soil horizons appears to have been inhibited or was masked by these precipitates.

After the coarse aggradation associated with **Qf2** (approximately interpreted as 9-4 ka), alluvial fans in the area generally experienced erosion. This degradation produced an erosional surface on **Qf2** (**Qf2**b). Local filling of low areas during this time resulted in the relatively sandy **Qf3** deposit. Unit **Qf3** has the most charcoal of the alluvial fan units, suggesting a relatively dry time marked by occasional fires. Historically and in modern times, local deposition of bouldery lobes on the alluvial fans has occurred, such as at the mouth of Marble Canyon. On the La Luz alluvial fan, the last 100 years or so has seen significant gully incision on the alluvial fans.

HYDROGEOLOGIC COMMENTS

Mapping alluvial fan deposits has resulted in a few important observations that are applicable to hydrogeology of the basin-fill. One, alluvial fan sediment in the area has a somewhat bi-modal character in terms of texture: gravelly, commonly clast-supported channel-fills interspersed with silty-clayey sand deposits with pebbles. The gravelly channel-fills probably have the higher hydraulic conductivity and storativity values. These gravelly channel-fills become less common at the toe of alluvial fans and in the basin-floor deposits. Two, inter-fan areas are notably finer-grained than near the axis of alluvial fans, an example being the inter-fan area immediately south of the filtration plant between Dry and La Luz Canyons. Consequently, wells drilled near the axis of alluvial fans upslope from the alluvial fan toe may produce better yields. Third, on the La Luz alluvial fan, the **Qf1** deposit observed at the floor of modern gullies is characteristically a clast-supported, sandy gravel consisting of pebbles to cobbles, presumably deposited during glacial time periods when there was a perennial stream exiting the relatively large Fresnal-La Luz canyons. Earlier glacial time periods in the Pleistocene can be expected to have produced on this fan similar gravelly deposits that could be expected to have relatively higher hydraulic conductivity and yield values.

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CAPTIONS

FIGURE 1. Index map of the Alamogordo North quadrangle that shows areas mapped by the respective authors relative to major physiographic features and highways.

FIGURE 2. Time-stratigraphic correlation of map units.

FIGURE 3. Stratigraphic sections of Quaternary sediment in the interfan area between La Luz Creek and Dry Canyon, arranged west to east.

FIGURE 4. Stratigraphic sections of Quaternary sediment along La Luz Creek, arranged west to east. Shading is explained in Figure 3.

TABLE 1. Summary of characteristic features of alluvial fan units.

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 are based on 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.

The map has not been reviewed according to New Mexico Bureau of Mines and Mineral Resources standards. Revision of the map is likely because of the on-going nature of work in the region. The contents of the report and map should not be considered final and complete until reviewed and published by the New Mexico Bureau of Mines 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. Cross-sections are constructed based upon the interpretations of the authors made from geologic mapping, and available geophysical (regional gravity and aeromagnetic surveys), 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.