# MAPPING REPORT FOR ALAMOGORDO SOUTH 7.5' QUADRANGLE, OTERO COUNTY, NEW MEXICO

by

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## ABSTRACT

A segment of the steep and rugged western escarpment of the Sacramento Mountains occupies the eastern half of the mapped area. This outstanding and abrupt topographical feature is the result of the uplift of the Mountain range along a north trending normal fault system on the eastern edge of the Basin and Range province. The escarpment offers an outstandingly well exposed and almost complete (about two kilometers thick, 6000 feet) Paleozoic sedimentary section that ranges in age from early Ordovician, at the base of the escarpment, to Pennsylvanian at higher elevations. Piedmont and basin fill Quaternary deposits, on the western half of the quadrangle, enclose part of the history of the uplift of the Mountains.

Two main deformational events in the geologic history of the area are evidenced in the structures mapped. The first one, pre-Permian, is characterized by gentle folding of the Lower and middle Paleozoic strata. These folds trend north south. The second, youngest (Tertiary) event is represented by the normal faults at the base of the escarpment. Faulting of Quaternary units indicates that this is an active fault system.

The compilation of the geologic map of this quadrangle was the result of the independent mapping work of each of the authors. This project was funded by The USGS and the New Mexico Bureau of Geology and Mineral Resources.

# INTRODUCTION

The Alamogordo South 7.5' quadrangle includes an area located east and south of the town of Alamogordo, Otero County, South Central New Mexico. In topographic and geologic terms the Alamogordo South 7.5 minutes Quadrangle can be divided in two halves. The desert plains on the western half, representing the Tularosa Basin Quaternary fill, and a sector (About 14 kilometers, 8.5 miles) of the steep west facing escarpment and canyons of the Sacramento Mountains occupying the eastern half of the quadrangle.

The mapping of the area and descriptions of units were carried out separately by the two authors. Koning mapped and described the western half of the quadrangle, extending from the foothills of the escarpment to the basin fill itself and floor of major canyons. These areas correspond to the Quaternary deposits. The Paleozoic section exposed in the western side of the quadrangle (escarpment and canyons of the Sacramento Mountains) and Quaternary deposits in higher areas were mapped and described by Romero who also compiled the map, cross-section, report, and other materials.

The Paleozoic units were mapped over a period of about eight weeks. All major canyons and the front of the escarpment were covered during mapping of the Paleozoic section. Mapping of the higher elevation areas to the east (above the 5800 feet contour interval) was based on topography, aerial photographs geologic observations, and revisions in the field of the work of Pray (1961). Visited locations in this area include the Long, Burleson, and Joplin Ridges.

The first published geologic data of the area is the reconnaissance work of Darton (1928). Other reports during the 30's and 40's deal with specific sections of the Paleozoic sequence of the Sacramento Mountains, including the studies of the Mississippian by Laudon and Bowsher (1941, 1949), the work of Stainbrook (1935, 1948) and Stevenson (1954) on the Devonian formations, and the Pennsylvanian studies by Thompson (1942). In 1947 Lloyd Pray began geologic studies in the area with the support of the New Mexico Bureau of Mines and Mineral Resources, culminating with publication of The Geology of the Sacramento Mountains Escarpment (Pray, 1961). This was the first comprehensive geologic map of the area. Many other geologic studies have been conducted in the area of the Alamogordo South Quadrangle and the Sacramento Mountains escarpment before and after Pray's work. However, few of these have been published. Several research projects for advanced degrees have been also carried out in the area. A considerable amount of data has been also collected by the oil industry but most is unpublished. The outcrops of Paleozoic rocks in the area represent excellent analogues for the interpretation of the subsurface of the Permian Basin, a prolific hydrocarbons province.

The segment of the western escarpment of the Sacramento Mountains in the Alamogordo South quadrangle offers a very well exposed and nearly complete Paleozoic section. This section ranges in age from Lower Ordovician, at the base of the escarpment, to Pennsylvanian at the higher elevations. The approximate average thickness of strata exposed along the escarpment in this quadrangle is about 1,800 meters (6000 feet). A schematic east-west cross section (A-A') shows the general stratigraphic architecture and structure of the escarpment near the center of the mapped area. The stratigraphic nomenclature used in this work follows the one used by Pray (1961). The map units presented here also correspond to the units used by Pray (1961) with the exception of the Mississippian section where different mapping units have been adopted.

The early Ordovician strata represent the oldest rocks mapped in the area, and they appear in continuous outcrops. The lateral continuity of the lower part of the Ordovician is interrupted by alluvium, colluvium and younger terrace deposits covering the base of the escarpment. The Silurian and Devonian units have a relatively homogeneous lithologic character along the area. In contrast the Mississippian strata change dramatically in lithology and thickness. Such variations are closely related to the presence of the Waulsortian mud mounds systems. The mounds origin and evolution is poorly understood. The first author of this report (Romero) is conducting research concerning the long-lasting enigmatic geneses of these carbonate accumulations. Most of the surface strata of the mapped area correspond to the Pennsylvanian section. This is an intricate sequence that reveals rapid changes in depositional environments and cyclic sedimentation. Its steep topographical expression at the upper parts of the escarpment provides lateral continuity.

The Quaternary units on this quadrangle are found in three topographic positions: on the flat basin floor in the western 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 Paleozoic Section of the Sacramento Mountains in the eastern part of the quadrangle. They are located locally at the foot of the mountains where these deposits were inferred by Koning to be over 2 m thick. The units of **Qf1**, **Qf2**, and **Qf3** were initially established by Koning (1999), who mapped the proximal portions of the alluvial fan to establish a paleoseismic chronology for the Alamogordo fault. This work carries these units to the toe of the alluvial fans, and also has refined the earlier mapping of Koning (1999) in the proximal portions of the alluvial fans.

These units were mapped by field traverses and aerial photography of the White Sands Missile Range and Fort Bliss region (photos taken November-1985 through January-1986). Initial work consisted of mapping parts of the alluvial fans with a hand-held GPS unit. 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 work. Line work 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; mapped terrace deposits in the mountains were generally not field-checked. In the field-checking process, there was an approximate 10-20% error in map unit identification from 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 **Qse** 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. 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 some lithostratigraphic differences present between the alluvial fan units (**Qf1**, **Qf2**, and **Qf3**), which are noted below, in many places one would be hard-pressed to identify one of these units based solely on their sedimentologic characteristics. Rather, features relating to the unconformities between the units are generally needed to identify them, such as soil development properties and surface characteristics.

Structurally, the Sacramento Mountains represent a fault- block range, tilting about one degree to the east and bordered on the west by a normal (gravity) fault zone at the base of the present escarpment (Pray, 1961). Faulting as the main mechanism for the uplift of the range is supported principally on the numerous small but steep faults near the edge of the mountain block reflected on steep piedmont scarps; stratigraphic configuration of the section and the regional tectonic pattern of the area (Pray 1961). A minimum estimated displacement of about 2,100 m exists along this boundary fault (Pray, 1961).

Broad anticlines, synclines, and high-angle, generally normal faults are evident structures along the area. Most of these features strike north-south and have been suggested to have been formed by major diastrophic movement during upper Carboniferous (late Pennsylvanian) and earliest Permian time, prior to deposition of the Abo Formation in the Wolfcampian (Wilson, 1975). Many of the structures were formed before the modern uplift

of the mountain block. Regional evidence suggests that the main uplift of the Sacramento Mountains fault block was initiated during late Tertiary time (Pray, 1961). Faulting in recent alluvium deposits advocate continued uplift at the present time.

Grain sizes in this report 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. Clast percentages were estimated in the field with the aid of percentage charts. 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 1 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).

Some of the mapping units in this work include more than one stratigraphic unit. In the following pages of this report is presented a description of the single stratigraphic units following the nomenclature of Pray, 1961 for the Paleozoic section exposed in the quadrangle. This report does not deal with specific data for ages or genetic interpretations of the units. The reader should be referred to the work of Pray, 1961 and other specific paleontological and stratigraphic studies for details on the ages and paleoenvironmental interpretations of the different units. Thickness of units and some details of the lithologic descriptions were compiled from the work of Pray, 1961 and field observations and revisions by Romero.

## DESCRIPTIONS OF STRATIGRAPHIC UNITS

In the following pages are presented the descriptions of the stratigraphic units framed in regard to the mapping units. Lithological descriptions are accompanied by descriptions of outcrop character, and diagnostic features for the recognizance of the units and contacts between them in the field. The descriptions are presented in ascending stratigraphic order (older to younger).

### WESTERN ESCARPMENT AND CANYONS OF THE SACRAMENTO MOUNTAINS

#### *ORDOVICIAN UNITS*

**Oe El Paso Formation**

This is the lowermost and oldest mapping unit. The El Paso formation outcrops at the base of the escarpment almost along the entire segment of the quadrangle. It is covered by quaternary in the sector within about1 kilometer north and south from the San Andreas

Canyon. The most complete section is exposed about 1 Km south of Alamo Canyon.

The El Paso formation is made of 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 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 as well. Thin to medium light to medium gray chert lenses, seams and nodules are common in the middle part. 131 meters thick (430 feet).

The lower contact with the underlying Cambrian Bliss Sandstone was not observed in this quadrangle. However, it outcrops a few kilometers south of the area of this quadrangle at the Niger Ed Canyon in the northern part of the Deadman Canyon quadrangle. The El Paso formation can be recognized by the light color of the slopes where it is weathered. The lower part of the overlying Montoya formation alters to a darker color and forms steep cliffs. This contrast in color and topography was used to identify the contact between these two units. This upper contact of the El Paso formation is a clearly defined regional erosional disconformity. Some resistant ledges within the El Paso slope are formed by the beds of dolomitic quartz sandstone.

**Om Montoya Formation**

Almost entirely crystalline dolomite and cherty dolomite. A few feet of thick and massive beds of quartz sandstone and sandy dolomite marks the base of the unit. Thick beds of chert (1-3 feet) characterized the upper section along the area. The dolomite ranges in color from medium dark gray to light olive gray. 57 to 69 meters thick (190-225 feet).

The Montoya formation outcrops continuously along the entire quadrangle at the base of the escarpment and extends east to some of the major canyons. The lower part of the unit (Cable Canyon and Upham members) forms a steep dark colored cliff about 30 meters high (100 feet). The sandstone grades upward transitionally to sandy dolomite and to sand free dolomite higher in the section. Thickness and massiveness of beds also decreases upward. Chert does not occur in the lower part but becomes common as the sandy beds decrease. Chert becomes dominant towards the upper few feet of the unit.

The upper part of the Montoya formation (Aleman member) consists of mostly cherty dolomite. Bedding is somewhat obscured and sometimes defined by chert seams and nodules as thin to medium beds. In the front of the escarpment dark to light gray solid thick beds

of chert indicate the upper part of the Aleman member and the proximity to the upper contact. The contact with the overlying Valmont formation is gradational (Pray, 1961).

**Ov Valmont Formation**

Sharply defined thin to medium (2-60 centimeter, 1 inch to 2 feet) beds of light to very light gray, finely crystalline sublitographic dolomite, and minor chert. The Valmont dolomite outcrops continuously along the escarp and bottom of canyons. The type section for the formation is located in the Alamo canyon. Its typical very light color of alteration (whitish to very light yellow) is consistent throughout the area and represents the most distinctive feature in the field together with the well defined beds. The lower contact with the cherty member of the Montoya formation is lithologically transitional. However, it could be identified based on the difference in color of alteration, texture and the character of the bedding. The Montoya formation is darker in color, coarser in texture and its bedding is obscure, contrasting with the Valmont formation.

Two argillaceous and shaly zones 0.6-2.5 meters thick (2-5 feet) can be traced along the area about 25 meters (80 feet) from the base of the unit, and represents the basal part of the upper member of the two in which the Valmont formation is divided. Chert is more common in the lower member, where it is present in large nodules up to 10-15 centimeters thick (4-7 inches) light gray in color. In the upper part of the upper member chert is also present in 5-15 centimeters thick (2-6 inches) light brown masses.

The upper contact of the Valmont dolomite is strikingly sharp. Its distinctive whitish color of alteration and bedding style contrasts with the darker overlying Fusselman formation, making the contact conspicuous and easily traceable throughout the area as an erosional disconformity.

***SILURIAN UNITS***

**S Fusselman Formation**

Dark colored cherty dolomite and very minor silisiclastics. Fresh samples vary in color from light gray to dark gray or olive and brown gray. Fine to medium crystalline. Bedding is obscure. Chert is very abundant (one third of the section) and it is present in irregular nodules. 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 as the lower major ledge along the of the escarpment. The top of this ledge is called the first bench in the Dog Canyon trail. 22-30 meters thick (70-100 feet). Both, the lower and

upper contacts are sharp disconformities. The nature of the contacts is reflected in the variation of thickness of the unit.

***DEVONIAN UNITS***

**D Onate, Sly Gap and Percha Shale Formations**

Being the unit less resistant to erosion it is poorly exposed, commonly covered by slope and wash. This makes the mapping of separate Devonian formations difficult, and any correlation very risky. Since it is not possible to follow beds as precisely as with other units. For this reason the three Devonian formations were grouped as a single mapping unit. However, here in this report separate descriptions are presented for each stratigraphic unit.

***Onate formation***

The Onate is the basal unit of the Devonian in the Sacramento Mountains and the most persistent throughout the area. Made of dark gray to brown gray silty dolomite and dolomitic quartz siltstones to very fine grain sand. Pebbly sandstones outcrop locally in basal levels. Some beds present a distinctive reddish color of alteration. Medium bedded although fine beds are not uncommon. The Onate formation is about 20 m thick (65 feet) in the vicinity north of Dog canyon and thins northward being about 13 m (45 feet) in the Purgatory canyon.

The discordant basal contact is easily recognized by the ferruginous, silicified surface. It outcrops throughout the area on the wide ledges formed by the contrastingly more resistant to erosion, Fusselman formation.

***Sly Gap formation***

Gray calcareous shale and nodular medium gray limestones, interbedded with minor black shale layers. Gray shale predominates in the lower half. Limestones increase towards the upper part interbedded with layers of black shales. In the vicinity of Alamo Canyon in the uppermost level some layers of black shales contain concentrations of pyrite. The Sly Gap formation can be easily, in most of the area when exposed, identified by the yellowish brown color of alteration. 9-12 m thick (30-40 feet) in the north and seems to thin southward. The upper contact is difficult to find because of the similar lithologies of the upper Sly Gap and lower Percha Shale.

***Percha Shale formation***

Black non-calcareous shale. Found in the southern part of the quadrangle, appears to pinch out to the north. Erosion of the unit to the north is evidenced on deep channels cutting as low as the upper part of the Sly Gap and filled with pre-caballero black shales. This discordance marks the upper boundary of the Devonian interval with the overlying Mississippian Caballero formation (Pray, 1961). 5 m thick (15 feet).

***MISSISSIPPIAN UNITS***

The Mississippian strata of the Sacramento Mountains were first described by Lawdon and Bowsher (1941, 1949). They established most of the stratigraphic framework, measure and described strata of Mississippian age in the region. They also were the first geologist to recognized and study the fascinating yet still puzzling Waulsortian mud mounds. The outcrops of these mounds in the Sacramento Mountains are the best exposures known in the world.

Detailed structural and stratigraphic observations on the Waulsortian mud mounds in the Sacramento Mountains of South-central Mexico is being conducted by Romero under the advisory of Katherine Giles at New Mexico State University. Their observations suggest syn-depositional deformation was an important factor in the mounds enigmatic evolution.

Two end-member evolutionary models have been proposed, referred as to biohermal and allochthonous models. Detailed mapping of the entire Mississippian during the mapping of the Alamogordo South quadrangle presented here has shown that syn-depositional deformation is restricted to mound systems, where it is pervasive. This relationship is inconsistent with both of the proposed models. The biohermal model generates relief by biotic buildup and does not account for the deformational features documented in around mound systems. Although the allochthonous model implies deformation related to mass transport processes, the deformation should extend away from the mounded areas. However, such implied deformational patterns have not been found.

Waulsortian mounds have been described as containing a mudstone core facies surrounded by flank facies of crinoidal and bryozoan debris. Detailed observations of mound facies in the Sacramento Mountains show mound cores as chaotic accumulations of mudstone to packstone beds, with the coarser facies being most abundant. Remnant bedding is observed throughout and is chaotically oriented. Mud-filled injection dikes cut across these core facies which often show soft sediment deformation such as slump folds and scars. Stratal geometries of the flanks indicate syn-depositional structural growth. The flank facies display both thinning and onlapping of beds as they approach the mound core, as well as stratal truncation patterns. These observations suggest that the cores of mounds were moving upward as the flank facies were being accumulated.

Ongoing structural, stratigraphic, petrographic and geochemical work will provide better constrain on the evolution of the Waulsortian mud mounds and will confirm the results obtained. In the study of

reefs, Waulsortian mounds represent an important evolutionary link following the late-Devonian decline of the stromatoporoid and tabulate coral reefs and prior to the rise of the Pennsylvanian-Permian phylloid algal reefs. If the mounds are built by resedimentation processes this evolutionary model will need to be reevaluated.

The Mississippian strata were divided for the purposes of this work into four mapping units (Ml, Mm, Mu, Mr). Such division follows the evolution of the Waulsortian mounds. The lower unit (Ml) corresponds to the pre-mound development. The middle unit (Mm) corresponds to the members on which the mounds show their entire development. While the upper mapping units (Mu and Mr) represent the post-mound members which sown onlapping on the cores of mounds, and truncation. Following a brief description of each of the members is presented framed on the mapping units.

**Ml Caballero Formation and Lower Lake Valley Formation (Andrecito Member)**

***Caballero formation***

Interbedded, gray, very nodular argillaceous limestone and gray calcareous shale. In the upper part evenly bedded crinoidal grainstones and packstones. Basal contact is sharply defined and interpreted as an unconformity. Thickness ranges from 18 meters (60 feet) in the north (Alamo Canyon) to about 5 meters (15 feet) where exposed in the south.

***Andrecito member***

Calcareous shale, wackstones, thin bedded argillaceous limestone, some well sorted crinoidal grainstones and minor quartzose siltstone. Basal bed in the north contains abundant quartz silt and some sand grains. 20-35 feet thick in the north and thins to the south. Basal contact is a clearly marked disconformity, locally with an observable low angular discordance.

**Mm Middle Lake Valley Formation (Alamogordo, Nunn and Tierra Members)**

***Alamogordo member***

Medium-gray cherty wackstones to packstones developed in massive beds a few to a few hundred centimeters (few inches to several feet) in thickness. Beds are hard and resistant to erosion forming a ledge or scarp. Thickness ranges from 5 meters (15 feet) to about 12 meters (40 feet) in most places in the north and thins to lees than 5 feet in the south. The Alamogordo member shows increase in thickness in the cores of mounds.

***Nunn member***

Interbedded friable or poorly cemented crinoidal grainstones to packstones, and minor amounts of crinoidal wackstones. Thickness varies dramatically depending on position with respect to the mounds. Up to 40 meters thick in the core of mounds and about 10 meters or less in off-mound areas. The Nunn member is the least satisfactory of the members of the Lake Valley formation to attempt to trace laterally.

***Tierra Blanca member***

Crinoidal grainstones and packstones. Large nodules of light colored chert are abundant. Limestone is normally well cemented. Forms a resistant cliff. Thickness varies from a maximum of nearly 60 meters (200 feet) to a more prevalent 30 meters (100 feet) in areas where it is near to mounds, and becomes thinner away from these areas.

**Mu Upper Lake Valley Formation (Arcente and Dona Ana Members)**

***Arcente member***

Dark calcareous shale and thin bedded (<1 foot) medium-gray argillaceous limestone. Maximum thickness of 60meters (200 feet). It becomes thinner, shaly and lighter in color towards the south and east. Approaching the mounds it shows abrupt thinning and local pinch out and onlap on mound cores. The Arcente member seems to level out some of the topographic relief caused by mound development.

***Dona Ana member***

Cherty, light gray, irregularly bedded crinoidal limestone very similar to the Tierra Blanca Member. Reaches a maximum thickness of 45 meters (150 feet) and thins abruptly or pinches out when approaching major mounds. Arcente and Dona Ana are absent in northern-most outcrops where they were probably removed by pre-Pennsylvanian erosion. They are also absent from the southern part of the escarpment (Deadman 7.5’ Quadrangle) where they may have initially been but thinly developed

**Mr Rancheria Formation**

Consists of a rather monotonous repetition of a few basic rock types. Dark gray, thin bedded, argillaceous and silty mudstones or similar calcareous siltstone that contains some porous chert. A minor, though significant rock type is medium-gray, silty or sandy, crinoidal grainstones with brachiopods, shark teeth and other fossils. About 50 meters tick (160 feet) in the south and traced northward as a thinning wedge. Basal contact is a clearly marked unconformity of low angular disconformity.

## *PENSSYLVANIAN UNITS*

**Pg Gobbler Formation**

The base of the Gobbler formation is a surface of sub-aerial erosion. In the northern wall of Alamo canyon unambiguous evidences of channels as deep as 30 m (100 feet) and several hundred feet wide were observed.

At the base of this unit, filling in the channels, Minor coarse grain and fine pebbly sandstones, chert cobble conglomerate with sandstone matrix, interbedded with abundant dark gray to black shales and dark gray cherty limestones. 80 to 160 meters (200-500 feet) above the base of this unit, one of the steepest and highest cliffs in the western escarpment of the Sacramento Mountains represents the Bug Scuffle member of the Gobbler formation. This member contains almost entirely limestones, cherty grainstones-wackstones. Above the Bug Scuffle member shales and quartz sandstones predominate. 400-500 m thick (1200-1400 feet)

**Pb Beeman Formation**

Thin beds of argillaceous limestone interbedded with calcareous shale. Locally sporadic olive gray feldespathic sandstones are found towards the base. The change between quartzose sandstone to feldespathic sandstones shows the transition into the Holder formation. The upper contact of the Beeman formation with the overlying unit is marked by the lower bed of, the non-common (in this part of the Paleozoic section in the area) dolomites. 110-150 meters thick (350-500 feet).

**Ph Holder Formation**

Dark to brown gray shales and Sandstones. The Holder formation is the uppermost unit of the Pennsylvanian of the Sacramento Mountains. The formation contains a variety of rock types and lateral changes of facies can be abrupt. Algal bioherms are evident in the basal part of the formation towards the north and east. The base of the bioherms marks the base of the unit. The lower contact of the Holder is transitional. The upper contact with the overlying Permian units was not observed in this quadrangle.

## *INTRUSIVE UNITS*

**Ti Tertiary Intrusives**

Intrusive igneous rocks are common in the outcrops of the western escarpment of the Sacramento Mountains. Most of the intrusive bodies can be classified as sills, in most cases cutting nearly parallel to bedding planes. These sills appear to be localized mostly

within the shaly sections. Most of these rocks are greenish-gray porphyries. Hornblende trachyandesite porphyry is the most common rock type. Alteration has affected most of the minerals in these rocks producing alteration minerals such as chlorite, epidote, sericite, calcite and clays.

The high resistance to erosion of the sills relative to the associated strata provides exposures that, in most cases, can be followed for several hundred meters. The thickness of the sills (1-1.5 meters, 3-5 feet) is relatively continuous in the lateral extend. The greenish color of alteration and presence of hornblende phenocrystals (up to 1 cm) are the most distinctive features. When enclosed in strata resistant to erosion (limestones, i.e. in the flanks of Sugar Loaf Mound), the green color contrast with the tan to yellowish altered hosting carbonate rocks.

## BASIN FLOOR DEPOSITS

**Qse Sheetwash and eolian deposits (middle to upper Holocene)**

Silt and very fine- to fine-grained sand that has a color of pale brown (10YR 6/3) to light yellowish brown (10YR 6/4) to brown (7.5YR 5/4 and 10YR 5/3) to light brown (7.5YR 6/4). Locally, there is minor medium- to very coarse-grained sand. Sediment is generally in thick, tabular beds and commonly overprinted by soil development. Locally, there are minor very thin to medium lenses of pebbly, very fine- to very coarse-grained sand. Within these tabular beds, sediment is locally planar- to ripple-laminated and bioturbation is common. The medium to very coarse sand (in the pebble lenses) is subrounded and dominated by limestone and dolomite lithic grains. The very fine to fine sand is subrounded to subangular and more arkosic. Weakly to moderately consolidated.

Buried soils are common in this deposit (see Figure 1 for illustration of soils at one localitiy). These are marked by stage I to II calcic horizon(s) underlain by gypsic horizon(s). Locally, a soil horizons on top of the calcic and gypsic horizons are preserved. The calcic and gypsic horizons may have a very hard dry consistency.

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# Qse sediment and soil exposure

**Location: 1 km NE of northeast-end of runway of Alamogordo-White Sands Regional Airport (UTM coordinates of 3,635,264 N; 408,722 E; NAD 27)**

| Depth (cm) | | Ground surface |
|---|---|---|
| | *Younger Holocene sediment* | **Sediment:** Silt and vfL-fL sand, minor fU-vcU sand<br>**Color:** Light brown (7.5YR 6/4)<br>**Bk soil horizon:** Stage I carbonate morphology, where mottles of CaC)3 cover 10-20% of surface area and there is moderate HCl effervescene; slightly hard to hard consistency. |
| | | *Planar, sharp contact* |
| 40 | | **Sediment:** Silt and vfL-fU sand that is organic-rich. Planar- to ripple-laminated in upper 4-5 cm<br>**Color:** Brown to pale brown (10YR 5-6/3); upper 4-5 cm is lt gray to lt brownish gray(10YR 6-7/2)<br>**A soil horizon (below upper 4-5 cm):** Much organic accumulation; slightly hard to hard |
| 65 | | *Planar, gradational contact (over 2 cm)* |
| | *Older Holocene-latest Pleistocene sediment* | **Sediment:** Silty vfL-fU sand<br>**Color:** Brown to light brown (7.5YR 5-6/4)<br>**Bt soil horizon**; 3,vf-f,abk peds; est 5-15% clay; 2,f-d, pf clay films; weak HCl effervescence; slightly hard to hard consistency |
| 103 | | *Slightly wavy, gradational contact over 5 cm* |
| | | **Sediment:** Clay, silt, vfL-fU sand<br>**Color:** Light brown (7.5YR 6/4)<br>**Btky soil horizon:** 3, vf-m, abk peds; stage II calcic horizon with moderate HCl effervescence; 30% CaCO3 mottles; few 1mm-diamater root casts; gypsum present; slighly hard to hard consistency. |
| 123 | | *Wavy, gradational contact over 5-7 cm* |
| | *Late Pleistocene sediment* | **Sediment:** Clay, silt, vfL-fU sand<br>**Color:** Strong brown to reddish yellow (7.5YR 5-6/6)<br>**Bt soil horizon**; 3,c,sbk peds; 3,d-p, pf clay films; 15% mottles of gypsum and gypsum crystals form fL-fU sand; very hard consistency. |
| 183 | | |

## Interpretations:

**Time 1: Late Pleistocene sediment is deposited (probably correlates with Qf1 on the alluvial fan).**

**Time 2: A soil develops on the Late Pleistocene deposit.**

**Time 3: Older Holocene-latest Pleistocene sediment is deposited (probably correlates in part with Qf2 on the alluvial fan).**

**Time 4: A soil develops with a stage II carbonate morphology on the Older Holocene-latest Pleistocene sediment ; gypsum precipitation extends down into the late Pleistocene sediment.**

**Time 5: Upper 4-5 cm of the older Holocene sediment is deposited**

**Time 6: Younger Holocene sediment is deposited (probably correlates with Qf3 on the alluvial fan)**

The soil preserved on the upper ~0.5 m of this deposit has a stage I or less calcic horizon.

Coppice dunes cover a subordinate area on the surface of this unit and are generally less than 1 meter in height. Coppice dunes consist of silty very fine- to fine-grained sand that is pale brown to

brown (7.5-10YR 6/3), subrounded to subangular, and well sorted. The surface between the dunes is locally incised by gullies less than 2 ft deep, and locally there is a sparse cover of lag pebbles. Mesquite is the dominant vegetation type.

**Qse-Qf3** **Both Qse and Qf3 deposits are present in the gradation between the alluvial fan and basin floor depositional environments; Qse deposits are more common than Qf3 deposits**

**Qce** **Colluvium incorporating reworked eolian sediment (Holocene)**

Very poorly sorted diamicton of silty sand plus gravel. Gravel are pebble- to boulder-size (mostly pebble-size), subangular (mostly) to angular, and composed predominately of limestone. Coats of calcium carbonate cover the clasts in various proportions. Clasts are matrix-supported. The matrix is very pale brown to light yellowish brown (10YR 6-7/4), silty sand. Estimate 10-40% silt. The sand is very fine- to very coarse-grained (mostly very fine- to fine-grianed); fine sand is subangular to angular and arkosic; medium to very coarse sand is mostly composed of carbonate detritus and is subrounded. Loose.

## ALLUVIAL FAN DEPOSITS

**Qar** **Recent gravel and sand deposits (0-300(?) years old)**

Sandy gravel that underlie recent channels on the alluvial fans. Gravel is predominately limestone and dolomite, very poorly sorted, commonly bouldery, and subrounded. The sand is generally coarse, poorly sorted, and composed predominately of limestone-dolomite detritus. Loose.

The typical surface developed on this unit is very rough because of abundant boulders and recent scours. No soil development is present. There is commonly sparse to moderate vegetation growth.

This unit typically is inset into the older fan units of **Qf1**, **Qf2**, and **Qf3**; however, there are local areas of aggradation of this unit over these older units.

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

**Qf3** **Gravel, sand, and silty very fine to medium sand deposits (middle to upper Holocene) –** Channel fills of sandy gravel and gravelly sand with minor matrix-supported debris flow deposits. There are medium to thick interbeds of sheetwash deposits of silty

very fine to lower-medium sand (mostly in the medial and distal alluvial fan regions); this fine sediment may be mixed with coarser sand and pebbles. The fine-grained sheetwash deposits are very pale brown (10YR 7/3) to pale brown (10YR 6/3) to light brown (7.5YR 6/4) in color, are preserved in the medial to distal portions of the alluvial fans, and generally powdery and loose. These fine deposits become increasingly more abundant and gypsiferous to the north of the quadrangle. Coarse channel-fills are light brownish gray (10YR 6/2) to pale brown (10YR 6/3) to brown (10YR 5/3), thin- to thick-bedded, and lenticular, broadly lenticular, or U-channel-shaped with a concave-up lower contact. Gravel consists of clast-supported (matrix-supported in debris flows), rounded to subangular (mostly subrounded), very poorly to poorly sorted (mostly poorly sorted) pebbles through boulders (generally greater pebbles than either cobbles or boulders). Gravel is composed of Paleozoic limestone and dolomite with 1-10% Paleozoic siltstone, 1-5% Paleozoic sandstone, and trace to 1% igneous intrusive rocks. The matrix in the clast-supported, coarse channel-fills consists of poorly sorted, very fine- to very coarse-grained sand. Medium to very coarse sand is dominated by Paleozoic lithic grains that are subangular-rounded. Very fine to fine sand is subangular to subrounded and more arkosic in composition than the coarser sand. Loose to weakly consolidated. Considering our interpreted ages for deposits **Qar** and **Qf2**, this deposit has an age range of 6 to 0.3 ka. 1-3 m-thick.

The typical surface developed on this unit is marked by bar-and-swale topography (up to 0.9 m relief), much boulders in the medial and proximal part of the fan (although not as much as unit **Qf2**), moderately dense to no clast armor, generally no to weak clast varnish (locally there is strong varnish on the older surfaces of this unit), and a soil possessing a calcic horizon of stage I to stage I+ carbonate morphology and gypsum accumulation. Calcium carbonate rinds on surface and subsurface clasts are non-existent or less than 0.2 mm-thick (commonly only a “dusting”) and discontinuous. Ocotillo and yucca may grow on this surface where it is bouldery or cobbly.

This deposit is inset into (generally by up to 0.8 m but locally >0.8 m), overlies, or is about the same relative height as the older deposits of **Qf1** and **Qf2**.

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

**Qf3-Qf2** **Both Qf3 and Qf2 deposits are present; Qf3 deposits are more common and Qf2 deposits exceed 10% by area.**

**Qf3-Qse** **Both Qf3 and Qse deposits are present in the gradation between the alluvial fan and basin floor depositional environments; Qf3 deposits are more common than Qse deposits**

**Qf2** **Gravel, sand, and silty very fine to medium sand deposits (lower to middle Holocene)**

This unit includes two deposits, whose age difference is probably slight, which generally cannot be differentiated because of their similar surface characteristics. One place where they can be differentiated is at the mouth of Mule Canyon (UTM coordinates of: 3,633,680 N, 412,580 E, NAD 27); here, one can observe the younger deposit inset into the older deposit (the older deposit has yielded charcoal with a radiocarbon age of 8750□□ 70 radiocarbon years (9520 – 9915 calendar years before present); Koning, 1999). Both deposits consist of channel fills of sandy gravel and gravelly sand in addition to significant debris flows. There are also medium to thick interbeds of sheetwash deposits of silty very fine to lower-medium sand (mostly in the medial and distal fan regions); the fine sediment may be mixed with coarser sand and pebbles. In the proximal to medial portions of the alluvial fans, a noteworthy lithologic feature of the older deposit is that it commonly coarsens upwards from a clast-supported, stream-laid deposit to a bouldery debris flow deposit. The fine-grained sheetwash deposits are very pale brown (10YR 7/3) to pale brown (10YR 6/3) to light brown (7.5YR 6/3-4), are preserved in the medial to distal portions of the alluvial fans, and generally powdery and loose. These fine deposits become increasingly common and gypsiferous to the north of the quadrangle. Coarse channel-fills are pale brown (10YR 6/3) to light brownish gray (2.5Y-10YR 6/2), thin- to thick-bedded, and lenticular, broadly lenticular, or U-channel-shaped with a concave-up lower contact. Gravel consists of clast- to matrix-supported, rounded to subangular (mostly subrounded), very poorly to poorly sorted (mostly poorly sorted) pebbles through boulders (generally more pebbles than cobbles or boulders) that are subrounded to subangular. Gravel is composed of Paleozoic limestone and dolomite with 1-10% Paleozoic siltstone, 1-5% Paleozoic sandstone, and trace to 1% igneous intrusive rocks. The matrix in the coarse channel-fills consists of poorly sorted, very fine- to very coarse-grained sand. Medium to very coarse sand is dominated by Paleozoic lithic grains that are subangular-rounded. Very fine to fine sand is subangular to subrounded and more arkosic in composition than the coarser sand. Prominent buried soils (i.e. soils with carbonate morphology greater than a weak stage I) have not been observed in Qf2. Loose to

weakly consolidated. Generally 1-3 m-thick, but locally as much as 5 m-thick.

In the proximal and medial portions of the alluvial fans, erosion of the debris flow-dominated, coarser upper part of this unit results in a bouldery-cobbly surface and bar and swale relief (up to 0.8 m); soil development here is marked by a calcic horizon having a stage I+ to II carbonate morphology. In areas that lack debris flows, particularly the distal part of the alluvial fan, the typical surface of this unit lacks bar and swale relief, has a moderate- to well-varnished, moderate to dense clast armor, and its soil possesses a calcic horizon of stage II carbonate morphology (locally stage I+ where its surface has been eroded). Gypsic soil horizons are typical under the calcic horizons, particularly in the northern part of the quadrangle. Calcium carbonate rinds on surface and subsurface clasts are generally up to 0.2 mm-thick (locally there are minor patches of calcium carbonate up to 2.0 mm-thick) and discontinuous. Ocotillo may grow on this surface where it is bouldery-cobbly, and yucca may be abundant.

This deposit is inset into, overlies, or is about the same relative height as **Qf1** (generally up to 0.8 m of relative height difference of the two surfaces, although locally the **Qf2** surface may be inset into **Qf1** by up to 2 m or rise above the **Qf1** surface by 1 m). **Qf2** is inset below **Qf1** upstream of large fault scarps. Unit correlates to Qf2 and Qf3u of Koning (1999), and is interpreted to have an age range of 10-6 ka.

**Qf2-Qf3** **Both Qf2 and Qf3 deposits are present; Qf2 deposits are more common and Qf3 deposits exceed 10% by area**

**Qf2-Qf1** **Both Qf2 and Qf1 deposits are present; Qf2 deposits are more common and Qf1 deposits exceed 10% by area**

**Qf1** **Gravel, sand, and silty very fine to medium sand deposits (upper Pleistocene)**

Several stacked allostratigraphic subunits (commonly 1-2 m-thick) which are bounded by buried soils. These subunits are typically composed of intercalated grayish, clast-supported pebbles and cobbles (generally interpreted as stream-flow deposits) and slightly reddish, matrix- to clast-supported pebbles, cobbles, and boulders (generally interpreted as debris flow deposits). Buried soils developed on an allostratigraphic subunit usually contain a distinct reddish Bw or Bt horizon overlying white Bk or Bky horizon(s) with Stage I+ to III+ carbonate morphology. There are also subordinate medium to thick interbeds of sheetwash deposits of silty very fine to lower-medium sand. This fine sediment is more common to the north and in the distal and medial alluvial fan regions. The fine-grained

sheetwash deposits are very pale brown (10YR 7/3) to pale brown (10YR 6/3) to pink (7.5YR 7/3) to light yellowish brown (10YR 6/4), and generally powdery and loose. The amount of gypsum in these fine deposits increases to the north. Coarse channel-fills of the stream-flow deposits are pale brown to light brown in color (10YR 6/3; 7.5YR 6/3), thin- to thick-bedded, and lenticular, broadly lenticular, or U-channel-shaped with a concave-up lower contact. Gravel consists of clast-supported (local matrix-supported), rounded to subangular (mostly subrounded), very poorly to moderately sorted (mostly poorly sorted) pebbles through boulders (generally greater pebbles than either cobbles or boulders). Gravel may be imbricated as to give a southwest to northwest paleoflow direction. Gravel is composed of Paleozoic limestone and dolomite with 1-10% Paleozoic siltstone, 1-5% Paleozoic sandstone, and trace to 1% igneous intrusive rocks. The matrix in the coarse channel-fills consists of poorly sorted, very fine- to very coarse-grained sand. Medium to very coarse sand is dominated by Paleozoic lithic grains that are rounded to subangular (mostly subrounded). Very fine to fine sand is subangular to subrounded, moderately sorted, and more arkosic in composition than the coarser sand. Debris flow deposits consist of slightly reddish, matrix- to clast-supported pebbles, cobbles, and boulders. Loose to weakly consolidated. Koning et al. (2002) have assigned a late to late middle(?) Pleistocene age for this deposit. Greater than 10 m thick.

Except where it has undergone erosion, the surface of this unit is marked by a lack of bar and swale relief, varnished clasts in a dense surface armor, and a top soil having calcic horizon(s) possessing stage II+ to stage IV carbonate morphology underlain and/or overprinted by gypsic horizons (gypsum becomes progressively more abundant northwards across this quadrangle). Under the calcic horizon(s) are gypsic horizon(s). Locally overlying the calcic horizons are reddish Bt or Bw soil horizon(s). Calcium carbonate rinds on surface and subsurface clasts are 0.1-1.0 mm-thick (minor 2 mm-thick) and discontinuous. This unit seems to possess a less bouldery surface compared to nearby units **Qf2** and **Qf3** in a given location on the alluvial fan. Ocotillo plants are generally not found on this surface, and creosote may be of a smaller size and sparser than on units **Qf2** and **Qf3**.

Locally, two surfaces have developed in Qf1. We cannot determine if there are unique deposits underlain by these two respective surfaces. The surface characteristics of these two surface are relatively similar.

**Qf1a:** Slightly above the Qf1b surface (by up to 1 m) in the proximal to medial part of the alluvial fan, but lower than the Qf1b surface in the distal to medial part of the alluvial fan.

**Qf1b:** Inset slightly below the Qf1a surface (by up to1 m) in the proximal to medial part of the alluvial fan, but higher than the Qf1a surface in the distal to medial part of the alluvial fan. Creosote appears to be larger than creosote growing on Qf1a, suggesting a less-developed calcic horizon.

**Qf1-Qf2** **Both Qf1 and Qf2 deposits are present; Qf1 deposits are more common and Qf2 deposits exceed 10% by area**

**STREAM TERRACE DEPOSITS IN MOUNTAIN CANYONS**

Sandy gravel (pebbles through cobbles) terrace deposits are present in the mountain canyons. The gravel in these deposits is clast- to matrix-supported, subrounded to angular, and poorly to very poorly sorted. Three terrace deposits were differentiated based on their relative heights, which may vary from canyon to canyon and may or may not correlate to the three alluvial fan deposits downstream:

**Qt1:** **Highest stream terrace deposit in a given canyon, 3 to 15 m-thick**

**Qt2:** **Intermediate level of stream terrace deposit in a given canyon, 2 to 9 m-thick**

**Qt3** **Lowest stream terrace deposit in a given canyon, less than 6 m-thick**

## STRUCTURE

The general structure of the Sacramento Mountains in the Alamogordo South Quadrangle corresponds to a tilted fault block dipping gently to the east. These mountains represent the local eastern border of the Basin and Range Province and exhibit many of the features typical of this province (Pray, 1961). The deformation in the area can be divided in two groups, one related to the Cenozoic uplift of the Range and the other including structures that predate and have been slightly modified by the uplift.

With the exception of the normal faults and thrust fault in the front of the escarpment, most structures appear to have been formed before the uplift of the Sacramento Mountains block. Most of such deformation occurred during late Paleozoic time (Pray, 1961), and the timing is relatively well constrained through the sedimentary record. The two main structures in the quadrangle corresponding to the pre-uplift history of the range are a broad very gentle syncline (Steamboat syncline; Pray, 1961) and a slightly more sharply folded and narrow anticline (Mule Peak syncline; Pray, 1961). These structures trend north-south. Stratigraphic relationships documented by Pray (1961) in other areas of the Sacramento Mountains, offer a far better constraint on the deformational history of the Sacramento Mountains.

The present topography was likely formed by uplift with respect to the Tularosa basin along a normal fault system that lies along the base of the escarpment. This fault zone is characterized by steep dips to the west. Faulting affecting the alluvial fan and some other Quaternary units in the piedmont suggest that these are still active faults at the present time.

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