Geologic Map of the Dunken 7.5-Minute Quadrangle, Chaves County, New Mexico

By

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Open-file Digital Geologic Map OF-GM 178

Scale 1:24,000

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INTRODUCTION

The Dunken 7.5' quadrangle was mapped at the same time as the Robertson Canyon 7.5' quadrangle immediately to the west. Since most of the rock descriptions, fossils, and structures are similar in each quadrangle, the two areas are included here in the same report.

The Dunken quadrangle rests on the east side of the gentle, east-dipping slope (the "Pecos Slope") of the uplifted Sacramento Mountains. To the west, the Sacramento Mountains rise to over 9000 feet, but most elevations in the Dunken quadrangle range between 5000 and 6000 feet. In the Robertson Canyon quadrangle they range from about 5800 to almost 7000 feet. The western part of the Dunken map skirts the subtle, but visible, transition from the last sizeable highlands of the Sacramento Mountains to the beginning of the Great Plains. This same transition is marked by a change from Juniper trees in the higher elevations to open grassland in the lower elevations. Almost all of the Sacramento Mountains are composed of Paleozoic sedimentary rocks and most of the eastern slope is composed of Permian formations—the most aerially extensive in the state.

Access within the map area is generally good. State Route 24 is a well maintained paved road that slices north-south across the Dunken quadrangle. Several other 2-wheel-drive-passable dirt roads branch off this road both east and west, particularly Road CR10, which follows Blackwater Creek in the Robertson Canyon quadrangle. The map area is a mixture of State Land, Public Land (BLM), and Private land. Field work was carried out during parts of October, November, and December, 2007. Since this is during hunting season access to some private land was not granted, particularly in the northwest corner of the Dunken quad. Aerial photographs were used to help fill in some areas on the map where access was denied. Also, aerial photos were used to help determine the strike and dip direction of nearly horizontal strata. Some of the animals seen during this study include fox, coyote, porcupine, rabbit, white tail deer, skunk, scorpion, falcon, and golden eagle.

PREVIOUS WORK

Although Kelly's (1971) synopsis of the Pecos Slope remains one of the more accessible publications about the lithology and structure of the area, several unpublished works include quite a bit of structural information specific to the Pecos Slope area. Cook (1960) produced a detailed photogeologic map of the Dunken area showing structural deformation. Trollinger et al. (1964) created a smaller-scale photogeologic/ geomorphologic map of a larger area encompassing the 'northwestern shelf area.' Inland Gas Corporation (no date) produced a regional magnetic map for part of the Pecos Slope. Jack Ahlen in Roswell, New Mexico, has been compiling information about the lithology and structure of southeastern New Mexico for many years. Summers (1968) described the San Andres Limestone from the perspective of its oil and water reservoir characteristics. Kues and Giles (2004) provide a good general overview of the history of deposition and deformation associated with the Ancestral Rocky Mountains, in southeastern New

Mexico. Telles and Ellison (1954) produced a beautiful color east-west cross-section across the Sacramento Mountains.

THE SAN ANDRES FORMATION

Lithology

The Permian (late Leonardian to early Guadalupian) San Andres Formation forms all of the bedrock exposed in the Dunken quadrangle. Within the study area the San Andres Formation is composed of a sequence of alternating dark and light gray medium- to thick-bedded dolomite and dolomitic limestone (Figure 1). As Kelley (1971) described, the distinction between the Bonney Canyon and Rio Bonito members observed farther to the north is not readily discernable in this area. As a result, there are no laterally continuous mappable units within the formation. This made it very difficult if not impossible to correlate stratigraphic positions within the formation between outcrops separated by valleys and/or younger deposits. One obvious distinction could be made, however, between darker, brown- and gray-colored beds (**Psd**) and lighter-colored beds (**Ps**). Caution should be used when attempting to correlate these two subunits with the two members of the San Andres Formation. **Psd** and **Ps** were not mapped separately based on any sedimentological criteria that were used to distinguish the two members farther north. Therefore, this distinction may only apply to this local area. To aid future correlation, and to help better visualize bedding attitudes in the northwest, selected ‘index horizons’ were traced from aerial photographs and transferred onto the map. The layers have no particular significance other than they were easy to see on the photos.

The San Andres Formation is characterized by medium to thick beds that are mostly sub-planar and commonly exhibit small-scale wavy upper and lower surfaces (Figures 2 and 3). No shale partings were observed between beds. Most beds are massive, and only some, usually the lightest gray colored dolomite beds, show abundant internal laminae. These laminae are commonly planar and parallel to bedding, and less commonly they are contorted. Except for the prevalence of laminae within the lighter colored dolomite, there does not appear to be an obvious genetic difference between the dark gray and the light gray carbonate beds. Both are composed mostly of dolomicrite and microdolospar. The darker carbonate beds locally appear to contain more abundant skeletal fossil debris and in places can be described as a skeletal packstone, but some of the lighter gray beds also contain skeletal debris. The laminae in the lighter colored laminated beds probably indicate that these beds did not undergo extensive bioturbation. Rare beds contain chips and/or pebbles of carbonate, cemented by carbonate, up to a few tens of centimeters thick that may represent storm rip-up deposits. All beds, from the bottom of the exposed San Andres section to the top, characteristically produce a weak to strong petroliferous odor when broken with a hammer.

In thin-sections, the San Andres Formation is composed mostly of microdolospar—very small but discernable subhedral crystals of dolomite. Fossil shell and crinoid debris is locally replaced by large, crystallographically continuous dolomite crystals, and in other sections is replaced by many smaller dolomite crystals. In several of the ten thin-sections examined, tiny sub-circular to oval forms are abundant. They show weak concentric laminae and resemble small oolites. Porosity in 9 of the 10 sections is intracrystalline and is typically between 2-5%, though in two sections appears to be closer to about 10% and locally vuggy.

Chert is abundant locally, but overall forms a minor component of the San Andres Formation. Chert is mostly medium to dark gray, commonly with light-colored spots or irregularly shaped areas. It is typically nodular with irregularly shaped nodules appearing more or less parallel to bedding when viewed from a distance. Locally, angular broken chert fragments form a darker lag on the surface. In places, the chert commonly weathers dark orange. Some cherts contain numerous tiny pits on weathered surfaces that may be the result of erosion of formerly entrained dolomite crystals and/or evaporite minerals. The cherts in the San Andres Formation probably formed as a result of selective replacement of carbonate by silica during burial and early diagenesis.

Kelly (1971) described the presence of well sorted, Glorieta-like, quartz sandstone layers to the north within the San Andres Formation. Only one such layer was seen during mapping. It crops out within the core of the largest anticline near the north side of the Robertson Canyon quadrangle. This position is the structurally lowest part of the stratigraphy, as far as can be discerned. It shows up as a slightly lighter yellowish gray layer compared to the slightly darker gray surrounding carbonate beds. The sandstone was not mapped separately, but is shown in cross-section B-B' where the top of the Yeso Group intersects the surface within the eastern side of the Tinnnie fold belt. The sand grains are subrounded to well rounded and moderately well sorted to well sorted. In thin-section the grains are surrounded and cemented by pink coarse-grained dolospar. This sand apparently represents the influx of far-traveled material, possibly shed off the Pedernal uplift to the north and west. Well logs in the area (Figure 4) also record the presence of Glorieta sandstones near the base of the San Andres Formation.

Fossils

Although fossils within the San Andres Formation are abundant, they are not easy to find everywhere. They are more abundant to the west in the Robertson Canyon quadrangle where relief is greater. Small diameter (2-3 mm) crinoid stem fragments are the most common fossils in many layers. Less common are perforated sheet-like bryozoans (Figure 5) and large 2-4 cm-wide productid brachiopods (Figures 6 and 7). Beautiful coiled gastropods are common (Figure 8) and occur as moulds, casts, and as replaced shell material. The gastropods are typically between 3 and 4 cm across, though one specimen was 10 cm in diameter, and can be differentiated from ammonites by the absence of (preserved) septae. Most of the coiled gastropods rest with the plane of their coils sub-parallel to the bedding planes, such that most of their coiled form is visible on weathered surfaces. Rare *turritella* gastropods 1-2 cm long were seen, as well as one remarkable specimen 12 cm long and 5 cm wide (Figure 9). Two partial ammonites containing convoluted septae (Figure 10) and a few nautiloids containing simple smooth septae were also observed, but these forms are rare (Figures 11, 12, and 13).

Locally in the Robertson Canyon quadrangle, branching corals are selectively replaced by dark gray, orange-weathering chert. The corals were only found in a few places (in the hills in the south-central part of the Robertson Canyon quadrangle, immediately north of Blackwater Creek) and occur in specific beds up to about 30-40 cm thick. They appear to branch upward from one basal branch and fan up and outward. Well-preserved specimens exhibit small rather equally spaced pores 2 mm in diameter on their outer surfaces (Figure 14). The corals were observed in only a few layers, but their apparent scarcity may also be a result of non replacement by silica in other areas. Considering that the layers of carbonate immediately below the coral layers are composed of micrite and microspar, and were likely carbonate mud at the time of deposition, it is uncertain as to what kind of hard substrate the corals attached themselves. Sparse, small, isolated horn corals up to 1 cm in diameter are selectively replaced by light gray chert (Figure 15).

Another striking and locally abundant fossil occurs as small, stretched oblate spheroids (stretched football shapes) up to 3 cm long and about 3-4 mm wide. In cross-section these forms are circular. They occur in great numbers in some beds and are absent in most others. They have been replaced by coarse calcite spar so no internal features are visible, but they are probably giant fusulinids. The forms are light gray and stand out in contrast to the darker gray carbonate layers in which they commonly reside (Figure 16).

The crinoid, brachiopod, bryozoan, and gastropod fossils have all been replaced by coarse calcite spar. Most of the spar is light gray, but the spar replacing the gastropods is for some reason commonly brown-colored. Even in carbonate layers showing no obvious fossils, the larger calcite crystals on fresh broken surfaces commonly bely the presence of fossil debris. The rarity of internal fabrics in the carbonate layers and the local abundance of tiny skeletal debris suggest that much of the original carbonate muds were extensively bioturbated.

Dissolution Features

Dissolution features are common throughout the San Andres Formation. Many such features are subtle and not obvious while others are quite clear. Subtle features include selective dissolution along bedding planes, in some areas only a centimeter or so thick, where the bed has turned to a light gray powdery residue. These beds are locally connected to other partially dissolved beds by subvertical zones. Dissolution cavities are in places completely filled with coarse calcite crystals several centimeters across. More rarely, dark yellow, banded, translucent calcite fills former voids. In other areas of the Southwest, this type of banded calcite commonly fluoresces bright pink under short-wave ultraviolet light.

Probably the most striking dissolution features occur as a mappable layer of carbonate breccia (map unit **Psx**), exposed in the central part of the Dunken quadrangle. This very poorly sorted breccia contains angular blocks of the San Andres Formation from pebble-size to large blocks 10 meters or more long, strongly cemented by light gray fine-grained carbonate (Figures 17 and 18). This kind of chaotic breccia can been seen throughout the map area, although on a much more local scale such as a few meters across. This unit in particular (**Psx**) is mostly exposed immediately beneath the higher Tertiary gravel deposits. It isn't clear if the breccia deposits somehow controlled the subsequent deposition of the gravels or if they just happen to be better preserved under the Tertiary deposits. In any case, the best interpretation of the breccias is that they represent break-down deposits that formed when the roofs of caves collapsed. These caverns may have formed due to preferential dissolution of evaporite minerals, particularly bedded anhydrite which is interbedded within the San Andres Formation farther north (Kelly, 1971).

High in the landscape along the tops of ridges and mesas, the San Andres Formation locally shows more pronounced dissolution than elsewhere. Carbonate layers are commonly broken and re-cemented such that the dips vary quite dramatically at the outcrop scale. These layers also commonly appear chalky white and contain abundant carbonate in the soil. Some of the best exposures of this type of dissolution feature can be seen actually outside the study area, in road cuts along Highway 82 and eastward for miles towards Artesia. The presence of thick and extensive carbonate rinds and carbonate pendant features indicates long-lived pedogenesis, and suggests that these layers high in the landscape may be part of a relict stable surface, probably of great age and extent (late Tertiary? Older?) that has since been deeply dissected by streams.

Probably the oldest such stable surface in the Dunken quadrangle occurs about 1-2 miles directly east of Dunken itself. Here, exposure is very poor, but a cap of laminar caliche is preserved and mostly covered by a dark brown soil. Blocks of this laminar caliche are exposed along the road. At first glance the blocks strongly resemble the nearby carbonate layers of the San Andres Formation. Upon closer examination the layers are composed of undulating calcite laminae draped over and around carbonate clasts. A small quarry here apparently mined this material and reveals at least five feet of pedogenic carbonate overlying an older reddish brown soil several feet thick. This caliche cap, and a few scattered remnants to the south (not mapped), also overlie the gravel deposits (**Tc**), indicating that this stable surface developed after deposition of these high gravels.

TERTIARY GRAVELS AND LANDSCAPE DEVELOPMENT

There are two similar, yet different, Tertiary gravel deposits in the Dunken quadrangle. It is not immediately apparent how the two are related. The first are the gravels resting at high levels in the landscape, commonly capping ridges and flat mesas in the central and eastern parts of the map area. These deposits were mapped as unit **Tc**. The second are the gravels slightly lower in the landscape that fill ancient paleochannels. These deposits were mapped as unit **Tcc**. Although the paucity of shrubs and trees allows for unobstructed views over great distances across much of the map area, the near-identical erosion and weathering of the San Andres Formation and the gravels, combined with pedogenic processes and grass cover, portends that the gravel deposits are nearly invisible from even a short distance away. Gravel deposits of both types are generally characterized by an assortment of subrounded to well rounded pebbles and cobbles, and less commonly boulders up to 1 meter across (Figure 19). However, weathering of the underlying carbonate can locally produce rounded clasts that mimic gravel deposits. By far the best way to distinguish the gravels from the carbonate bedrock (in the absence of definitive outcrop) is the nearly universal presence of multicolored carbonate clasts within the gravels—both light and dark gray clasts (plus or minus chert clasts). Pedogenic (soil-forming) processes tend to break apart the rounded clasts into angular fragments and add angular chips of caliche, so that some of the older preserved upper surfaces of the gravels look confusingly like weathered carbonate bedrock. The presence of multicolored clasts, however, is typically diagnostic (Figures 20, 21, and 22). Deposits of **Tc** were also mapped in the southwestern part of the Robertson Canyon quadrangle where they form high, dissected hills with sharp, apparently high-angle contacts with the San Andres Formation along tributaries of Blackwater Creek.

Erosional remnants of **Tc** high in the landscape are quite extensive. Their outcrop pattern and position in the landscape in the Dunken quad suggests that they originally blanketed much of the area in deposits between 100 and 200 feet thick. The position of the modern outcrops suggests that **Tc** formed by sediment disgorged from the stream valleys entrenched into the mountains to the west. East and southeast of Dunken, the basal contact drapes down into two of the modern drainages, indicating that the gravel deposits filled paleo-relief in the underlying bedrock. If the uppermost surface of these deposits is projected eastward it butts up against the high bedrock hills in the northwest quarter of the map area. If this was really the uppermost surface of the gravels, then the gravels likely did not completely cover all the bedrock in the area. The present drainage pattern, although deeply entrenched, appears to have been at least partly controlled by the same preexisting topography.

In the northeast quarter of the Dunken quad gravel deposits form curvilinear bands that cut across the bedrock near, but not exactly following, the modern drainages. These deposits are **Tcc**. Where discernable, contacts between the gravel deposits and the carbonate bedrock are locally vertical. Sorting in the deposits is generally poor, with clasts ranging from gravel to large boulders over 1 meter across (a few boulders are up to 2 meters across—sand is less than a few percent and is composed of angular dolomite and chert). Clasts are subrounded to well rounded. Good exposures are almost nonexistent, except in a few near-vertical stream cuts (Figure 23). In these exposures no bedding is visible and imbrication is questionable. The deposits are strongly cemented in most places by a matrix of fine-grained light gray carbonate, forming a very resistant, cement-like rock. The map pattern suggests that these gravel deposits fill older, ancient stream valleys possessing depths and widths comparable to the modern stream valleys. These ancient stream valleys were incised by down-cutting streams, then back-filled to overflowing by the gravel deposits. Sometime later the streams yet again began incising downward, but the older channels were not re-exhumed because cementation made the deposits just as hard and resistant at the surrounding bedrock. Subsequent incision did not ‘see’ these deposits and locally cut right across the old channels.

An important question is, are the ancient stream valleys older or younger than the high gravels on the ridges. It is possible that the ancient stream valleys were cut first then back-filled all the way to the top of the ridges, and then the more recent incision ensued. It is also possible that the higher gravels formed first, and were later incised by the ancient stream valleys, which were then subsequently back-filled. It isn't clear which one of these is the better interpretation.

QUATERNARY DEPOSITS

The Holocene deposits (map units **Qyc**, **Qy$_1$**, **Qy$_2$** and **Qy$_3$**) form the lowest terrace surfaces in the landscape. In this study two distinct levels were mapped—an older, incised flood plain terrace that is typically between 5-8 feet above the modern channel, and the modern channel itself. Near the modern creek beds this distinction is easy to see, but away from the creek beds it is less distinct. Away from the creek beds map unit **Qy$_1$** forms broad, smooth gentle slopes showing minimal relief. In some areas subdivision of the Quaternary units was not attempted and in these areas the deposits are mapped simply as **Qs**. On the surface mapped as **Qy$_1$**, much of the sediment is tan to brown silty soil, but where exposed in stream cuts much of the underlying material is composed of loosely consolidated pebble and cobble conglomerate interbedded with silt layers (Figures 24 and 25). On some of the steeper slopes along the Dunken Well Road the thin brown silty surface layer overlies older soils containing light gray nodular and laminar caliche (Figures 26 and 27). In other areas, therefore, this widespread relatively young mantling layer of Holocene alluvium is fairly thin and may have been deposited relatively recently (<10,000 years ago).

Twelve small closed depressions occur in the study area. None contain any lakes presently, but all contain brown silty soil that was probably washed in and deposited when these depressions contained water. The ranchers living in the area said that at least the lakes downstream from Dunken were partially filled when the springs upstream were running within recent memory. Depressions like these act as traps for accumulating sediment, dust, and pollen, and may preserve a record of changes in vegetation and past climates.

Mapping of the Holocene deposits is useful because it is these surfaces that are prone to flooding during heavy rains. On the night of October 1(?) 2007 a very large thunderstorm dumped rain on the upper reaches of Cherry(?) Canyon. Sometime during that night, flow in the normally dry creek was strong enough to wash out the pavement of State Route 24 about 2.5 miles north of Dunken. A few days later, while mapping about two miles downstream, plant debris was seen stuck in the tops of some of the trees in places over 12 feet above the level of the wash. In that area, the water during the storm and subsequent flood was deep enough to fill the 6-7 foot-deep main channel (map unit **Qyc**) and overtop the next highest terrace (map unit **Qy$_1$**) by five feet.

Tufa deposits are found along Rio Peñasco and the tributary immediately to the south, in the northeast part of the Dunken quadrangle. They are found only in the older Holocene deposits (**Qy$_1$**), where they most commonly crop out along the edges of the dissected terrace, and raised about 2-5 meters above the modern stream level (Figures 28 and 29). The deposits are commonly covered by a thin layer of silty brown alluvium, but locally that alluvial cover has been stripped away and the tufa deposits form an exposed bench. In some areas the tufa forms a layer composed of cavernous pillars of relatively porous and low-density granular and fine-grained carbonate, resembling a miniature karst terrain. These deposits can be broken relatively easily. In other places they form a cemented intergrown mass of thin hollow carbonate tubes that bend and wind around one another. These tubes probably formed partly subaqueously as carbonate precipitated onto filamentous algae growing within the perennial streams. In one excellent exposure along Rio Peñasco, near the right-angle turn about 1.5 miles west of the eastern side of the map tubular, tufa forms a cemented deposit accreted to a preexisting 1-2 meter-high waterfall in the carbonate bedrock. The modern stream still flows in the same position but part of the tufa is above the water on the sides of the waterfall. Also at this location is exposed a slightly older tufa layer associated with an older Holocene terrace deposit a few meters above the modern stream.

STRUCTURE

The structure in southeastern New Mexico is complex and long-lived. Early Paleozoic shallow-water and near-shore cratonic marine deposition was interrupted in the Pennsylvanian by block uplifts associated with the ancestral Rocky Mountains (Kues and Giles, 2004). In the Sacramento Mountains the Pedernal uplift rose above sea level and was eroded down to the crystalline basement before siliciclastic deposition of the Abo Formation in the early Permian. Subsequent marine deposits of the Yeso and San Andres Formations conformably overlie the Abo Formation. An erosional unconformity exposes the San Andres Formation across much of the eastern side of the modern Sacramento Mountains.

Numerous folds have been identified in the map area. All of these folds are exposed within the San Andres Formation, the only bedrock formation currently exposed at the surface. The folds take the form of very abrupt monoclinal kinks and much broader synclines and anticlines. The axes of these folds are shown in Figure 30. The Dunken area is complex because it is an area where fold axes of different orientations appear to intersect (see Figure 12 on page 36 of Kelly, 1971 for a regional perspective). In the Dunken quadrangle several prominent fold axes strike northeast and project for quite a ways beyond the boundaries of the map. One of these, the Six Mile Buckle, is a sharp, narrow anticline (see cross-section) containing beds on the limbs of the fold that dip up to 60°. The fold can best be seen from a distance on the south side of Rio Peñasco, near the north edge of the map. Kelly (1971) interpreted the Six Mile Buckle as a strike-slip fault. However, at least in the vicinity of the Dunken area there is no evidence for faulting in this fold at the surface. It is possible that deeper levels of the fold may be cored by a fault, as illustrated on the cross-section. Aeromagnetic data (Inland gas Corp.) suggests the possibility of right-lateral strike-slip motion of the basement.

The larger, unnamed fold about one mile west of the Six Mile Buckle is characterized by a rather gentle east-facing monocline with maximum eastward dips up to about 23°. The fold axis for this, and other, monoclines is drawn along the inflection point of the fold—the position of maximum dip. To the southwest, there are several more fold axes parallel to this larger flexure. About 1 mile to the west, another sharp kink contains maximum eastward dips of about 75°. Progressing southward, the fold axes change orientation from northeast to north-south and slightly southeast. In the northeast corner of the Dunken quad northwest-striking fold axes strike nearly perpendicular to the axes of the Six Mile Buckle. There are no cross-cutting relationships visible within the map area, so it is not certain if these perpendicular fold axes represent two separate deformational events or part of the same event.

The Robertson Canyon quadrangle is dominated by many north-south-striking fold axes that are interpreted to belong to the Tinnie fold belt exposed farther north (Kelly, 1971). As seen in the cross-section, this fold belt contains several shallow anticlines and synclines, but is dominated by two or three rather sharp kinks. The easternmost kink contains eastward dips up to 75° (Figure 31). Projection of the stratigraphy within the State A-6 No.1 well, located about 5 miles north, provides some control on the stratigraphy at depth. If the stratigraphy can be projected this far south, it shows that the pre-Yeso formations thin to the west, towards the presumed Pedernal uplift. Projections of two other wells (see text on cross-section) indicate that the pre-Yeso formations are missing altogether of the western side of the Tinnie fold belt, and this is represented in the cross-section. The sharp, west-facing kink-fold near the middle of the fold belt contains vertically dipping beds. A reasonable explanation for the presence of this steeply dipping fold is the presence of a high-angle fault at depth. As drawn, this speculative fault dips steeply eastward, and forms the fault-bounded boundary of the Pedernal uplift. Normal motion on this fault allowed uplift of the block on the west in pre-Abo time. Subsequent reverse motion in post-San Andres time created the sharp fold in the San Andres Formation. It is also possible that the sharp fold to the east is also cored by a similar fault.

Near-vertical joints in the San Andres Formation are exposed in almost every outcrop (Figure 32 and 33). The strike of the joints is constrained within a relatively narrow arc—between about N30°E and N55°E, with an average of about N40°E.

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UNIT DESCRIPTIONS

Quaternary Deposits

Qp **Playa deposits (Quaternary).** Closed depressions contain mostly dark tan to brown silt and clay. Top surfaces are commonly disturbed by cows.

Qyc **Modern channel deposits (Quaternary).** Dominated by unconsolidated limestone gravel and interbedded tan silt. The scratched surfaces, roughened by bedload abrasion during recent flow events, imparts a lighter gray color to these deposits that shows up prominently from a distance and on aerial photos.

Qy **Holocene alluvial deposits, undivided (Quaternary).** This unit consists of map units $\mathbf{Qy_3}$, $\mathbf{Qy_2}$, $\mathbf{Qy_1}$, and **Qyc**.

$\mathbf{Qy_3}$ **Holocene alluvial deposits, younger deposits (Quaternary).**

$\mathbf{Qy_2}$ **Holocene alluvial deposits, middle deposits (Quaternary).**

$\mathbf{Qy_1}$ **Holocene alluvial deposits, older deposits (Quaternary).**

Qm **Middle Quaternary alluvial deposits.** These deposits were mapped separately on the basis of aerial photographs.

Qo **Older alluvial deposits (Quaternary).** Most surfaces are mantles with thin dark brown soil. Where exposed, these deposits consist of interbedded limestone conglomerate and interbedded tan silt. Stage III and IV caliche is visible in the uppermost 1-2 meters exposed locally. As mapped, some areas contain broad swales that are likely floored by younger Holocene deposits, but were not mapped separately.

Qs **Quaternary alluvial deposits, undivided (Quaternary).** As mapped, this unit may include Quaternary sedimentary deposits of any age.

Quaternary or Tertiary Deposits

QTc **Quaternary and/or Late Tertiary sedimentary deposits.** This unit was mapped in only one place near the central part of the map, east of Dunken. It is expressed by a relatively flat, apparently constructional surface that has not been eroded. Poking through the thin dark brown soil is abundant thick laminar caliche. A small quarry exposes more than 2 meters of laminar caliche overlying reddish brown silt.

Tertiary Deposits

Tcc **Channelized Tertiary Sedimentary Deposits (Late Miocene and/or Pliocene?).** Dominated by conglomerate containing subrounded to rounded, poorly sorted pebbles to boulders derived from the San Andres Formation. The matrix is mostly strongly cemented silt and carbonate, with minor carbonate sand. Exposures are rare. No bedding or grading is visible. These deposits fill deep paleochannels locally exhibiting vertical walls, and are strongly cemented.

Tc **Mesa-capping Tertiary Sedimentary Deposits (Late Miocene and/or Pliocene?).** These deposits are nearly identical to those of **Tcc**. They are dominated by conglomerate containing subrounded to well rounded pebbles to boulders locally over 1 meter across, composed almost entirely of limestone, dolomite, and minor chert derived from the San Andres Formation. Where rarely exposed, matrix is lighter gray fine-grained carbonate. Conglomerates can be best distinguished from neighboring San Andres Formation by the presence of light- and dark-gray-colored clasts, and rounded clasts. Top surfaces have been altered by pedogenesis and clasts here are commonly broken and angular. Exposures are rare. No bedding or grading was seen. These deposits cap the tops of flat mesas along the central and eastern parts of the map. These exposures probably formed a continuous sheet before dissection, and may be correlative to the Ogallala Formation.

Paleozoic Rocks

Psx **Breccia (post-depositional).** Poorly sorted, angular fragments of limestone and dolomite are surrounded by a fine-grained matrix of carbonate either the same color as the clasts or slightly lighter. Bedding within individual clasts is oriented randomly, indicating that the clasts have been rotated with respect to one another. Poorly exposed. Best exposures are in the north immediately east of the State Route 24. Resembles cave-roof break-down breccia (cavern-collapse breccia).

Psc **Chaotic zones within the San Andres Formation (post-depositional).** Dominated by large areas where bedding is highly variable on the scale of meters to tens of meters. Up close, individual beds do not appear brecciated, but undulate, in some cases dipping up to 30 degrees or more in one direction and a few meters away dipping the same amount in another direction. These apparent folds show no preferred orientation, and many appear to form bowl-shaped structures. It is possible this chaotic bedding was formed during dissolution and removal of evaporite minerals and subsequent partial collapse of the overlying beds.

Psd **San Andres Formation, brown unit (Permian).** Alternating beds of light to dark brown and light to medium gray dolomite. Dolomite is mostly fine-grained dolomicrite. The brown color is apparent in some outcrops and subtle in others. The difference between this unit and **Ps** is best seen on aerial photos. No evaporite minerals were seen, so correlation with the Bonney Canyon member of the San Andres Formation is speculative and may not be accurate. This unit was mapped only in the northeast part of the Dunken quadrangle where it is most clearly visible. It may exist farther south, but exposures are poor.

Ps **San Andres Formation, undivided (Permian).** Interbedded medium- to thick-bedded light to dark gray dolomite and limestone. Darker grey beds are commonly more fossiliferous than the lighter gray dolomite beds, which are commonly laminated and show no signs of bioturbation. Dissolution features include small to large vugs millimeters to several centimeters or more across, and small irregularly shaped chaotic zones filled with light yellowish gray carbonate. Dissolution features commonly form discrete zones parallel to bedding. No clay partings were seen between beds. Fossils include productid brachiopods, coiled gastropods, crinoids, and large fusulinids (*Triticites*?) up to 2 cm long. Less common fossils include turritella-like gastropods, ammonites, nautiloids(?), and branching corals.

Figure captions:

1. Hills composed of the San Andres Formation showing thin to medium bedded dolomite and limestone. View is to the northwest on the west side of the Tinnie fold belt in the Robertson Canyon quadrangle.
2. Outcrop of the San Andres Formation, northern Dunken quadrangle.
3. Outcrop of the San Andres Formation, southern Dunken quadrangle.
4. Lithologic interpretations of available well logs in the Dunken area.
5. Bryozoan fossils in the San Andres Formation.
6. Brachiopod fossils in the San Andres Formation.
7. Brachiopod fossils in the San Andres Formation.
8. Typical coiled gastropods replaced by brown calcite in the San Andres Formation.
9. Very large *Turritella*-like gastropod in the San Andres Formation.
10. Complex suture pattern in ammonite in the San Andres Formation.
11. Large probably nautiloid weathering out of limestone of the San Andres Formation.
12. Nautiloid weathering out of limestone of the San Andres Formation.
13. Nautiloid weathering out of limestone of the San Andres Formation.
14. Portion of a colonial branching coral replaced by chert in the San Andres Formation.
15. Solitary horn coral in the San Andres Formation.
16. Possible very large fusulinids in the San Andres Formation.
17. Outcrop of cemented **Psx** breccia in the San Andres Formation, southern Dunken quadrangle.
18. Outcrop of cemented **Psx** breccia in the San Andres Formation, southern Dunken quadrangle.
19. Weathered exposure of **Tc** showing multi-colored rounded clasts of various sizes.
20. Fresh exposure of **Tc** in stream-cut.
21. Weathered surface of **Tc** deposits high in the landscape, central Dunken quadrangle.
22. Weathered surface of **Tc** deposits high in the landscape, central Dunken quadrangle.
23. Stream-cut exposure of **Tcc** deposits in paleochannel. Layers in foreground are San Andres Formation. Contact between the two units on the right is vertical.
24. Typical stream-cut exposure of $\mathbf{Qy_1}$ showing interbedded tan sit and gray carbonate pebbles. View is to the north, southern Robertson Canyon quadrangle.
25. Close-up of $\mathbf{Qy_1}$ deposits in a stream-cut exposure.
26. Remarkable stream-cut exposure showing three different ages of Quaternary deposits. The youngest, darkest gravels are weakly consolidated, and overlie an older moderately cemented deposit containing abundant disseminated pedogenic carbonate. Both overlie an erosion surface in yet an older deposit containing pedogenic carbonate nodules. Southern Robertson Canyon quadrangle.
27. Younger gravel deposit overlies older soil containing pedogenic carbonate nodules. Mapped as **Tc** near confluence of Blackwater Creek and Left Hand Canyon.

28. Low-density tufa deposit exposed within **Qy_1** deposits along Rio Peñasco, northeast Dunken quadrangle.
29. Close-up of a piece of tufa showing tubular structure.
30. Fold axes in the Robertson Canyon and Dunken 7.5’ quadrangles.
31. Dramatic folds in the San Andres Formation, eastern side of the Tinnie fold belt. View is to the north about 1 mile south of the northern boundary of the quadrangle. Folds are slightly exaggerated due to distortion.
32. Joints in the San Andres Formation, northern Dunken quadrangle.
33. Joints in the San Andres Formation, southern Dunken quadrangle.