



Arroyo de Las Calabacillas

OF-DM 9

**GEOLOGY OF THE
SKY VILLAGE SE† 7.5-MINUTE QUADRANGLE,
SANDOVAL COUNTY, NEW MEXICO**

by

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801 Leroy Place

†The quadrangle name has been recently changed to "Arroyo de Las Calabacillas."
Socorro, NM 87801-4796

EXPLANATION OF MAP UNITS

Quaternary System

Quaternary alluvial deposits of the Sky Village SE 7.5-minute quadrangle contain variable proportions of gravel, sand and silt, deposited by ephemeral streams, eolian activity and mass-movement processes. Colluvial deposits typically occur on hill slopes. Eolian deposits commonly occur on the margins of broad arroyos and on isolated hill tops. Stream alluvium is confined within valleys incised into Cenozoic deposits. Many units are covered by relatively thin and extensive cover of sand with local scattered pebbles that obscures most surficial map relations. Because of poor exposures, map-unit differentiation is based primarily on morphostratigraphic relations (surface morphology and geomorphic position), and to a lesser extent, on stratigraphic position (inset or depositional relations), degree of soil-profile development (see Gile and others, 1981) and sedimentary character. Where exposed, deposits are a mixture of poorly sorted, poorly to moderately stratified, clast- and matrix-supported alluvium, having predominantly sandy to gravelly textures; silt-clay textures are locally common. Clast constituents typically reflect lithologic composition of local upland drainage systems developed on the Llano de Albuquerque and the eastern escarpment of the Rio Puerco drainage divide, known as the Ceja del Rio Puerco. Alluvial deposits are divided into three major classes: 1) valley-fill and valley-border alluvium; 2) mixed eolian, colluvial and alluvial deposits; and 3) colluvium. The general characteristics of these classes are:

Valley-fill and valley-border alluvium (Qa and Qv subunits) – Stream (floodplain, fill-terrace) deposits are restricted to entrenched valleys and tributaries, such as Arroyo de las Calabacillas and Arroyo de los Montoyas and tributaries. Valley-border units are sloping surfaces that are graded to former positions of entrenched valleys and tributaries.

Mixed eolian, colluvial and alluvial deposits (Qe and Qve subunits) – Sandy deposits that commonly form a relatively thin mantle over Santa Fe Group basin fill.

Colluvium (Qca subunits) – Mass-movement deposits with interbedded eolian and stream deposits. Units typically form along relatively steep hillslopes and are discontinuously preserved on the hanging-wall of major faults.

- Qa** Stream alluvium (historic to Holocene) – Poorly consolidated, fine-to coarse-grained sand and pebbly sand with minor silt and clay. Soils are very weakly developed and contain disseminated or no pedogenic calcium carbonate. Unit underlies arroyo floors and modern stream channels.
- Qay** Stream alluvium, undivided (Holocene) – Poorly consolidated, fine-to coarse-grained sand and pebbly sand with minor silt and clay. Soils are very weakly developed and contain disseminated or no pedogenic calcium carbonate. Unit forms low terraces and valley-border fans that grade to low terraces within major arroyos.
- Qvy** Stream alluvium, eolian deposits and colluvium, undivided (upper Pleistocene to Holocene) – Poorly consolidated and poorly exposed, light yellowish-brown to yellowish-brown (10YR 6/4 to 5/2) and reddish-yellow (10YR 6/6), very fine- to medium-grained sand with scattered pebbles and rare silt- and clay-rich beds. Soils are weakly developed and possess stage I pedogenic calcium-carbonate morphology. The unit forms broad valley-floor and valley-border deposits within broad valleys of Calabacillas and Montoyas arroyos. Valley floors are underlain by sand and gravel deposited by ephemeral streams. Valley borders are dominated by small fan and colluvial deposits derived from Qae and Santa Fe Group sediments. Unit **Qvy(e)** delineates valley-border deposits covered with fine-grained eolian sand (see description of Qe).

- Qvae** Stream alluvium, eolian and alluvial-slope deposits, undivided (middle Pleistocene to Holocene)
– Moderately consolidated, brownish-yellow to yellowish-brown (10YR 6/6 to 5/6) pebbly sand and fine-to coarse-grained sand with rare cobbles. Unit is discontinuously exposed along major arroyos and commonly covered by colluvium and eolian deposits. Where exposed, deposits rest on Santa Fe Group sandstone (QTsas) and conglomerate (QTsacs) and are locally cross-bedded. Clast imbrication indicates paleostream flow was subparallel to modern valleys.
- Qvoe** Alluvial-slope and eolian deposits, undivided (middle Pleistocene) – Moderately to poorly consolidated and very poorly exposed sand with scattered pebbles forming along borders of Calabacillas and Montoyas valleys. Unit forms valley-border surfaces that are graded to former positions of major arroyos. surface slopes range from 4 to 10%. The surface is commonly covered by eolian sand that is underlain by moderate to strongly developed soil possessing stage III calcium-carbonate morphology.
- Qae** Eolian and alluvial deposits, undivided (uppermost Pleistocene to Holocene) – Poorly consolidated and poorly exposed, brown (7.5YR 5/4 to 10YR 5/3 and 5/4), fine-to medium-grained sand and silty sand with rare scattered pebbles. Unit forms relatively thin (<1-m thick) mantle over Santa Fe Group deposits and is common on interfluves (summits and shoulders of valleys). Soils are weakly developed and possess stage I carbonate morphology and thin clay films.
- Qe** Eolian deposits (Holocene) – Poorly consolidated, yellowish-brown (10YR 5/4), fine-to medium-grained subrounded, quartz-rich sand; clasts are absent. Unit forms elongated and isolated hills underlain by 6 to 9 m of sand along the northern and eastern margins of broad arroyo valleys, such as Arroyo de los Montoyas and Arroyos de las Calabacillas.
- Qcay** Younger undivided colluvium and alluvium (Holocene to upper Pleistocene) – Poorly consolidated and sorted, fine- to coarse-grained, matrix-supported deposits derived from debris flow, shallow slump and creep on steep to moderate sloping hills. Colluvium is common on side-slopes and toe-slopes formed along valley borders. Unit is differentiated only where areally extensive.
- Qcao** Older colluvium, colluvial wedge deposits (middle to lower Pleistocene) – Weakly indurated and moderately consolidated, light yellowish-brown (10YR 6/4), white (N8/0) and orange-buff sand with scattered pebbles and pebbly sand beds and subordinate mudstone. Deposits contain multiple moderate to strongly developed calcic soils that possess stage II to III calcium-carbonate morphology. Unit unconformably overlies partially stripped calcic soil (associated with the Llano de Albuquerque surface of Machette (1985)) developed on light-gray sandstone of the Santa Fe Group. Deposits are of alluvial and colluvial origin and are derived from adjacent upland areas associated with footwall blocks of normal faults. Sand has largely been reworked from eolian sources. The top of the unit is marked by a strongly developed calcic soil exhibiting stage III calcium-carbonate morphology. Deposits are typically covered by a thin veneer of unit Qae. Represents discontinuous, east-tapering scarp-derived alluvium and colluvium developed locally on the hanging walls of the Calabacillas and Zia faults.
- af** Artificial fill (historic) – Dumped fill and areas effected by human disturbances. Unit is not mapped everywhere on quadrangle.

Tertiary System

Santa Fe Group (lower Miocene to lower Pleistocene(?))

The Santa Fe Group is a thick sequence of fluvial, eolian, and lacustrine deposits that represent the syntectonic fill of the Rio Grande rift. In the quadrangle, the Santa Fe Group consists of two unconformity-bounded formations: the Zia Formation and the overlying Sierra Ladrones Formation. Lozinsky (1988) reported a thickness of 1,218 m for the Santa Fe Group in the Shell Santa Fe No. 3 well in the northwest part of the quadrangle. The Santa Fe Group thickens eastward across down-to-the-east faults in the quadrangle. Map units within formations of the Santa Fe Group are delineated on the basis of depositional systems and textural lithofacies (Cather, 1997). Undivided Santa Fe Group deposits (QTsfu) are shown in cross-section only.

Sierra Ladrones Formation (Pliocene-lower Pleistocene(?)) – We use the term Sierra Ladrones Formation (Machette, 1978) to denote the rocks of the upper Santa Fe Group that unconformably overlie the Zia Formation (lower Santa Fe Group). As such, our usage of the term Sierra Ladrones is nearly synonymous with the previous usage of Ceja Member of the Santa Fe Formation by Kelley (1977) and the upper buff member of Bryan and McCann (1937) to describe these deposits. In the quadrangle, the Sierra Ladrones Formation has an exposed thickness of approximately 50 m and thickens eastward an unknown amount across east-down faults. The Sierra Ladrones Formation consists dominantly of tributary axial-fluvial deposits that drained areas to the northwest and west. Although fluvial sandstones reworked from eolian deposits are common, primary cross-bedded eolian deposits are minor and only locally present. The top of the Sierra Ladrones Formation is locally marked by a light-gray to white strongly developed calcic soil, which defines the Llano de Albuquerque surface of Machette (1985). This soil is discontinuously exposed and exhibits stage III to IV pedogenic carbonate morphology in the study area. Using the criteria of Cather (1997), we divide the tributary axial-fluvial system of the Sierra Ladrones into four textural lithofacies (see below).

QTsac Conglomerate lithofacies of the tributary axial-fluvial system – Characterized by conglomerate:sandstone ratios of >2:1. Unit crops out only in a small area in southwest part of the quadrangle where it appears to represent a paleocanyon-fill on the footwall of the Sand Hill fault. Color is gray-buff. Clast lithologies include quartzite, chert (including the Pedernal variety), granite, and sandstone. Conglomerate consists mostly of pebbles and cobbles; sandstone is medium to very coarse. Paleoflow was toward the southeast.

QTsacs Conglomerate-sandstone lithofacies of the tributary axial-fluvial system – Characterized by conglomerate:sandstone ratios between 2:1 and 1:2. Unit is widespread in the western portions of the quadrangle. It unconformably overlies QTsas in the southwest part of the quadrangle; elsewhere contact relations appear conformable. Conglomerates are thin and form broadly lenticular to channel-shaped units. Conglomerate clasts are mostly quartzite, chert (including Pedernal chert, except in QTsacs exposures west of the Sand Hill fault where this variety is rare or absent), sandstone, petrified wood, intermediate volcanics, and granite in the southern part of the quadrangle; granite and volcanic clasts become more abundant in the north half of the quadrangle. Sandstones are fine- to very coarse-grained and exhibit mostly trough crossbedding and horizontal stratification. Sandstones range in color from gray or grayish-buff in the south to pink-buff in the

northern part of the quadrangle. Induration is weak to moderate. Paleoflow was generally toward the southeast or east.

QTsas Sandstone lithofacies of the tributary axial-fluvial system – Characterized by conglomerate:sandstone ratios of <1:2 and sandstone:mudstone ratios of >2:1. The sandstone lithofacies crops out over broad areas of the quadrangle. Bedding characteristics, grain size, induration and color distribution are similar to sandstones of QTsacs. Paleoflow was toward the southeast.

QTsasm Sandstone-mudstone lithofacies of the tributary axial-fluvial system – Characterized by sandstone:mudstone ratios between 2:1 and 1:2. Sandstones are very fine to medium grained, buff in color, and exhibit horizontal lamination and subordinate trough crossbedding. Mudstones are tabular in shape and typically devoid of internal stratification. Colors are mostly light brown to pink-buff. Induration is weak to moderate in both sandstones and mudstones. Mudstones appear to have accumulated in ponds and on floodplains of the tributary axial-fluvial system.

Zia Formation (lower to middle Miocene) – The lower part of the Santa Fe Group is composed of the Zia Formation (sensu Tedford, 1982). Rather than subdividing the Zia into members (Piedra Parada, Chamisa Mesa, Cañada Pilares, and unnamed members; see Galusha, 1966; Galusha and Blick, 1971; Gawne, 1981; Tedford, 1982), for reasons of hydrogeologic significance we have opted to divide the Zia on the basis of depositional paleoenvironments and textural lithofacies. In the study area, the Zia consists of two depositional systems, the eolian system and a tributary axial-fluvial system that drained areas to the northwest. The eolian system is sand-dominated, whereas the axial-fluvial system consists of sandstone and sandstone-mudstone lithofacies (see Cather, 1997 for an explanation of map-unit nomenclature). The tributary axial-fluvial system transitionally overlies the eolian system in the northwest part of the quadrangle near Navajo Draw, but the two systems are distinctly interfingered at map scale in the southwest part of the quadrangle (see Correlation of Map Units). Although a complete section of the Zia Formation is nowhere exposed in the quadrangle, total thickness of the Zia may exceed 200 m in nearby areas.

Tzes Sandstone lithofacies of the eolian system – Consists of very fine to medium grained sandstones that commonly exhibit large-scale (1-3 m) crossbedding of eolian origin. Minor amounts of fluvial sandstone and mudstone are locally intercalated with eolian deposits. Eolian sands are well sorted and commonly exhibit numerous calcitic concretions, including those of cigar, spherical, and tabular shapes. In the southwest part of the quadrangle, this unit consists of two tongues that correlate with the Piedra Parada and Chamisa Mesa Members (lower tongue) and the lower part of the unnamed member (upper tongue). In the Navajo Draw area, the lower Zia Formation is composed of a single tongue of eolian sandstone that transitions upward into Tzas. Color ranges from gray to buff. Induration is moderate to weak except in concretionary zones. Paleowind direction was toward the northeast or east.

Tzasm Sandstone-mudstone lithofacies of the tributary axial-fluvial system – Characterized by sandstone:mudstone ratios between 2:1 and 1:2. Color ranges from buff to red. Sandstones are very fine to coarse grained and exhibit trough crossbedding and horizontal stratification. Mudstones are tabular to broadly lenticular in shape. Induration is moderate. Unit is restricted to the southwest part of the map, where it occurs as tongues in two distinct stratigraphic positions (see Correlation of Map Units). The lowermost tongue is correlative with the Cañada Pilares Member of Gawne (1981) and is characterized by abundance of thick red mudstones that accumulated in pond or lacustrine floodplain environments. The upper tongue correlates with the upper part of

the unnamed member of Tedford (1982) and is exposed only in the extreme southwest part of the quadrangle. Not as fine-grained as the lower, the upper tongue represents mixed sand-mud deposition in tributary axial-fluvial and floodplain environments.

Tzas Sandstone lithofacies of the tributary axial-fluvial system – Characterized by conglomerate:sandstone ratios of <1:2 and sandstone:mudstone ratios of >2:1. Sandstones are very fine to very coarse grained and show a dominance of trough crossbedding and horizontal stratification. Mudstone is minor and occurs as thin tabular and lenticular beds. Conglomerate is rare except in the Navajo Draw area where it is a minor constituent of this unit. Conglomerate occurs as thin lens- and channel-shaped bodies which contain granules and pebbles of quartzite, chert, granite, and sandstone. Induration is moderate except in localities where well-indurated calcitic concretions are present. Correlates with middle part of unnamed member of Tedford (1982). A less-than-0.5-m thick stromatolitic marker bed is present in the middle part of Tzas (fine dotted line on map) in the southwest part of the quadrangle and in adjacent areas to the southwest. This bed represents algal growth in a widespread, shallow, fresh-water lake that existed in the area for a short time during deposition of the Zia Formation.

Tg Galisteo Formation (Eocene) – Orange-gray, gray, and pink sandstone and conglomerate. Sandstone is medium to very coarse, moderately sorted, and has calcite cement. Conglomerate consists of well-rounded pebbles and cobbles of quartzite, schist, gneiss, chert, limestone, and minor granite. No Pedernal chert or volcanic clasts are present except those occurring as float derived from nearby Sierra Ladrone exposures. Crops out only in extreme northwest part of quadrangle. Paleoflow was toward the east.

Cretaceous System

Kmv(?) Mesaverde Group (?) (Upper Cretaceous) – Interbedded yellowish-gray sandstones and gray carbonaceous shales that disconformably underlie the Galisteo Formation in the extreme northwest part of quadrangle.

EXPLANATION OF MAP SYMBOLS

Strike and dip of bedding.

Horizontal bedding.

Paleoflow direction based on pebble imbrication or crossbedding.

Paleowind direction based on eolian crossbedding.

Well.

Contact, dashed where approximately located, dotted where concealed (Santa Fe Group lithofacies only), queried where poorly constrained or inferred.

Fault, showing dip and up- and down-thrown sides. Dashed where approximately located, dotted where concealed, queried where poorly constrained or inferred.

High-resolution aeromagnetic anomalies (USGS unpublished data). Queried where weakly developed. Aeromagnetic anomalies may represent buried faults. Note that aeromagnetic anomalies have been omitted where they coincide with geologically constrained fault traces and where they are interpreted to be the result of topographic differences.

Exposure of strongly developed calcic soil of the Llano de Albuquerque (Machette, 1985). Soil exhibits stage III to IV calcium-carbonate morphology and caps deposits of the Santa Fe Group.

Exposure of strongly developed calcic soil exhibiting stage III calcium-carbonate morphology.

REFERENCES

- Bryan, K. and McCann, F. T., 1937, The Ceja del Rio Puerco: a border feature of the Basin and Range province in New Mexico, I. Stratigraphy and structure: *Journal of Geology*, v. 45, p. 801-828.
- Cather, S. M., 1997, Toward a hydrogeologic classification of map units in the Santa Fe Group, Rio Grande rift, New Mexico: *New Mexico Geology*, v. 19, p 15-21.
- Galusha, T., 1966, The Zia Sand Formation, new early to medial Miocene beds in New Mexico: *American Museum Novitates* 2271, 12 p.
- Galusha, T. and Blick, J. C., 1971, Stratigraphy of the Santa Fe Group, New Mexico: *Bulletin of the American Museum of Natural History*, v. 144, 127 p.
- Gawne, C. E., 1981, Sedimentology and stratigraphy of the Miocene Zia Sand of New Mexico: *Geological Society of America Bulletin*, v. 92, part I (summary), p. 999-1007.
- Gile, L.H., Hawley, J.W., and Grossman, R.B., 1981, Soils and geomorphology in the Basin and Range area of southern New Mexico-Guidebook to the Desert Project: *New Mexico Bureau of Mines and Mineral Resources Memoir 39*, 222p.
- Kelley, V. C., 1977, *Geology of the Albuquerque Basin, New Mexico*: *New Mexico Bureau of Mines and Mineral Resources Memoir 33*, 60 p.
- Lozinsky, R. P., 1988, Stratigraphy, sedimentology, and sand petrology of the Santa Fe Group and pre-Santa Fe Tertiary deposits in the Albuquerque Basin, central New Mexico [Ph.D. thesis]: Socorro, New Mexico Institute of Mining and Technology, 298 p.
- Machette, M.N., 1985, Calcic soils of the southwestern United States, in Weide, D.L., and Faber, M.L., eds., *Soil and Quaternary geology of the southwestern United States: Geological Society of America Special Paper 203*, p.1-42
- Machette, M. N., 1978, *Geologic map of the San Acacia quadrangle, Socorro County, New Mexico*: U.S. Geological Survey, *Geologic Quadrangle Map GQ-1415*, scale 1:24,000.
- Tedford, R. H., 1982, Neogene stratigraphy of the northwestern Albuquerque Basin: *New Mexico Geological Society Guidebook 33*, p. 273-278.

HYDROGEOLOGY AND SEISMIC RISK IN THE SKY VILLAGE SE 7.5-MINUTE QUADRANGLE

SUMMARY

Mapping within the Sky Village SE quadrangle has progressed with two main goals: 1) a better understanding of the distribution of hydrogeologic units within the quadrangle to improve our ability to evaluate water resources in the area and 2) consideration of the timing of faulting, with the aim of providing information for seismic hazard assessments in the Albuquerque Basin. The adoption of map units that both allow us to evaluate faulting history and have probable hydrologic significance, and careful observation of how fault-zone deformation and diagenesis act to modify original sedimentary structures, have been critical to completion of these goals.

We have divided the lower Miocene - lower Pleistocene, synrift sediments of the Santa Fe Group on the basis of depositional paleoenvironments and textural lithofacies. Not only are these natural divisions (they are generally separated by unconformities and are easily mapped), they also have qualitative hydrogeologic significance. Units with substantial mudstone can, for example, be expected to be significantly less permeable than units dominated by sandstone. The disposition of units of differing permeability with respect to faults, and permeability relationships within the fault zones, will determine both the location and quantity of available water resources. Most faults within the Sky Village SE quadrangle are at least partially buried by Holocene surficial deposits, so fault-zone permeability and age of faulting are difficult to assess. The Sand Hill fault, however, is very well exposed in the western margin of the quadrangle, and provides an unparalleled opportunity to assess fault-zone characteristics. In addition, two faults east of the Sand Hill fault can be examined in adjacent quadrangles where they are locally well exposed.

The Sand Hill fault is one of the major normal faults bounding the Rio Grande rift, and separates synrift sediments of the lower-middle Miocene Lower Santa Fe Group from those of the Pliocene - lower Pleistocene Upper Santa Fe Group (see map and cross sections). Field relationships indicate that the Sand Hill fault, like other faults associated with the Rio Grande rift, is a growth fault. As a consequence, sediments of different age that are cut by the fault have experienced different amounts of deformation. Information from the Shell Santa Fe #3 borehole demonstrates that the base of the Lower Santa Fe Group is offset ~4200 feet by the fault (cross section A-A'). In contrast, the uppermost unit of the Upper Santa Fe Group, the youngest sediment cut by the Sand Hill fault, is vertically displaced only ~30 feet (cross section B-B').

Investigation of the Sand Hill fault indicates that fault-zone permeability at any point is affected by three factors: 1) the permeability of units juxtaposed by the fault, 2) fault zone structures, and 3) amount of pore-filling, syndeformational cement. The latter two factors are fundamentally controlled by the grain size of the faulted sediments, as indicated by the following end-member relationships: Where juxtaposed sediments are fine-grained (e.g., clay and silt-rich), the zone of deformation is narrow and structurally simple, and the fault is only nominally cemented with micritic calcite. Where juxtaposed sediments are coarse-grained (e.g., dominated by sand and gravel) the zone of deformation is wide and structurally complex, and the fault is well cemented with sparry calcite. These consistent relationships allow us to qualitatively predict fault-zone characteristics from a knowledge of the grain size variation in faulted sediments in areas where faults are not exposed but borehole data provide information about subsurface stratigraphy. These data will provide useful input to models such as that the USGS has developed for assessment of groundwater resources in the Albuquerque Basin.

Investigation of faults that extend outside the Sky Village SE quadrangle reveals two points of importance. First, where exposed to the north, the Calabacillas fault is, like the Sand Hill fault, locally well cemented. This observation suggests that the Sand Hill fault is representative of large-displacement faults in the basin. Second, a fault to the south which appears to be connected to the Calabacillas fault by an aeromagnetic anomaly, exhibits

important paleoseismic information. The fault displaces the base of the overlying uppermost Pleistocene - Holocene eolian deposits ~1m; the upper part of the unit is deposited across the fault trace. This suggests that some of the faults in the area have been active as recently as the Holocene, even where they are partially buried.

Qa Stream alluvium (historic to Holocene) – Poorly consolidated, fine-to coarse-grained sand and pebbly sand with minor silt and clay. Soils are very weakly developed and contain disseminated or no pedogenic calcium carbonate. Unit underlies arroyo floors and modern stream channels.

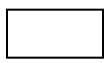
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Qvae Stream alluvium, eolian and alluvial-slope deposits, undivided (middle Pleistocene to Holocene) – Moderately consolidated, brownish-yellow to yellowish-brown (10YR 6/6 to 5/6) pebbly sand and fine-to coarse-grained sand with rare cobbles. Unit is discontinuously exposed along major arroyos and commonly covered by colluvium and eolian deposits. Where exposed, deposits rest on Santa Fe Group sandstone (QTsas) and conglomerate (QTsacs) and are locally cross-bedded. Clast imbrication indicates paleostream flow was subparallel to modern valleys.

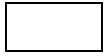
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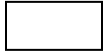
Qae

Eolian and alluvial deposits, undivided (uppermost Pleistocene to Holocene) – Poorly consolidated and poorly exposed, brown (7.5YR 5/4 to 10YR 5/3 and 5/4), fine-to medium-grained sand and silty sand with rare scattered pebbles. Unit forms relatively thin (<1-m thick) mantle over Santa Fe Group deposits and is common on interfluves (summits and shoulders of valleys). Soils are weakly developed and possess stage I carbonate morphology and thin clay films.



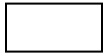
Qe

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Qcay

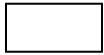
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Qcao

Older colluvium, colluvial wedge deposits (middle to lower Pleistocene) – Weakly indurated and moderately consolidated, light yellowish-brown (10YR 6/4), white (N8/0) and orange-buff sand with scattered pebbles and pebbly sand beds and subordinate mudstone. Deposits contain multiple moderate to strongly developed calcic soils that possess stage II to III calcium-carbonate morphology. Unit unconformably overlies partially stripped calcic soil (associated with the Llano de Albuquerque surface of Machette (1985)) developed on light-gray sandstone of the Santa Fe Group. Deposits are of alluvial and colluvial origin and are derived from adjacent upland areas associated with footwall blocks of normal faults. Sand has largely been reworked from eolian sources. The top of the unit is marked by a strongly developed calcic soil exhibiting stage III calcium-carbonate morphology. Deposits are typically covered by a thin veneer of unit Qae. Represents discontinuous, east-tapering scarp-derived alluvium and colluvium

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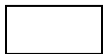
QTsac

Conglomerate lithofacies of the tributary axial-fluvial system – Characterized by conglomerate:sandstone ratios of >2:1. Unit crops out only in a small area in southwest part of the quadrangle where it appears to represent a paleocanyon-fill on the footwall of the Sand Hill fault. Color is gray-buff. Clast lithologies include quartzite, chert (including the Pedernal variety), granite, and sandstone. Conglomerate consists mostly of pebbles and cobbles; sandstone is medium to very coarse. Paleoflow was toward the southeast.



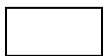
QTsacs

Conglomerate-sandstone lithofacies of the tributary axial-fluvial system – Characterized by conglomerate:sandstone ratios between 2:1 and 1:2. Unit is widespread in the western portions of the quadrangle. It unconformably overlies QTsas in the southwest part of the quadrangle; elsewhere contact relations appear conformable. Conglomerates are thin and form broadly lenticular to channel-shaped units. Conglomerate clasts are mostly quartzite, chert (including Pedernal chert, except in QTsacs exposures west of the Sand Hill fault where this variety is rare or absent), sandstone, petrified wood, intermediate volcanics, and granite in the southern part of the quadrangle; granite and volcanic clasts become more abundant in the north half of the quadrangle. Sandstones are fine- to very coarse-grained and exhibit mostly trough crossbedding and horizontal stratification. Sandstones range in color from gray or grayish-buff in the south to pink-buff in the northern part of the quadrangle. Induration is weak to moderate. Paleoflow was generally toward the southeast or east.



QTsas

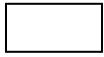
Sandstone lithofacies of the tributary axial-fluvial system – Characterized by conglomerate:sandstone ratios of <1:2 and sandstone:mudstone ratios of >2:1. The sandstone lithofacies crops out over broad areas of the quadrangle. Bedding characteristics, grain size, induration and color distribution are similar to sandstones of QTsacs. Paleoflow was toward the southeast.



QTsasm

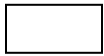
Sandstone-mudstone lithofacies of the tributary axial-fluvial system – Characterized by sandstone:mudstone ratios between 2:1 and 1:2. Sandstones are very fine to medium grained, buff in color, and exhibit horizontal lamination and subordinate trough crossbedding. Mudstones are tabular in shape and typically devoid of internal stratification. Colors are mostly light brown to

pink-buff. Induration is weak to moderate in both sandstones and mudstones. Mudstones appear to have accumulated in ponds and on floodplains of the tributary axial-fluvial system.



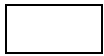
Tzes

Sandstone lithofacies of the eolian system – Consists of very fine to medium grained sandstones that commonly exhibit large-scale (1-3 m) crossbedding of eolian origin. Minor amounts of fluvial sandstone and mudstone are locally intercalated with eolian deposits. Eolian sands are well sorted and commonly exhibit numerous calcitic concretions, including those of cigar, spherical, and tabular shapes. In the southwest part of the quadrangle, this unit consists of two tongues that correlate with the Piedra Parada and Chamisa Mesa Members (lower tongue) and the lower part of the unnamed member (upper tongue). In the Navajo Draw area, the lower Zia Formation is composed of a single tongue of eolian sandstone that transitions upward into Tzas. Color ranges from gray to buff. Induration is moderate to weak except in concretionary zones. Paleowind direction was toward the northeast or east.



Tzasm

Sandstone-mudstone lithofacies of the tributary axial-fluvial system – Characterized by sandstone:mudstone ratios between 2:1 and 1:2. Color ranges from buff to red. Sandstones are very fine to coarse grained and exhibit trough crossbedding and horizontal stratification. Mudstones are tabular to broadly lenticular in shape. Induration is moderate. Unit is restricted to the southwest part of the map, where it occurs as tongues in two distinct stratigraphic positions (see Correlation of Map Units). The lowermost tongue is correlative with the Cañada Pilares Member of Gawne (1981) and is characterized by abundance of thick red mudstones that accumulated in pond or lacustrine floodplain environments. The upper tongue correlates with the upper part of the unnamed member of Tedford (1982) and is exposed only in the extreme southwest part of the quadrangle. Not as fine-grained as the lower, the upper tongue represents mixed sand-mud deposition in tributary axial-fluvial and floodplain environments.

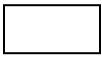


Tzas

Sandstone lithofacies of the tributary axial-fluvial system – Characterized by conglomerate:sandstone ratios of <1:2 and sandstone:mudstone ratios of >2:1.

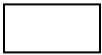
algal marker Sandstones are very fine to very coarse grained and show a dominance of trough crossbedding and horizontal stratification. Mudstone is minor and occurs as thin tabular and lenticular beds.

Conglomerate is rare except in the Navajo Draw area where it is a minor constituent of this unit. Conglomerate occurs as thin lens- and channel-shaped bodies which contain granules and pebbles of quartzite, chert, granite, and sandstone. Induration is moderate except in localities where well-indurated calcitic concretions are present. Correlates with middle part of unnamed member of Tedford (1982). A less-than-0.5-m thick stromatolitic marker bed is present in the middle part of Tzas (fine dotted line on map) in the southwest part of the quadrangle and in adjacent areas to the southwest. This bed represents algal growth in a widespread, shallow, fresh-water lake that existed in the area for a short time during deposition of the Zia Formation.



Tg

Galisteo Formation (Eocene) – Orange-gray, gray, and pink sandstone and conglomerate. Sandstone is medium to very coarse, moderately sorted, and has calcite cement. Conglomerate consists of well-rounded pebbles and cobbles of quartzite, schist, gneiss, chert, limestone, and minor granite. No Pedernal chert or volcanic clasts are present except those occurring as float derived from nearby Sierra Ladrones exposures. Crops out only in extreme northwest part of quadrangle. Paleoflow was toward the east.



Kmv(?)

Mesaverde Group (?) (Upper Cretaceous) – Interbedded yellowish-gray sandstones and gray carbonaceous shales that disconformably underlie the Galisteo Formation in the extreme northwest part of quadrangle.

Strike and dip of bedding.

Horizontal bedding.

Paleoflow direction based on pebble imbrication or crossbedding.

Paleowind direction based on eolian crossbedding.

Well.

Contact, dashed where approximately located, dotted where concealed (Santa Fe Group lithofacies only), queried where poorly constrained or inferred.

Fault, showing dip and up- and down-thrown sides. Dashed where approximately located, dotted where concealed, queried where poorly constrained or inferred.

High-resolution aeromagnetic anomalies (USGS unpublished data). Queried where weakly developed. Aeromagnetic anomalies may represent buried faults. Note that aeromagnetic anomalies have been omitted where they coincide with geologically constrained fault traces and where they are interpreted to be the result of topographic differences.

Exposure of strongly developed calcic soil of the Llano de Albuquerque (Machette, 1985). Soil exhibits stage III to IV calcium-carbonate morphology and caps deposits of the Santa Fe Group.

Exposure of strongly developed calcic soil exhibiting stage III calcium-carbonate morphology.

