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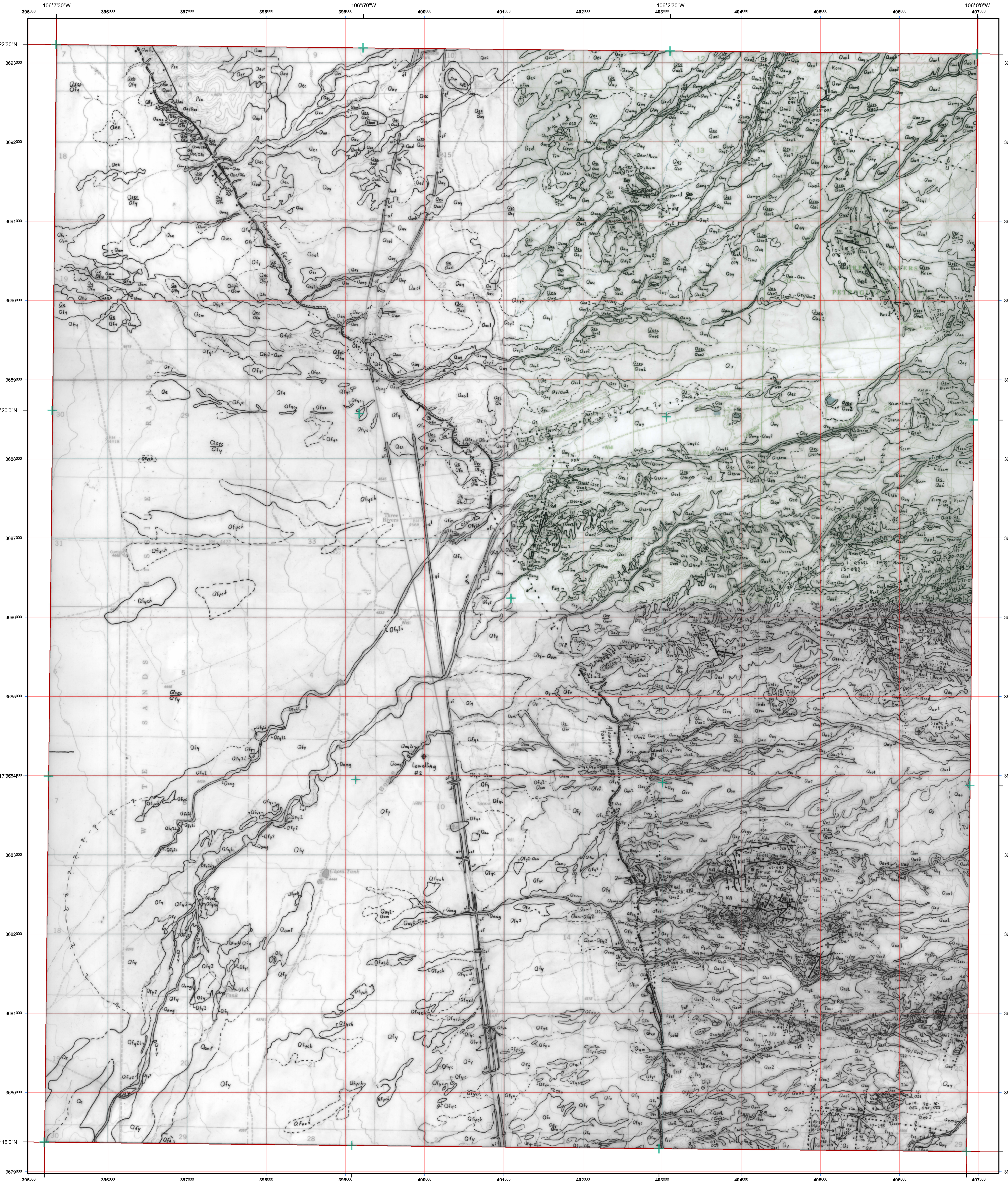

Base map from U.S. Geological Survey 1981, from photographs taken 1972, field checked in 1975, edited in 1981.
1927 North American datum. New Mexico coordinate system (transverse Mercator), reprojected to UTM projection -- zone 13N
1000-meter Universal Transverse Mercator grid, zone 13, shown in red

QUADRANGLE LOCATION

Magnetic Declination
March, 2008
9º 8' East
At Map Center

1:24,000

CONTOUR INTERVAL 20 FEET

NATIONAL GEODETIC VERTICAL DATUM OF 1929

This draft geologic map is preliminary and will undergo revision. It was produced from either scans of hand-drafted originals or from digitally drafted original maps and figures using a wide variety of software, and is currently in cartographic production. It is being distributed in this draft form as part of the bureau's Open-file map series (OFGM), due to high demand for current geologic map data in these areas where STATEMAP quadrangles are located, and it is the bureau's policy to disseminate geologic data to the public as soon as possible.

After this map has undergone scientific peer review, editing, and final cartographic production adhering to bureau map standards, it will be released in our Geologic Map (GM) series. This final version will receive a new GM number and will supercede this preliminary open-file geologic map.

DRAFT

New Mexico Bureau of Geology and Mineral Resources
Open-file Map Series
OFGM 187

Mapping of this quadrangle was funded by a matching-funds grant from the STATEMAP program of the National Cooperative Geologic Mapping Act, administered by the U. S. Geological Survey, and by the New Mexico Bureau of Geology and Mineral Resources, (Dr. Peter A. Scholle, *Director and State Geologist*, Dr. J. Michael Timmons, *Geologic Mapping Program Manager*).

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This and other STATEMAP quadrangles are (or soon will be) available for free download in both PDF and ArcGIS formats at:

http://geoinfo.nmt.edu/publications/maps/geologic/ofgm/home.html

Geologic map of the Three Rivers quadrangle, Otero County, New Mexico

May 2009

by
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COMMENTS TO MAP USERS

A geologic map displays information on the distribution, nature, orientation, and age relationships of rock and deposits and the occurrence of structural features. Geologic and fault contacts are irregular surfaces that form boundaries between different types or ages of units. Data depicted on this geologic quadrangle map may be based on any of the following: reconnaissance field geologic mapping, compilation of published and unpublished work, and photogeologic interpretation. Locations of contacts are not surveyed, but are plotted by interpretation of the position of a given contact onto a topographic base map; therefore, the accuracy of contact locations depends on the scale of mapping and the interpretation of the geologist(s). Any enlargement of this map could cause misunderstanding in the detail of mapping and may result in erroneous interpretations. Site-specific conditions should be verified by detailed surface mapping or subsurface exploration. Topographic and cultural changes associated with recent development may not be shown.

Cross sections are constructed based upon the interpretations of the author made from geologic mapping, and available geophysical, and subsurface (drillhole) data. Cross-sections should be used as an aid to understanding the general geologic framework of the map area, and not be the sole source of information for use in locating or designing wells, buildings, roads, or other man-made structures.

The map has not been reviewed according to New Mexico Bureau of Geology and Mineral Resources standards. The contents of the report and map should not be considered final and complete until reviewed and published by the New Mexico Bureau of Geology and Mineral Resources. The views and conclusions contained in this document are those of the authors and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the State of New Mexico, or the U.S. Government.

MODERN ALLUVIUM

Qam **Modern alluvium (less than 50 years old) –** Gravelly sand and sand deposited by recent discharge events in topographically low, but relatively wide, areas or as lobes at the mouths of incised arroyos. Unit overlies units **Qfy** or **Qay**. Bedding is very thin to medium and planar-horizontal, with internal planar-laminations(minor wavy laminations) and local cross-stratification. Gravel include pebbles and cobbles that are subrounded (minor subangular) and poorly sorted. Clasts consist of varying proportions of Mesozoic sandstone, Paleozoic limestone and siltstone, and Tertiary intrusive and volcanic clasts, depending on the source area of a given drainage. Colors of sand range from brown to pale brown (10YR 5-6/3) and grayish brown to light brownish gray (10YR 5-6/2). Sand is very fine- to very coarse-grained, subangular to subrounded, moderately to poorly sorted, and composed of plagioclase and quartz with minor potassium feldspar and lithic grains. Surface has fresh bar- and swale topography up to ~50 cm. No soil development. Loose. This unit includes subordinate amounts of the **Qamf** and **Qamg** units. Generally 1-2 m-thick.

Qamf **Fine-grained modern alluvium (less than 50 years old) –** Clay, silt, and very fine- to fine-grained sand deposited on top of Qay or Qfy by baffling of sheetflooding due to dense grass and other vegetation. Incised channels are few, discontinouse, and relatively shallow (less than 50 cm). Colors of sediment ranges from pale brown (10YR 6/3) to light gray to light brownish gray (10YR 6-7/2). No soil development. Deposit is relatively thin (1 m-thick or less), well-sorted, and loose.

Qamg **Modern alluvium deposited in gullies or arroyos (less than 50 years old) –** Gravelly sand, sandy gravel, and sand deposited by recent discharge events at the bottoms of incised gullies or arroyos. Unit typically incised below the top of units **Qfy** or **Qay**. There may be up to 1.5 m of erosional (gullied) relief on the surface of this unit; typical bar and swale topography is generally 30-60 cm-tall. Bedding is very thin to medium and planar-horizontal, with internal planar-laminations (minor wavy laminations) and local cross-stratification. Gravel consist of poorly to very poorly sorted pebbles, cobbles, and boulders that are mostly subrounded. Clasts are composed of varying proportions of Mesozoic sandstone, Paleozoic limestone and siltstone, and Tertiary and volcanic clasts, depending on the source area of a given drainage. Colors of sand range from brown to pale brown (10YR 5-6/3) and grayish brown to light brownish gray (10YR 5-6/2). Sand is very fine- to very coarse-grained (mostly medium- to very coarse-grained), subangular to subrounded, moderately to poorly sorted, and commonly dominated by lithic, plagioclase, and quartz grains. No soil development. 1-3 m-thick.

ARTIFICIAL FILL AND EXCAVATIONS

ae **Artificial excavation (modern) –** Pit, quarry, or reservoir; the base of these excavations have generally been filled by >10 cm-thick deposits of clay, silt, sand, and gravel carried into the pit by mass-wasting or slopewash processes.

af **Artificial fill (modern) –** Compacted silt, clay, and sand (minor pebbles) under highways and railroads; also found in berms surrounding pits, quarries, or reservoirs. In the case of railroads, coarse to very coarse pebbles and fine cobbles drape compacted fill.

SHEETFLOOD. SLOPEWASH, COLLUVIAL, AND EOLIAN DEPOSITS

Note: These two deposits are grouped together because most eolian sheet deposits have been affected to some degree by sheetflooding

Qs **Sheetflood and slopewash deposits (middle to present) --** Clayey-silty sand found near the headwaters of small drainage; unit commonly grades down-slope into unit **Qay1** or **Qay**. Mostly a pale brown color (10YR 6/3); less common colors include pink (7.5YR 7/3) and light gray (10YR 7/2). Very minor to minor scattered pebbles, but a very thin pebble bed is commonly present at base of the deposit. Sand is mostly very fine- to fine-grained, subangular to subrounded, moderately sorted, and an arkose to litharenite. Sand in pebble lenses is very fine- to very coarse-grained, subrounded to subangular, and poorly sorted. Composition varies with the local source area. Generally less than 25% fines, but locally as much as 50%. Internally massive, with very minor, very thin to thin, sandy pebble lenses. Unit grades laterally into **Qfy** and **Qay,** but is differentiated based on its interpreted thinness and lack of thick, significant channel-fills. Stage I gypsic horizon, marked by gypsum filaments. Surface of unit is sandy with weak to no desert pavement development. Loose to moderately consolidated. Less than 1 m-thick.

Unit Qs commonly is mapped as overlying other units:

Qs/Qfy -- Sheetflood and slopewash deposits over younger alluvial fan deposits

Qs/Qay -- Sheetflood and slopewash deposits over younger alluvial slope deposits

Qs/Qfo -- Sheetflood and slopewash deposits over older alluvial fan deposits

Qs/Qao -- Sheetflood and slopewash deposits over older alluvial slope deposits

Qsgy **Highly gypsiferous heetflood and slopewash deposits (middle to upper Holocene) --** Unit **Qs**, as described above, containing significant amounts of gypsum (comparable to stage III morphology in a calcic horizon or a petrogypsic horizon). 1-3 m-thick.

Qsgy/Kccl Sheetflood and slopewash deposits over lower unit of Crevasse Canyon Formation.

Qse **Sheetflood and slopewash deposits from locally reworked eolian sand sheets (middle to upper Holocene) --** Light brown to brown (7.5YR 5-6/3-4) and strong brown to reddish yellow (7.5YR 5-6/6), very fine to lower-medium sand with minor coarser-grained sand. Very minor (~1%) very fine to coarse pebbles. A very thin pebble bed may be present at base of deposit. Internally massive with weak soil development characterized by ped development and minor gypsum accumulation (stage I). Local, very thin to thin pebble lenses. Sand is subrounded, moderately to well sorted, and a lithic arenite to arkosic arenite in composition. Very minor coppice dunes may be present on the surface, generally less than 5%. Unit differs from **Qs** by its redder hue, subrounded sand that includes common lower-medium sand grains, and spatial association with nearby eolian deposits. Surface commonly has a sparse lag gravel and no desert pavement development. Loose to moderately consolidated. Generally less than 1 m-thick.

Qsec **Sheetflood and slopewash deposits from locally reworked eolian sand sheets, with coppice dunes on the surface (middle to upper Holocene) --** Similar to unit **Qse**, but with 5% or greater surface coverage by coppice dunes (coppice dunes described in unit **Qec**).

Qc **Colluvium (Holocene) --** Gypsiferous sand and gravel deposited adjacent to steep slopes. Sand is mostly very fine- to medium-grained. Sediment lacks distinctive bedding. Only mapped locally adjacent to the Alamogordo fault scarp in the southern part of the quadrangle. Probably 1-3 m-thick.

Qec **Coppice dunes (middle to upper Holocene) --** Mounds of sand accumulated under and in the immediate vicinity of mesquite bushes (and cresosote bushes, to a lesser extent). Mounds range from 10 to 200 cm in height. Color of sand ranges from light brown to pale brown to brown (7.5-10YR 5-6/3), yellowish brown to light yellowish brown (10YR 5-6/4), and brown to light brown (7.5YR 5-6/4). Sand is very fine- to medium-grained, subrounded (lesser rounded and subangular), well- to moderately-sorted, and composed of quartz, with 15-18% estimated lithic grains and subequal to lesser potassium feldspar. 1-5% coarse to very coarse-grained sand that is scattered. Coppice dunes overlie a bioturbated eolian sand sheet or sheetflood deposits (with a sparse pebble lag); this underlying deposit is grouped with this unit. The coppice dunes are likely upper Holocene in age, but underlying deposit may be middle Holocene. Loose. Deposit under the dunes is up to ~ 2 m-thick.

Qecr **Coppice dunes developed on a sand ramp (middle to upper Holocene) --** Coppice dunes (as described in unit **Qec**) that overlie several meters of sand deposited as an eolian sand ramp. The sand ramp slopes away from a topographic high. Sand is mostly brown to light brown (7.5YR 5-6/4), very fine- to medium-grained (minor coarser sand), subrounded, moderately to well sorted, and composed of quartz grains with 10-15% inferred potassium feldspar and lithic grains). Loose and several meters thick.

Qed **Eolian sand in dune forms other than coppice dunes (middle to upper Holocene) --** Eolian sand in mound-like deposits that extend over several meters. East of Highway 54, near the northern quadrangle boundary, dunes may be classified as longitudinal. These longitudinal dunes are aligned NE-SW, parallel to the dominant wind direction. Up to 3 m-thick.

Qe **Undifferentiated eolian sand deposits (middle to upper Holocene) --** Unit includes undifferentiated **Qse**, **Qsec**, **Qec**, and **Qer** (see descriptions of these units above). Up to several meters thick.

Qee **Undifferentiated eolian sand deposits that have been eroded (middle to upper Holocene) --**Irregular polygon margin and gullies suggest erosion of unit Qe. Mapped in the northwest quadrangle, inside the White Sands Missile Range, using airphotos. Inferred thickness of 1-2 m.

TERRACES, PEDIMENTS, AND TERRACE DEPOSITS

Qt **Undifferentiated terrace (Pleistocene) --** Relatively flat terrace surfaces greater than 10 m above active drainages. Surfaces are probably underlain by a thin deposit associated with a stream that formed the terrace. However, a post-terrace gypsum mantle obscures such a deposit, and all that is seen is a layer of pebbles and cobbles (minor boulders) overlying the gypsum. Because of the prevalent poor exposure, I am uncertain whether a given terrace has a significant deposit, or is simply an erosion surface.

Qttrl **Lower Three Rivers terrace (upper Pleistocene) --** Terrace located on the north side of lower Three Rivers; surface stands a few meters above the **Qay** surface to the south. A strong desert pavement has developed on the tread of this terrace and strong gypsum surface indications are present. Surface clasts contain gravel derived from slopewash from adjoining **Qao1** topographic high to the north. Terrace is primarily an erosional feature.

Qttrm **Middle Three Rivers terrace (upper(?) Pleistocene) --** A prominent terrace located south of and 10-15 m above the Three Rivers active channel. A terrace at a similar level was included in this unit in the next canyon to the south. A thin gravel deposit, 0.2-3 m-thick, is likely associated with this terrace. However, this terrace overlies a very coarse paleovalley-fill **(Qao3**), so a definitive strath is difficult to establish. Immediately south of Three Rivers drainage, the strath was drawn using a boulder bed (2.1 km east of the Alamogordo fault) or the base of a cemented 4.5 m-thick interval (1.5 km east of the Alamogordo fault). Whether this boulder bed or cemented zone is associated with the terrace or the inferred, underlying paleovalley-fill is not certain. The paleovalley-fill is not included with the terrace because the terrace extends laterally beyond the location of the relatively narrow paleovalley. However, it is possible that the terrace and its inferred gravel deposit was formed immediately after the back-filling of the paleovalley with gravel. Gravel are subrounded to rounded, moderately to poorly sorted, and consist of pebbles and cobbles with lesser boulders. Clasts consist largely of andesite and intermediate intrusives, with minor coarse syenite. Generally 0.5-2.0 m-thick, but locally as thick as 5 m.

Qttru **Undifferentiated upper Three River terraces (lower to middle Pleistocene) --** Undivided, relatively flat terrace surfaces above the middle Three Rivers terrace tread (greater than 10 m above the Three Rivers drainage). Surfaces are probably underlain by a thin deposit associated with the Three Rivers. However, a post-terrace gypsum mantle obscures such a deposit, and all that is seen is a layer of pebbles and cobbles (minor boulders) overlying the gypsum. These clasts include Tertiary andesite extrusives or coarse syenite (the latter commonly occuring as boulders or coarse cobbles). Because of the prevalent poor exposure, it is uncertain whether a given terrace has a significant deposit, or is simply an erosion surface. Clasts include pebbles, cobbles, and boulders of andesite, intermediate intrusions, and minor coarse syenite. Although gravel were likely initially subrounded, spallation has created many angular and subangular clasts. Where a gravel deposit is relatively certain, a label of **Qttrug** is assigned (see below).

Qttrug **Gravelly sediment associated with undifferentiated upper Three River terraces (lower to middle Pleistocene) --** Sandy gravel whose clasts consist of pebbles with subordinate cobbles and 1-10% boulders. Gravel composed of Tertiary intrusives and intermediate flow rocks, with trace to subordinate Mesozoic-Paleozoic sedimentary clasts (mostly sandstone and limestone). Trace to 5% coarse syenite cobbles and boulders. Gravel are poorly sorted and subrounded. Spallation of exposed clasts has created abundant subangular and angular gravel on the surface. Clasts are very strongly varnished on the surface, and generally overlie a strong gypsic soil. 1-2 m-thick.

Qtg **Gravel terrace gravel deposit associated with drainage south of Three Rivers (upper Pleistocene) --** Sandy gravel of a terrace deposit within 15 m of present drainage bottoms. Gravel are poorly sorted, subrounded to subangular, and consist of pebbles to boulders (mostly pebbles) of Tertiary intrusive clasts, with subordinate Mesozoic-Paleozoic clasts (mostly sandstone and limestone). Gravel deposited on top of Mesozoic strata or unit **Qao**. Unit generally forms unpaired terraces. Nature of surface various; higher surfaces have good desert pavement development, but lower surfaces have weak pavements. 1-5 m-thick.

Qp **Pediment gravel (middle to upper Pleistocene) --** Thin, strongly varnished pebbles and gravel overlying unit **Qao2** in the vicinity of Crosby well. Good pavement developement. Deposit related to a pediment developed in the area. This pediment is about 6 m above the surface related to **Qao3** observed east of Kitty spring. Less than 1 m-thick.

Qtgh **High-level terrace gravel deposit associated with drainages south of Three Rivers (middle to lower Pleistocene) --** Sandy gravel of a terrace deposit more than 15 m above present drainage bottoms. Unit not exposed, but gravel on surface are angular to subrounded (mostly subangular to subrounded) and consist of pebbles and cobbles with 1-10% boulders. Where present, an eroded horizon of relatively large clasts is used to map the base of the terrace deposit. Gravel are poorly to very poorly sorted and are composed of various Tertiary intrusive clasts, with subordinate Mesozoic and Paleozoic sedimentary clasts (mostly sandstone and limestone). 1-3 m-thick.

ALLUVIAL FAN DEPOSITS

Qfy **Younger alluvial fan deposits (uppermost Pleistocene to upper Holocene) –** This unit underlies the majority of alluvial fan surfaces in the study area. Color is generally pale brown to light brown to light yellowish brown (10YR-7.5YR 6/3-4), but pink colors are locally common (7.5YR 7/3-4). Sediment consists of a clayey-silty, very fine- to medium-lower sand interbedded with very thin to medium, lenticular beds of medium- to very coarse-grained sand, pebbly sand, and sandy pebbles. Outside of coarse channel-fills, sand is mostly well-sorted and subangular-subrounded. Within coarse channel-fills, gravel consists of pebbles with minor cobbles, and sand is fine- to very coarse-grained, poorly sorted, subrounded to subangular, and contains abundant lithic grains. In the medial and distal fans, the fine-grained sediment generally dominates. In the fine sand are 1-15% scattered pebbles and scattered medium-upper to very coarse-sand. Most of the clayey- to silty fine-grained sand is internally massive and pedogenically modified, with moderate ped development and gypsum accumulation marked by scattered filaments (typically 10-20% surface coverage); locally, there are minor laminations to thin beds. Both fining-upward and coarsening-upward trends noted, as manifested by the amounts of interbedded, gravelly sediment. Locally subdivided into **Qfyc**, **Qfych**, **Qfy2**, and **Qfy2i**. Base of unit defined at top of calcic horizon associated with the top of unit **Qai** (see description of that unit below). However, this calcic horizon has not been observed west of the Alamogordo fault in this quadrangle (although it is seen on the Tularosa NE quadrangle to the south), nor does **Qai** occur on the surface of the alluvial fans (it is mapped east of the Alamogordo fault). Uppermost Pleistocene and lower Holocene sediment is probably relatively thin and minor (less than 1 m), and incorporated into the cumulic soil overlying the calcic horizon at the top of unit **Qai**. Greater than 80% of unit is middle to upper Holocene in age. Unit correlates to **Qf3** in the Tularosa NE quadrangle to the south. Moderately to well consolidated and 1-4 m-thick.

Qfyc **Relatively coarse, younger alluvial fan deposits (middle to upper Holocene) -- Qfy**, as described above, with relatively abundant gravelly interbeds. Located in the medial to proximal alluvial fans (generally east of Highway 54). 1-4 m-thick.

Qfych **Younger alluvial fan deposits with a coarse lag capping a subdued topographic high (middle Holocene) -- Qfy**, as described above, with a gravel lag on its surface. The gravel has slightly inhibited erosion, creating a subdued topographic high. Surface gravel is generally weakly to moderately varnished. Weak to moderate desert pavement development and no to very sparse surface gypsum indications. Unit correlates to **Qf3gh** in the Tularosa NE quadrangle to the south. 1-4 m-thick.

Qfy2 **Younger subunit of younger alluvial fan deposits (upper Holocene) --** Well-stratified sand and subordinate gravel. Unconformably overlies older **Qfy** sediment. Stratification is mostly laminated to very thin, planar-horizontal to wavy to cross-stratified. No soil development. Sand is very fine- to very coarse-grained, subrounded to subangular, moderately to poorly sorted, and contains abundant lithic grains. Surface is relatively fresh, with bar and swale topography up to about 50 cm-tall. No desert pavement development or clast varnish. Unit correlates to the **Qah** unit in the Tularosa NE quadrangle to the south. This unit is generally less than ~150 years in age. Loose to weakly consolidated. 1-2 m-thick.

Qfy2i **Thin younger subunit of younger alluvial fan deposits overlying incised surfaces (upper Holocene) -- Qfy2**, as described above, overlying an erosion surface cut below the level of Qfy or Qfy2. This unit is generally less than ~150 years in age. 1-2 m-thick.

Qfo **Older alluvial fan deposits (upper Pleistocene) --** Intercalated clayey sand and sandy gravel. Clayey sand generally is light brown (7.5YR 6/3-4), highly gypsiferous, and mostly contains very fine to fine sand grains. Moderately to well consolidated. Base not defined and not exposed. Deposit grades downward into undifferentiated, basin-fill alluvium. Surface generally covered by slopewash or sheetflood deposits (**unit Qs**), but where slopewash is relatively thin strong gypsum is recognized on the surface, commonly along with moderately to strongly varnished clasts. Unit found on the proximal fans and forms slight topographic highs. Unit is recognized by its reddish color and strong surface gypsum.

ALLUVIAL SLOPE DEPOSITS

Qay **Younger alluvium (latest Pleistocene to Holocene (uppermost Pleistocene to upper Holocene) --** Color is generally pale brown to light yellowish brown to light brown (10YR-7.5YR 6/3-4). Sediment consists of a clayey-silty very fine- to fine-grained sand interbedded with very thin to medium, lenticular beds of medium- to very coarse-grained sand, pebbly sand, and sandy pebbles. Most of the clayey- to silty fine-grained sand is internally massive and pedogenically modified (marked by moderate ped development and stage I gypsum accumulation. Scattered pebbles and minor, scattered medium- to very coarse-sand are present. Both fining-upward and coarsening-upward trends noted, as manifested by the amounts of interbedded, gravelly sediment. Locally subdivided into **Qay2 and Qay1** (see below). Base of unit defined at top of calcic horizon associated with the top of unit **Qai** (see description of that unit below). Uppermost Pleistocene and lower Holocene sediment is probably relatively thin and minor (less than 1 m), and incorporated into the cumulic soil overlying the calcic horizon at the top of unit **Qai**. Greater than 80% of unit is middle to upper Holocene in age. Unit correlates to **Qf3** in the Tularosa NE quadrangle to the south. Moderately to well consolidated and 1-4 m-thick.

Qay2 **Younger subunit of younger alluvium (upper Holocene) --** Well-stratified sand and minor gravel. Unconformably overlies **Qay1**. Stratification is laminated to very thin to medium, planar-horizontal to wavy to cross-stratified. No soil development. Sand is light yellowish brown to pale brown (10YR 6/3-4), very fine- to very coarse-grained, subrounded to subangular, moderately to poorly sorted, and contains abundant lithic grains. Surface is relatively fresh, with bar and swale topography up to about 50 cm-tall. No desert pavement development or clast varnish. Unit correlates to the **Qah** unit in the Tularosa NE quadrangle to the south. This unit is generally less than ~150 years in age. Loose to weakly consolidated. 1-2 m-thick.

Qay2i **Thin younger subunit of younger alluvium(upper Holocene) -- Qay2**, as described above, overlying an erosion surface cut below the level of Qfy or Qfy2. This unit is generally less than ~150 years in age. 1-2 m-thick.

Qay1 **Older subunit of younger alluvium (uppermost Pleistocene to middle Holocene) --** Pale brown to light yellowish brown (10YR6/3-4), with lesser pink, reddish yellow, and brown colors. Sediment consists of a clayey-silty very fine- to fine-grained sand interbedded with very thin to medium, lenticular beds of medium- to very coarse-grained sand, pebbly sand, and sandy pebbles. In general, the clayey- to silty fine-grained sand is internally massive and pedogenically modified (marked by moderate ped development and stage I gypsum accumulation. Scattered pebbles and minor, scattered medium- to very coarse-sand are present. Both fining-upward and coarsening-upward trends noted, as manifested in the proportion of gravelly beds. Subunit comprises most of the undifferentiated **Qay** unit. Unit commonly grades up-slope into Qs deposits, and most of this unit represents sheetwash deposits. Differentiated from **Qs** by the presence of medium to thick channel-fills. Generally moderately to well consolidated and 1-4 m-thick.

Qay-Qam Unit containing both Qay and Qam that are not differentiated.

Qai **Intermediary alluvium (upper Pleistocene) --** Light brown (7.5YR 6/4), clayey very fine- to fine-grained sand (minor medium- to very coarse-grained sand), commonly grading downward into sandy gravel. Scattered coarser sand and pebbles may be present. Lower sandy gravel is in very thin to medium, lenticular to tabular beds; gravel are clast-supported, subrounded, and poorly sorted; matrix is pale brown (10YR 6/3), very fine- to very coarse-grained sand that is subrounded, poorly sorted, and contains abundant lithic grains. Unit is inset into older alluvium (**Qao**). A nodular, stage II to II+ calcic horizon has developed on top of the unit. The calcium carbonate nodules in this horizon are commonly 0.5-2.0 cm. This calcic horizon is about 10-70 cm-thick. Unit is inset into **Qao**, and found in most topographic lows. Only subaerially exposed in a few places near the quadrangle's eastern boundary because it is generally overlain by unit **Qay**.

Qait **Terrace developed on gravel of intermediary alluvium (upper Pleistocene) --** Unit **Qai** eroded to expose the lower gravel; forms a terrace along lower Rocky Arroyo. 1-3 m-thick.

Qao **Older alluvium (Pleistocene) --** Undifferentiated older alluvium. Generally subdivided into units **Qao3**, **Qao2**, and **Qao1** (see descriptions below). Unit recognized by its red hue and abundant gypsum. Rhizoliths commonly seen that are cemented by gypsum. Commonly internally massive or in thick, vague beds. Varying proportions of gravelly channel-fills. Base defined as top of Santa Fe Group deposits (**Tsf**). Well consolidated and up to 25 m-thick.

Qao3 **Inset valley-fills associated with older alluvium (upper Pleistocene) --** Paleo-valley fills older than unit **Qai** that are inset into older alluvium (**Qao2**). South of Boone Draw, unit commonly fines-upward from a sandy gravel at its base to clayey very fine- to fine-grained sand at its top. Finer sediment is a light brown (7.5YR 6/4) color. Gravel is clast-supported, highly gypsiferous, and includes pebbles with lesser cobbles and boulders. Beds are vague and mostly medium-thick and lenticular. Clasts are rounded to subangular and poorly sorted. The upper finer-grained sediment has 5-10% pebbles (scattered or in thin lenses), is internally massive, and has gypsum filaments. Between Crosby well and Kitty spring, the preserved tread of this unit is 4-6 m lower than a pediment surface on **Qao2** to the south (**Qp**). Locally, sediment extends hundreds of meters away from paleovalley as a tabular deposit up to a few meters thick. A strong gypsum horizon is developed on the surface of the unit (comparable morphology to a stage III calcium carbonate horizon), clast varnish is relatively strong, and there is a well-developed desert pavement where unit is not covered by slopewash. Paleovalley in-fill is up to about 6 m-thick south of Boone Draw. South of the Three Rivers drainage, this unit is noteably gravelly and 10-14 m-thick. Gravel is clast-supported, well-graded pebbles through boulders in thick, vague, tabular beds.

Qao2 **Younger subunit of older alluvium (middle? to upper Pleistocene) --** The most common older alluvium subunit, this deposit has a reddish hue and contains abundant gypsum. Color is light brown (7.5YR 6/3-4) to pink (7.5YR 7/3). Sediment consists of gypsiferous, very fine- to fine-grained sand and clayey fine sand, with minor medium- to very coarse-grained sand and pebbles (scattered or in very thin to medium lenses). Internally massive and commonly affected by pedogenesis (illuviated clay and ped development), with common rhizoliths cemented by gypsum. Varying proportions of pebbly beds (locally with cobbles). Base of deposit overlies Mesozoic strata or various Tertiary igneous rocks. Base appears to be several meters below the base of unit **Qao1**. A strong gypsum horizon is developed on the surface of the unit (comparable morphology to a stage III calcium carbonate horizon or else a petrogypsic horizon), clast varnish is relatively strong, and there is a well-developed desert pavement where unit is not covered by slopewash. Several different erosion surfaces have developed on this unit, which are most obvious immediately adjacent to the Alamogordo fault. Well consolidated and greater than 5 m-thick.

Qao2c **Coarse-grained younger subunit of older alluvium (middle? to upper Pleistocene) --** Clast-supported, sandy gravel filling paleovalleys. Very thin to thin, planar-horizontal beds; 10% medium, lenticular beds. Gravel consist of pebbles with minor cobbles and boulders, moderately to poorly sorted, subrounded (minor subangular), and composed of various Tertiary intrusives with minor limestone and sandstone. Sand in matrix is light yellowish brown (2.5Y 6/3), mostly medium- to very coarse-grained, subrounded (minor subangular), poorly sorted, and rich in lithic grains. Top of sandy gravel is at the same level as adjoining **Qoa2**, so it is inferred to be older than unit **Qao3**. Mapped near the mouth of Rocky Arroyo. Weakly conslidated and up to 5-6 m-thick.

Qao1 **Older subunit of older alluvium, occupying high-level topographic positions (upper Pliocene to middle Pleistocene) --** Generally a sandy gravel with subordinate interbeds of clayey-silty, gypsiferous, very fine- to fine-grained sand (minor medium to very coarse sand). Finer-grained sediment appears to dominate progressively south of the Three Rivers drainage. Gravel contains pebbles with variable cobbles, locally with minor boulders. Gravel are subrounded, poorly to moderately sorted, and composed of intermediate intrusive rocks together with subordinate Tertiary andesite and Mesozoic sandstone. Sand is pale brown to very pale brown (10YR 6-8/3), very fine to fine-grained, with subordinate medium to very coarse grains. Base of deposit is generally several meters above the base of unit **Qao2**. South of the cross-section line, where exposure does not permit comparison of strath heights, this unit is assigned to topographically high alluvium whose tread is at least 6 m above the tread of adjacent **Qao2**. Prevalent petrogypsic horizon developed on its surface with very strongly varnished surface clasts. Differentiation of this unit from **Qao2** becomes increasingly difficult southwards from Boone Draw. It is possible that south of Boone Draw, at least some of what is mapped as **Qao1** is actually **Qao2** that has witnessed relatively little erosion. 5-25 m-thick.

SANTA FE GROUP

Tsf **Santa Fe Group basin-fill (Miocene to lower Pliocene?) --** Clayey-silty, very fine- to medium-grained sand, locally with minor scattered medium- to very coarse-grained sand and 1-10% pebbles. Colors range from very pale brown to light yellowish brown (10YR 7/3-6/4) to light brown (7.5YR 6/4) to pink (7.5YR 7/3). Thin to thick (mostly thin to medium), tabular-bedded and internally massive. Sand is subrounded to subangular, modertely sorted, and composed of quartz and plagioclase, with ~10% estimated potassium feldspar and 10% estimated lithic grains. Paleosols are locally common; these are characterized by calcic horizons (stage II morphology in limited exposures) underlain by gypsic horizons; locally, the calcic horizons are overlain by thin, yellowish red (5YR 5/6), illuviated clay (argillic?) horizons. Other lithologic types include minor gravelly beds, either as: 1) local, very thin to medium lenses of sandy pebbles and sandstone, locally moderately cemented by calcium carbonate, within the aforementioned, relatively fine-grained sediment, or 2) thin to thick beds of clast-supported, sandy pebbles and cobbles (minor boulders); gravel are subrounded to rounded, imbricated (westward paleoflow direction), and composed of Tertiary intrusive clasts, andesite, and subordinate Mesozoic sandstone; matrix is fine- to very coarse-grained sand that is subrounded and poorly sorted. Gravel is commonly strongly impregnated by calcium carbonate. Exposed in the northeastern quadrangle, where it lies beneath an unconformity at the base of gravelly **Qao1** deposits. Here, it differs from **Qao1** by its smaller gravel size and better cementation and consolidation. On the footwall of the Alamogordo fault, unit probably fills large-scale embayments or paleovalleys, particularly in the Three Rivers area. Greatest exposed thickness is 2 m, but unit is 120 m (400 ft) thick at the Lewelling #1 well (see cross-section). On the immediate fault hanging wall, unit is up to ~700 m-thick (2300 ft) (see cross-section).

TERTIARY INTRUSIVES

Numerous intrusive rocks related to the Sierra Blanca volcanic complex are located in this quadrangle. These rocks occur as dikes (marked on map by a line with "d's"), sills, or laccoliths. Laccoliths are generally restricted to the Mancos Shale, whereas sills are common in the Crevasse Canyon Formation. Age discussed in accompanying report.

Tim **Megacrystic trachyte porphyry occupying sills and laccoliths --** Gray to light gray, porphyritic hypabyssal rocks occupying sills and laccoliths. Texture is commonly subhedral, with phenocrysts being subhedral to euhedral. Grain size of groundmass 0.2-0.5 mm, less commonly to 1.0 mm. Mineral assemblage of groundmass consists of plagioclase with 15-25% hornblende and pyroxene. Phenocrysts consist of hornblende and subordinate pyroxene (5-25% of rock voume and up to 20-30 mm long) and smaller plagioclase (5-20% of rock volume). Exposed rock commonly develops a strong to very strong varnish. Most laccoliths and sills consist of this rock type, including the prominent ridge at the Three Rivers Petroglyph site.

Tims **Megacrystic trachyte porphyry as sills -- Tim**, as described above, that occupies a definitive sill.

Tid **Equigranular, diorite to gabbro-syenogabbro intrusions occupying sills and laccoliths --** Light gray to gray, equigranular to slightly porphyritic hypabyssal rocks occupying sills and laccoliths. Texture is commonly subhedral. Grain size of ground mass is 0.1-0.5 mm, less commonly to 1.0 mm. Mineral assemblage consists of plagioclase with 15-25% hornblende and pyroxene. Exposed rock commonly develops a strong varnish.

Tidf **Fine-grained diorite to gabbro --** Aphanetic hypabyssal rock commonly filling dikes. Dark gray in color. Minerals include plagioclase and unidentified dark mafics. No olivine observed in handlense.

Tidm **Intermediate intrusions --** An intermediary unit between units **Tim** and **Tid**, particularly in regards to degree of porphyritic character and the grain size of the phenocrysts.

Tita **Porphyritic trachyandesite --** Porphyritic hypabyssal rock that generally fills dikes, and less commonly small laccoliths. Rock is light gray to gray and consists of a fine-grained groundmass (0.1-0.2 mm grain size) hosting minor phenocrysts up to 0.2-10 mm in length. Phenocrysts are subhedral to euhedral and include pyroxene(?) and smaller plagioclase.

Titdb **Prominent trachytic dacite rock observed north of Boone Draw --** A very hard, porphyritic (5-15% surface coverage by phenocrysts), light reddish gray to light gray (fresh) to light cream-colored (weathered) dike rock that extends 5 km in a ENE direction north of Boone Draw. Dike is at least 4 m-wide. Groundmass is aphanetic. Phenocrysts include feldspar (0.5-10 mm), pyroxene (0.2-6 mm), and subordinate biotite (0.2-3.0 mm).

Tit **Trachyte(?) --** A distinctive hypabyssal rock containing about 20% large phenocrysts (0.5-2.0 cm-long) of aligned feldspar in a groundmass consisting of fedlspar with 20% mafic grains (0.1-0.2 mm). Light gray to gray.

Tim-Kccm Interbedded megacrystic sills with the middle unit of the Crevasse Canyon Formation.

MESOZOIC STRATA

Kccu **Crevasse Canyon Formation, upper unit (Upper Cretaceous, Coniacian North American Stage) --** A prominent ledge-forming sandstone in the upper part of the Crevasse Canyon Formation. Overlies sandstone and shale beds of **Kccm**. Overlying strata not exposed. Sand is white to light gray, medium- to coarse-grained, subrounded to subangular, well-sorted, and composed of quartz with 1-5% mafics and cherty lithics. Bedding is laminated to thin, and tangential cross-stratified to planar-horizontal bedded. Sand is strongly cemented. Interpreted to correlate to the basal unit of the Cub Mountain Formation of Arkell (1983), but we follow the stratigraphic schemes of Weber (1964), Lucas et al. (1989) and Cather (1991) in keeping this sandstone in the upper Crevasse Canyon Formation. Not observed south of Three Rivers drainage. Up to 110 m-thick in the northeast corner of the quadrangle, but thins to the south.

Kccm **Crevasse Canyon Formation, middle unit (Upper Cretaceous, Coniacian North American Stage) --** Fluvial strata consisting of interbedded channel-fills of sandstone and shaly floodplain deposits; very minor coal beds. Sandstone is mostly fine- to medium-grained, subrounded to subangular, well-sorted, and composed of quartz, feldspar, and 5-10% lithic grains; high amounts (around 20%) of glauconite(?); these were classified as sublithic to subarkosic by Arkell (1982). Colors of the sand range from pale yellow, golden, light olive gray, pale olive, very pale brown, and light brownish gray. Beds are generally tangential to trough cross-stratified (laminated or very thin to thin beds), with subordinate to subequal planar-horizontal bedding (laminated to thin). Sandy channel-fill complexes may be up to 6 m-thick, are well-cemented, and form ledges. Floodplain deposits consist of shale and very fine- to fine-grained sandstone and silty sandstone, with local, very minor coal beds. Shale is pale yellow to light gray to gray to light olive gray in color and fissile. Carbonaceous shale is dark gray to black in color. Unit correlates with the Barren Member and Coal-Bearing Member of the Mesa Verde Group of Arkell (1983), but coal in this unit is not common in the map area. Base of unit not well-exposed on this quadrangle, but noted to be gradational in Arkell (1983). Thickness not well constrained, due to variability in dips, but on the scale of 450 to 600 m.

Kccl **Crevasse Canyon Formation, lower unit (Upper Cretaceous, lower Coniacian North American Stage) --** Interbedded sandstone and shale interpreted to reflect marginal marine (shoreface, foreshore, lagoonal pond, and deltaic) and fluvial depositional environments (Arkell, 1983). Unit gradationally overlies Mancos Shale, and its lowest strata are clearly shoreface facies. Base assigned to lower shoreface sandstone bed that is interbedded in gray, marine shale, below which shale exceeds about 80% of strata. Lower shoreface sandstones are thick, tabular, internally massive to planar-laminated, and interbedded with gray marine shales. Sand is very fine- to fine-grained, calcareous, subrounded to subangular, well-sorted, and composed of quartz with 5-10% lithic grains; glauconite(?) may be present. Colors range from light gray to olive-yellow to light yellowish brown to pale yellow. Upper shoreface sandstones are slightly coarser (mostly fine-grained) and in very thin to thick, tabular beds that are internally planar-laminated or cross-stratified (tangential or trough-cross-laminated). Sand is pale yellow to light gray, well-sorted, subrounded to subangular, and a lithic to feldspathic arenite; glauconite(?) is present in the matrix (20-25% surface area). The upper shoreface sandstone grades upward into a ~150 m(?) thick interval of interbedded, interpreted upper shoreface sandstones and fluvial sandstones, with subordinate oyster beds and light shale intervals 1-3 m-thick. One coal bed observed. The sand is commonly golden, medium- to thickly bedded, and internally planar-laminated to low angle cross-laminated to very thinly bedded. About 20% glauconite(?) is present in the sand. The sand is fine- to medium-grained, subrounded to subangular, well-sorted, and a lithic to feldspathic arenite. Although the upper shoreface sand may correlate to the Gallup Sandstone, it is not continuously exposed across the quadrangle and brackish water facies (containing oyster beds), are locally beneath it; therefore, this strata is subsumed into the Crevasse Canyon Formation. Upper contact placed at highest, golden brown, highly calcerous, very fine- to fine-grained sandstone bed containing marine or brackish water fossils; this bed is generally 30-100 cm-thick. This golden brown, fossiliferous sandstone(s) is relatively continuous throughout the study area and commonly form ledges. 50-150 m-thick.

Km **Mancos Shale (Upper Cretaceous, upper Cenomanian(?) through Turionian North American Stage) --** Fissile shale that is planar- to wavy-laminated; colors range from gray to light gray to light olive gray to light greenish gray. Metamorphosed to a black to gray argillite adjacent to laccoliths. Strata hosts laccoliths in the southeast part of the quadrangle; emplacement of these laccoliths has folded and deformed the adjoining Mancos Shale. Unit includes the pale yellow to white, fine-grained, shoreface sands of the Tres Hermanos Formation. Unit gradational overlies the Dakota Sandstone. Cross-section A-A' and well data indicate a thickness of 185-215 m.

Kd **Undifferentiated Dakota Sandstone (upper Cretaceous) --** Combined unit of upper and lower Dakota Sandstone (units Kdu and Kdl), which are described in detail below. Not differentiated due to insufficient exposure or extensive faulting. 45-55 m-thick.

Kdu **upper Dakota Sandstone (upper Cretaceous) --** Intercalated light gray siltstone, very fine-grained sandstone, and light to dark gray shale with subordinate beds of fine- to medium-grained sandstone. Shale is laminated and friable. Sandstone beds are medium to thick, tabular, and internally cross-stratified (very thin beds to laminations that are trough-cross-stratified to tangential-cross-stratified; up to 20 cm-thick); also planar-laminated. Trough cross-stratification commonly indicates a northeast paleoflow direction. Sand is white, well-sorted, subrounded to subangular, and composed of quartz. Sandstone beds are well-cemented. Uppermost sandstone beds are extensively burrowed, with *ophiomorpha* burrows common. Slightly purplish brown desert varnish forms on weathered sandstone. Top contact placed at top of upper quartz arenite sandstone with *ophiomorpha* burrows, which is overlain by dark gray shale of the Mancos Formation. 25-30 m-thick

Kdl **lower Dakota Sandstone (upper Cretaceous) --** Ledge-forming, quartz arenite sandstone. Beds are laminated to very thin and tangential- to trough-cross-stratified; also some planar-horizontal-beds (laminated to medium). Sand size is fine-upper to medium-upper. Sand is white, subrounded to subangular, and mostly well-sorted. Locally, beds of aforementioned sand are mixed with minor lithic grains (including chert), coarse- to very coarse-grained sand (composed largely of lithic grains), and sparse, very fine to very coarse, subrounded to rounded pebbles of quartz, chert, and quartzite. Lower contact is a scoured unconformity, and deposit locally fills paleovalleys at its base. This valley-fill is up to 6 m-thick and contains reddish to purplish shale beds and lithic arenite sandstone beds. Slightly purplish brown desert varnish forms on weathered sandstone. Approximately 20 m-thick.

Trm **Moenkopi Formation (middle Triassic, Anisian North American Stage) --** Cross-stratified, fine- to coarse-grained sandstone (mostly fine- to medium-grained). Colors of the sand range from reddish brown to light reddish brown to pale-weak red to pinkish gray. Varying proportions of weak red to reddish brown shale, claystone, and siltstone; these fine-grained lithologies are subordinate to the south, but may increase in abundance northwards. Sandstone is extensively cross-stratified (commonly trough- to tangential-cross-stratified and laminated to very thinly-bedded; 10-15 cm-thick foresets); minor planar-horizontal bedding and thin to medium, lenticular beds. Sandstone is subrounded to subangular, moderately to well sorted, and a lithic arenite (5-25% lithic grains, including mica, and ~5% estimated potassium feldspar). Locally, very minor (1-5%) beds of pebbly medium- to very coarse-grained sandstone (subrounded and composed of quartz with abundant chert and quartzite grains); pebbles are very fine to coarse and composed of rounded-subrounded chert and quartzite. Lower contact is a planar to scoured unconformity over the Artesia Group (scour relief of 1-3 m). Strata immediately below the overlying Dakota Sandstone may locally be bleached to a pale green and yellowish gray color. Assigned to Anton Chico Member by Lucas (1991); correlation to this member was verified in a field visit by Lucas during the spring of 2009. No fossils observed. Mostly 30-50 m-thick, but possibly as much as 70 m-thick at a location 0.5 m-thick of lower Three Rivers drainage.

PALEOZOIC STRATA

Pag **Grayburg Formation, Artesia Group (upper Permian, middle Guadalupian North American Stage) --** Very fine- to fine-grained sandstone and silty to clayey very fine- to fine-grained sandstone; subordinate siltstone and shale. Colors range from orange to red to light red to reddish brown (most to least common). Strata are generally in very thin to thick, tabular (minor irregular) beds. Reduction (bleached) spots 0.5-2 mm in diameter cover 1-15% of rock area, with higher coverage along bedding and fault planes (where they are dm-scale and irregular). Sand is subangular to rounded (mostly subrounded), well-sorted, and composed of quartz, with less than 10% possible feldspar. No fossils observed. Thick gypsum or anhydrite beds are absent to the north but increase to the south (to about 5%-10% of the unit; more common towards the top). Gypsum and anhydrite beds are generally deformed. Although definitively Artesia Group, we assign this to the Grayburg Formation because of lithologic characteristics, thickness, and the fact that higher formations of this group extend progressively shorter distances from the deepest parts of the Delaware Basin to the south (Kelley, 1971 and 1972). We did not recognize the Queen Formation of the Artesia Group because we did not note scattered large, rounded, frosted quartz grains indicative of the upper part of this formation (Tait et al., 1962). Orangish color, fine texture, and quartz arenite composition serve to differentiate this unit from the overlying Moenkopi Formation. Lower contact with San Andres Formation is a disconformity (see report for more discussion). Thickness is difficult to estimate based on map data because of irregular bedding attitudes where this unit is relatively well-exposed to the south. Well data at cross-section A-A' indicate a thickness of 90-110 m.

Psa **San Andres Formation, undifferentiated (lower to upper Permian, Leonardian to Guadalupian North American Stage) --** Most of the San Andres Formation on the quadrangle belongs to the Four-mile Draw Member, which is described below. However, inaccessible strata of the southern Phillips Hills were lumped together into this undifferentiated unit, which includes limestone and dolomite strata below the Four-mile Draw Member (i.e., Rio Bonito Member of Kelley, 1971). 240-250 m-thick, based on subsurface data for wells used in cross-section A-A'.

Psaf **Fourmile Draw Member of the San Andres Formation (upper Permian, Guadalupian North American Stage) --** Micritic, dark gray limestone, grayish tan to light gray dolomite, and gypsum. Beds are medium to thick and tabular. Carbonates become more dolomitic up-section, and the proportion of gypsum beds increases up-section. Approximately 100-120 m-thick.

Psafd **Dissolution-collapsed Fourmile Draw Member of the San Andres Formation (upper Permian) --** Chaotic assemblage of limestone and fine-grained sandstone that involves the upper Fourmile Draw Member and overlying Grayburg Formations. Interpreted to be due to dissolution of gypsum beds in the Fourmile Draw Member.

SUBSURFACE STRATA DEPICTED ONLY IN CROSS-SECTION

Note: Below the Bursum Formation, depth picks of Paleozoic strata are from King and Harder (1985).

Py **Yeso Formation (lower Permian) --** Yellow and red siltstone, limestone, and gypsum. 630 m-thick.

Pa **Abo Formation (lower Permian) --** Reddish color; consists of overbank deposits of mudstone and clayey fine-grained sandstone that are intercalated with coarse channel-fills of sandstone and pebbly sandstone. Approximately 450 m-thick.

Pb **Bursum Formation (uppermost Pennsylvanian(?) to lowermost Permian) --** Marine strata (shales and limestone beds) interbedded with fluvial sediment of overbank reddish shale together with channel-fill sandstone and pebbly sandstone. Approximately 500 m-thick.

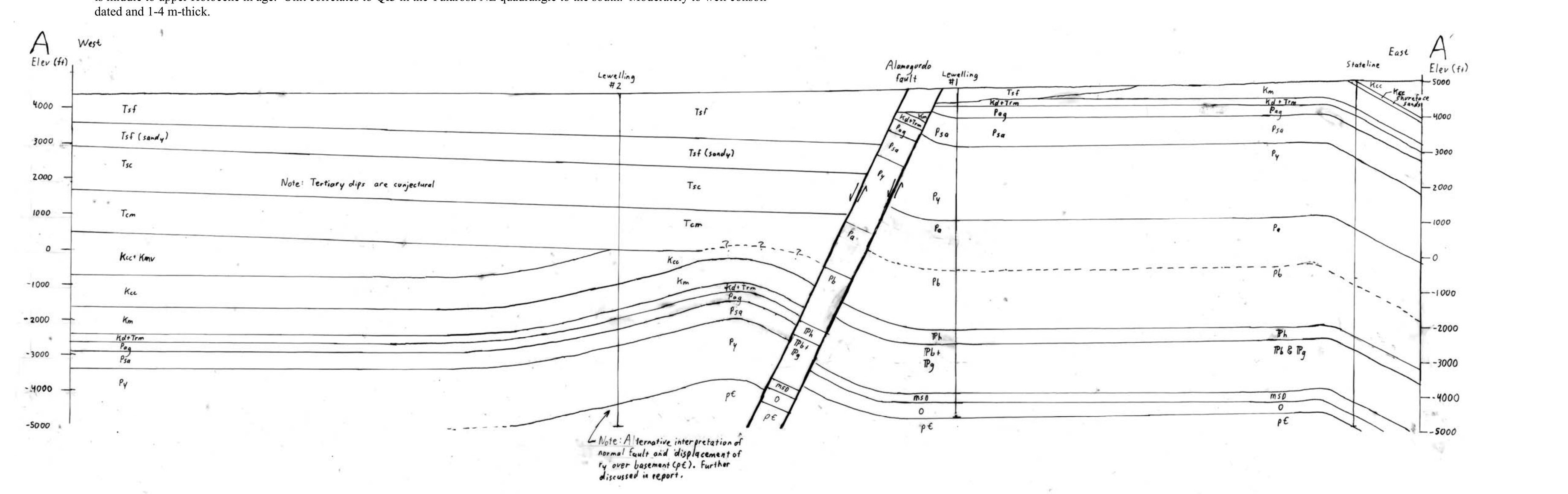
IPh **Holder Formation (upper Pennsylvanian) --** Limestone, gray and red calcareous shale, sandstone, and conglomerate (from Pray, 1961, fig. 3). 120 m-thick.

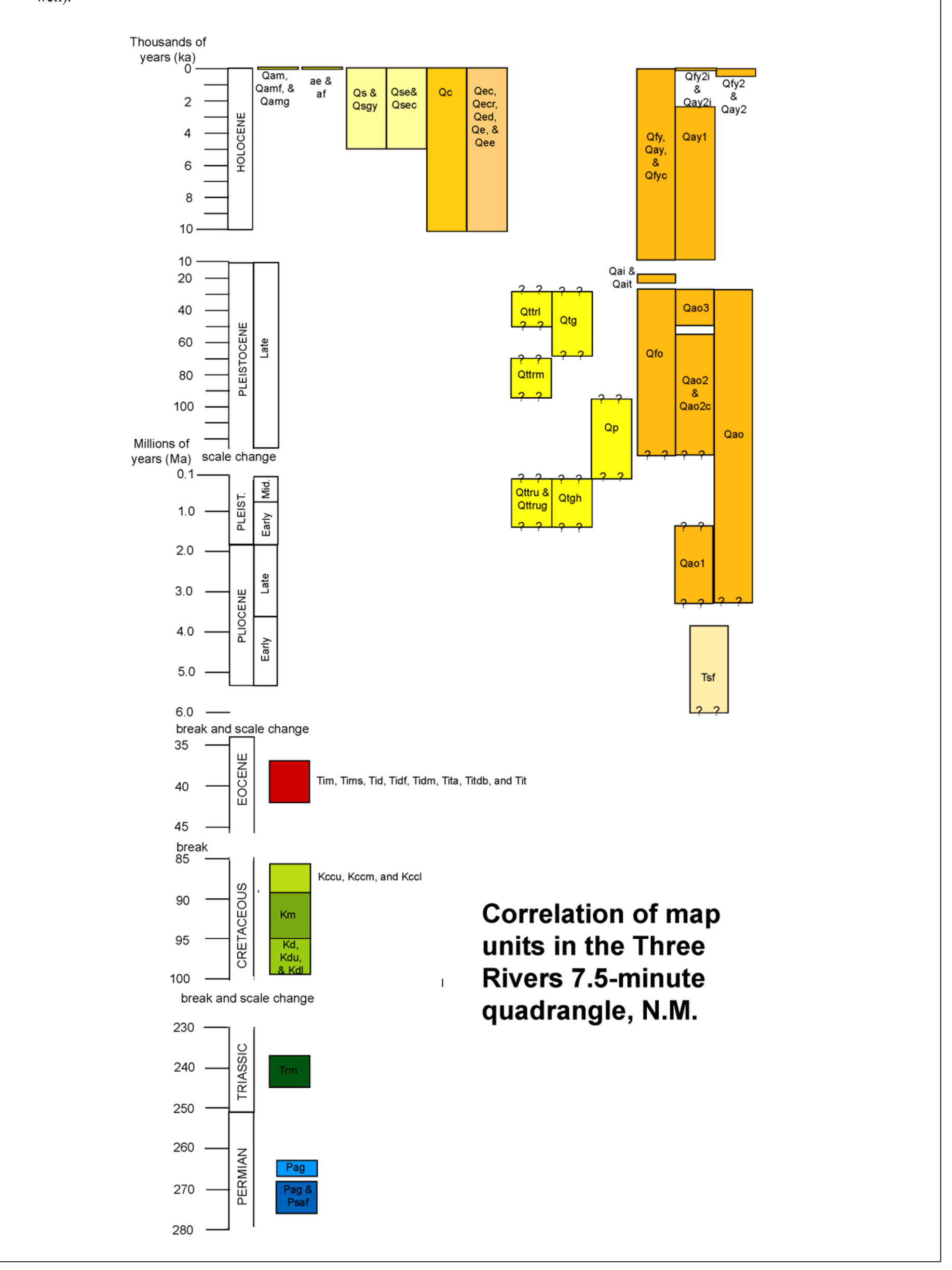
IPb + IPg **Beeman and Gobbler Formations, undifferentiated (lower to upper Pennsylvanian) --** Interbedded limestone, shale, and sandstone (from Pray, 1961, fig. 3). 400-430 m-thick.

MDS **Undifferentiated strata of Mississippian, Devonian and Silurian age --** Unit may include Lake Valley, Percha, and Fusselman formations, among others discussed in Pray (1961) and listed in King and Harder, 1985, fig. 21). 64-85 m-thick.

O **Undifferentiated strata of Ordivician age --** Unit includes Montoya and El Paso Formations (King and Harder, 1985, fig. 21). 120-150 m-thick.

pC **Precambrian rocks --** Rhyolite or granite, reddish and composed largely of quartz and feldspar (from mud log of the Lewelling #2 well).





Correlation of map units in the Three Rivers 7.5-minute quadrangle, N.M.