Geologic Map of the Cub Mountain Quadrangle, Lincoln County, New Mexico

By

Daniel Koning, Kirt Kempter, Kate E. Zeigler, and Colin Cikoski

June 2011

New Mexico Bureau of Geology and Mineral Resources
Open-file Digital Geologic Map OF-GM 138

Scale 1:24,000

This work was supported by the U.S. Geological Survey, National Cooperative Geologic Mapping Program (STATEMAP) under USGS Cooperative Agreement 10HQPA0003 and the New Mexico Bureau of Geology and Mineral Resources.

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PRELIMINARY GEOLOGIC MAP OF THE CUB MOUNTAIN 7.5-MINUTE QUADRANGLE, LINCOLN COUNTY, NEW MEXICO

BY

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YEAR 2 OF 2-YEAR QUADRANGLE

June, 2011

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DESCRIPTION OF MAP UNITS

The units described below were mapped by field traverses and inspection of aerial photography. Grain sizes follow the Udden-Wentworth scale for clastic sediments (Udden, 1914; Wentworth, 1922) and are based on field estimates. Pebbles are subdivided as shown in Compton (1985). The term "clast(s)" refers to the grain size fraction greater than 2 mm in diameter. Descriptions of bedding thickness follow Ingram (1954). Colors of sediment are based on visual comparison of dry samples to the Munsell Soil Color Charts (Munsell Color, 1994). Soil horizon designations and descriptive terms follow those of the Soil Survey Staff (1992), Birkeland et al. (1991), and Birkeland (1999). Stages of pedogenic calcium carbonate morphology are consistent with those of Gile et al. (1966) and Birkeland (1999). Description of sedimentary and igneous rocks was based solely on inspection using a hand lens.

QUATERNARY AND PLIOCENE SEDIMENT

Qs **Sheetflood deposits surrounding topographic highs –** Pebbly sand and sand on the lower flanks of Steele Hill and Jakes Hill. Inferred to have been deposited by sheetfloods. Esimated thickness of 1-2 m.

Qse/Qao1 **Sheetflood and eolian deposits overlying unit Qao1 –** Sheetflood deposits are pale brown to brown, pebbly-clayey sand that is loose and internally massive; sand is mostly fine-grained. A component of the fine-grained sediment is likely eolian. **Qao1** is described below. Up to 1-2 m-thick.

Qse/Kcc **Sheet flood and eolian deposits overlying unit Kcc –** Sheetflood deposits are pale brown to brown, pebbly-clayey sand that is loose and internally massive; sand is mostly fine-grained. A component of the fine-grained sediment is likely eolian. **Kcc** is described below. Up to 1-2 m-thick.

Qamh **Modern and historical alluvium (less than 200 years old) –** Gravel and sand that lie in active channels or were deposited in historical time. Fresh bar-and-swale topography is present and soil development is very weak to non-existent. Vegetation density is very low. Inferred to be less than 3 m-thick.

Qay2mh **Undifferentiated late Holocene alluvium filling incised, narrow valleys (upper Holocene) –** A combination of unit **Qamh** and slightly older Holocene sediment. This unit occupies the floor of modern valleys and consists of gravel and sand. Vegetation density can be moderate and weak soils may be present (characterized by a stage I carbonate morphology). Inferred to be less than 4 m-thick.

Qay **Younger alluvium, undivided (lower to upper Holocene) --** This unit contains two major cut- and fill deposits that were generally not differentiated. The older deposit (**Qay1**) is volumetrically the greatest and consists of pale brown to brown, very fine- to medium-grained sand and clayey sand. Sand exhibits fining-upward trends and contains sparse pebble lenses. Sediment is non- to weakly bedded The presence of Native American hearths confirm the older unit is Holocene in age. The surface of the older unit is commonly eroded and covered by younger sheetflood deposits. The younger unit (**Qay2)** is inset into the older unit and is typically well-bedded and slightly coarser (less clayey; sand and pebbles are common). The younger unit is likely late Holocene in age based on the lack of a notable soil. Qay becomes finer-grained to the west, where it consists of clay, silt, and very fine- to fine-grained sand, and the two subunits become increasingly difficult to differentiate. Unit is commonly 2-5 m-thick and inset below **Qao3**.

Qay1 **Older subunit of younger alluvium (lower to middle Holocene) –** Pale brown to brownish gray, very fine- to fine-grained sand and clayey-silty very fine- to medium-grained sand. Fine-grained sediment is massive to poorly bedded. Locally within the fine-grained sand are minor scattered pebbles and coarse sand grains. Minor (5-10%) very thin to medium, lenticular beds of medium- to very coarse-grained sand and gravel (mostly pebbles and cobbles). Except where eroded, the surface of the unit typically contains a stage I+ calcic horizon, where surface clasts are covered by coats of calcium carbonate. Top of unit is commonly eroded and capped by a gravel lag or 10-30 cm of locally derived sand and gravel. 1-5 m-thick.

Qay2 **Younger subunit of younger alluvium (upper Holocene) –** Pale brown to very pale brown, well-bedded sand. Unit either disconformably overlies Qay1 (0.5-3 m-thick) or, less commonly, fills narrow paleovalleys inset into Qay1 (up to 5 m-thick). Unit is generally ligher-colored than Qay1, lacks clay, and exhibits obvious bedding. Bedding commonly consists of laminations to thin beds that are horizontal-planar to cross-stratified. Sand ranges from very fine- to very coarse-grained but is mostly fine- to coarse-grained. Minor very thin to thin, lenticular to tabular beds of very fine to very coarse sandy pebbles. Weakly to moderately consolidated. Mostly 0.5-3.0 m-thick.

Qao **Older alluvium, undifferentiated (lower to upper Pleistocene) –** Unit generally consists of **Qao2** or **Qao1**, which are described in more detail below.

Qao3 **Older alluvium, subunit 3 (uppermost Pleistocene) --** A clast-supported, sandy gravel with a reddish yellow matrix. Clasts are imbricated and consist of pebbles and cobbles. Away from topographic highs, the sediment becomes progressively sandier and finer-grained. Topsoil of unit has a stage I to II carbonate morphology. Unit underlies terraces 2-15 m in height.

Qao2 **Older alluvium, subunit 2 (upper Pleistocene) –** Sand and gravel deposits that appear to be inset into nearby **Qao1** sediment. The tread of this unit lies up to 6 m below nearby **Qao1** surfaces. Strath is not exposed. A good exposure along Chaves Draw (UTM coord: 413910 m E and 3710870 m N, NAD27) shows interfingering axial and floodplain facies. Floodplain sediment is light brown to reddish yellow, hard, and composed of silty-clayey very fine- to fine-grained sand in thin to thick, tabular beds. Within the floodplain sediment are 20-25% interbeds of fine- to very coarse-grained sand and sandy pebbles; these coarse beds are very thin to thin and lenticular to tabular.

The axial sediment at the Chaves Draw exposure consists of well-bedded sandy gravel. Beds are laminated to very thin and horizontal-planar to cross-stratified (30 cm-thick foresents). Elsewhere, the sandy gravel is commonly in very thin to thin, tabular beds, with minor thin to thick, lenticular, pebble-boulder beds. In general the sand fraction is gray, fine- to very coarse-grained, subrounded, poorly sorted, and contains abundant volcanic lithic grains. Where not eroded, this unit has a strong calcic horizon at its surface (commonly overlain by a reddish yellow Bw or Bt soil horizon). The calcic soil horizon has a stage III to IV carbonate morphology. Along Willow Draw and Harkey Draw, the matrix of this gravelly unit has a reddish brown to light brown color and the surface has been eroded, resulting in a general lack of a notable calcic horizon. Moderately consolidated and 1-12 m-thick.

Qao1 **Older alluvium, subunit 1 (lower to upper Pleistocene) –** Interbedded sandy gravel, pebbly sand, and sand that is inset into unit **QTa**. Pebbly sand and sand are in laminated to thin, planar-horizontal beds; pebbly beds tend to be lenticular. Gravel are subrounded, moderately to poorly sorted, and consist of pebbles with subordinate beds rich in cobbles and boulders. Clasts are locally imbricated and composed of syenite clasts, intermediate volcanic clasts, and subordinate sandstone clasts. Sand is very pale brown (10YR 7/3-4) to light yellowish brown (10YR 6/4), very fine- to very coarse-grained, subrounded to subangular, poorly to well-sorted, and composed of quartz, 0-25% feldspar, and 10-15% lithic and mafic grains. Sand is internally massive and has 15% gypsum filaments. Base of deposit is commonly not exposed, in contrast to the higher strath of unit **QTa**. Thickness is variable due to erosion; generally less than 12 m-thick.

QTa **High-level alluvium, (upper Pliocene to lower Pleistocene) --** Sandy gravel near topographic highs that grades westward into intercalated sandy pebbles, pebbly sand, sand, and clayey sand. Sandy sediment bedding is commonly laminated to very thin, horizontal-planar to cross-stratified. Gravel contains pebbles, subordinate cobbles, and very minor boulders. Clasts are subrounded to subangular, poorly sorted, and composed mostly of intermediate volcanic rocks. Finer-grained sediment is commonly reddish brown. Basal 1-6 m of unit may be strongly cemented, otherwise weakly to moderately consolidated. Up to ~15 m thick.

QTac **High-level alluvium deposited by Chavez drainage (upper Pliocene to lower Pleistocene) --** Demarcated only along Chaves Draw, this unit consists of clast-supported gravel composed of dark, intermediate volcanic clasts; gravel is interbedded with clayey to slightly clayey sand. Commonly medium-bedded. Gravel are subangular to rounded, poorly to moderately sorted, and composed of intermediate volcanic rocks that range from pebbles to cobbles (mostly pebbles), with less than 10% boulders. Color of sand ranges from weak red to reddish gray to reddish brown to brown to reddish yellow. Sand is very fine- to very coarse-grained, subrounded to rounded, poorly sorted, and a volcanic litharenite. Unit becomes more sandy in a downstream direction. Basal part of unit may be strongly cemented. Unit interfingers with **QTalp**, but **QTalp** prograded over this unit. As much as 8 m-thick.

QTap **High-level alluvium, subunit 1, piedmont facies (upper Pliocene to lower Pleistocene) --** Demarcated only south of Cub Mountain, this unit is predominately sandy gravel in vague, medium to thick, tabular to lenticular beds. Gravel consists of cobbles with minor pebbles and boulders. Clasts are subrounded, very poorly sorted, and composed of syenite. Sand is brown to strong brown to light brown, fine- to very coarse-grained, subangular to subrounded, moderately to poorly sorted, and arkosic (with 5-7% lithic grains). Unit has prograded over **QTac**. Approximately 20 m-thick.

Tg **High-level sandy gravel (Pliocene) --** Sandy gravel overlying high-level straths that are above the straths associated with unit QTa or QTac. Poorly exposed and less than 10 m-thick.

MASS-WASTING DEPOSITS

Qls **Landslides (upper(?) Pleistocene) --** Angular cobbles and boulders (minor pebbles) that are non-bedded and very poorly sorted. Matrix is a light brown (7.5YR 6/4), very fine- to fine-grained sand, with 5-10% silt and clay and ~25% medium- to very coarse grained sand. An erosional lag layer of boulders and cobbles is commonly found on the surface of the unit. Weakly consolidated. Up to 60 m-thick.

COLLUVIAL AND DEBRIS FLOW DEPOSITS

Qct **Colluvium and talus (upper Pleistocene to Holocene) --** Angular gravel that are non-bedded and very poorly sorted. Gravel consist of cobbles and pebbles with minor boulders. Clasts are angular to subangular and very poorly sorted. Matrix consists of sand (mostly very fine- to fine-grained) and minor clay-silt. 1-6(?) m-thick.

Qdct **Debris flows, colluvium, and talus on steep hillslopes (upper Pleistocene to Holocene) –** Gravelly sediment on steep slopes inferred to have been deposited by debris flows or processes associated with colluvium or talus. Sediment is massive or in vague, medium to thick, lenticular beds. Commonly matrix-supported. Gravel is angular and mostly consists of medium to very coarse pebbles and cobbles, but includes minor finer pebbles and boulders. Weakly to non consolidated. 1-10(?) m thick.

IGNEOUS ROCKS

Flows

Qbm **Basalt of the Malpais (middle Holocene) --** Gray, vesicular basalt that contains 5% phenocrysts of pyroxene (0.5-2.0 mm-long). Groundmass is 0.1-0.3 mm and a mix of plagioclase and pyroxene(?). Up to several meters thick.

Intrusions

Tit **Trachyte intrusion or dike (upper Eocene to lower Oligocene) --** Intrusive rock that exhibits a creamy tan to creamy white color and is composed of feldspar (probably albite, microline or orthoclase) grains less than 1 m mlong. Feldspar grains are commonly platy and stacked on top of one another, producing a foliated texture. Up to 25% mafic, unidentified mafic minerals 0.1-0.5 mm long. Up to 1% quartz and 1-5% possible sanidine. Orangish swirly pattern is common on weathered surfaces.

Tits **Trachyte sill (upper Eocene to lower Oligocene) --** Trachyte, as in unit Tit, in sills that are greater than 3 m-thick.

Tiss **Syenite sill (upper Eocene to lower Oligocene) --** Feldspar-rich rock with phenocrysts of albite, microline, or orthoclase. 1-5 m-thick.

Titlc **Trachyte of Little Cub Mountain (Oligocene).** Grains are 0.1-0.8 mm and composed predominately of feldspar. There are 3-8% unidentified mafic grains (possibly amphibole) 0.5-2 mm long. Rock has up to 10% cavities up to 7 mm long that do not seem to be connected or aligned. Rock weathers to a brown color. Maximum thickness of 100 m.

Tisch **Syenite of Chaves Mountain (Oligocene?) --** Slightly porphyritic syenite that contains 5% phenocrysts of potassium feldspar (orthoclase; Weber, 1964) and biotite. This syenite forms a sill near the Cub Mountain – Sanders Canyon Formation contact. Groundmass is composed of feldspar with 10% bioite. Augite, aegerite, and analcite were reported by Weber (1964) in the groundmass but were not identified in the field. Grains are not aligned and sanidine was not observed. Maximum thickness of 120 m.

Tiscu **Syenite of Cub Mountain (Oligocene?) --** Light reddish gray to light gray (fresh) to very pale brown (weathered), porphyritic syenite that forms a stock. Groundmass is 0.1-0.5 mm and composed of potassium feldspar (orthoclase; Weber, 1964) with 15% hornblende. 10-15% phenocrysts of euhderal to subhedral plagioclase and orthoclase that are 1-18 mm-long, and 7% phenocrysts of subhedral hornblende that are 0.3-7.0 mm long. Nepheline was in this unit by Weber (1964).

Tisw **Sill of Willow Hill (Oligocene?) –** Slightly greenish-light gray intrusion that caps Willow Hill. Grains are 0.1-1.0 mm, euhdral to subhedral, and are composed of feldspar with 20% mafics and trace quartz. Phenocrysts cover about 5% of rock surface, are 1-2 mm long, and consist of orthoclase (~3%) and pyroxene (~2%). Rock was called a leucosyenite by Weber (1964), who described the matrix as being composed of altered orthoclase with minor aegerite-augite and biotite. 240-250 m-thick.

Tip1 **Upper trachyandesite sill at the Polly Hills (upper Eocene?) –** Upper exposed sill at the Polly Hills that extends the entire length of the hills. Rock is dark gray, fine-grained, and similar in composition to the sills at Jake Hill. 5-6 m-thick.

Tip2 **Syenite(?) sill at the Polly Hills (Oligocene?) –** Light pink, fine- to medium-grained syenite(?) with a granular groundmass of alkali feldspar, biotite, pyroxene, and plagioclase. Slightly porphyritic, with phenocrysts of plagioclase that are typically altered white. Cross-cutting relations with the **Tip1** sill is unclear. ~15 m-thick.

Tip3 **Lower trachyandesite sill at the Polly Hills (upper Eocene?) –** Lowest exposed sill at the Polly Hills; pinches out to the northeast. Rock is dark gray, fine-grained, and similar in composition to the sills at Jake Hill. 0-12(?) m-thick.

Tij1 **Upper trachyandesite sill at Jake Hill (upper Eocene?) –** Upper of two sills emplaced at Jakes Hill. Rock is gray to dark gray, fine-grained intrusive. Grains are 01.-0.3 mm, anhedral, and composed of plagioclase with ~10% mafic minerals that were not identified (probably pyroxene +/- amphibole). Less than 5% phenocrysts of plagioclase and hornblende. 15-20 m-thick.

Tij2 **Lower trachyandesite sill at Jake Hill (upper Eocene?) –** Lower of two sills emplaced at Jakes Hill. Rock is gray to dark gray, fine-grained intrusive. Grains are 01.-0.3 mm, anhedral, and composed of plagioclase with ~10% mafic minerals that were not identified (probably pyroxene +/- amphibole). Less than 5% phenocrysts of plagioclase and hornblende. 9-12 m-thick.

Tita **Trachyandesite (upper Eocene to lower Oligocene) –** Gray, porphyritic igneous rock in sills or dikes that contain pyroxene and/or plagioclase phenocrysts. Phenocrysts are commonly 0.5-5 mm in length and subhedral; locally, pyroxene phenocrysts are as much as 22 mm long. Groundmass is commonly 0.1-0.5 mm, subhedral to euhedral and composed of plagioclase with minor pyroxene. Rock produces a strong varnish upon weathering. Dikes are up to 6 m-wide.

Tib **Basaltic dike (upper Eocene to lower Oligocene) --** Fine-grained, dark gray to greenish gray rock that is commonly chloritized or otherwise altered. Dikes are less than 2 m wide and generally strike east-west.

Tibta **Basaltic trachyandesite (upper Eocene to lower Oligocene) –** Gray (fresh), extremely porphyrtic dike rocks. Weathers to a brownish gray color and produces a strong varnish. This distinct rock contains large, subhedral to euhedral, plagioclase phenocrysts that are 1-15 mm long, with trace phenocrysts up to 18 mm-long. Ground mass is 0.1-0.2 mm and composed of plagioclase with minor mafic minerals. Dikes are as wide as 6 m.

Titabr **Trachyandesite correlative to Barber Ridge unit (upper Eocene to lower Oligocene) –** Gray (fresh), porphyritic rock with pyroxene +/- plagioclase phenocrysts. Rock weathers to brownish gray. This rock fills dikes that strike southeast. The dikes contain 10-15% pyroxene phenocrysts that are 0.5-23 mm long. Groundmass is 0.1-1.0 mm and composed of plagioclase with 20-25% mafic minerals ~0.1 mm in size. Dikes are up to 6 m wide.

Tig **Gabbroic dike (upper Eocene) –** Dark gray rock composed of plagioclase with ~30% mafic minerals of pyroxene or hornblende. Plagioclase is 0.1-0.5 mm and the mafic minerals are euhedral and 1-2 mm.

LOWER TERTIARY STRATA

Twtb **Walker Group, trachybasalt flows (upper Eocene)** -- Aphanetic, very dark gray rock inferred to be a basalt. Weathered surfaces are light gray and shiny, and locally a 1-3 mm splotchy pattern is present. Flows appear to be 1-3 m-thick, but exposure is poor. Unit includes minor fine-grained flows containing pyroxene and plagioclase phenocrysts. In the Oscura quadrangle to the south, trachybasalts in a similar stratigraphic position are interbedded with volcaniclastic sediment composed of reddish brown clay with 10-15% scattered andesite pebbles (unit Ttbs of Koning et al., 2010). Age is not constrained. Unit is 115-130 m-thick on the Oscura quadrangle (Koning et al., 2010).

Twsf **Walker Group, sediments and minor volcanic flows (middle? to upper Eocene)--** Conglomerates and sandstones interbedded with minor volcanic flows that include tradchybasalt (unit **Twtb**) and possibly pyroxene- and plagioclase-phyric flows. Probably correlates to unit Twl in the Oscura quadrangle, where it is at least 200 m-thick (Koning et al., 2010)

Tws **Walker Group, sediments (middle? to upper Eocene) --** Light gray volcaniclastic sediment consisting of interbedded sandstone and conglomerate. Sandstone is fine- to very coarse-grained, subangular to subrounded, poorly sorted, and composed of feldspar (probably mostly plagioclase), minor quartz, and 12-15% volcanic lithic grains and mafics. Gravel consist of pebbles and cobbles that are poorly sorted, subrounded to rounded, and composed of porphyritic, intermediate volcanic rocks. Unit it 270 m-thick at one locality in the Oscura quadrangle to the south (Koning et al., 2010), but its thickness here is difficult to ascertain.

Tsc **Sanders Canyon Formation (middle Eocene) --** Light gray strata that disconformably(?) overlies the Cub Mountain Formation. This fluvial sediment consists of interbedded channel-fills and floodplain deposits. Bedding in channel-fills is horizontal-planar (locally slightly wavy) in laminated to very thin beds. Locally, planar- to tangential cross-lamination is present (foresets up to 4 cm-thick). Sand is light gray (7.5YR 7/1), very fine- to medium-grained (mostly fine-grained), subangular, well-sorted, and composed of plagioclase, 15-25% volcanic lithic grains, and 5-10% potassium feldspar (field estimates). Sandstone petrologic study by Cather (1991) for the Sanders Canyon Formation give ranges of: 31-65% volcanic rock fragments, 8-41% twinned plagioclase, 7-31% quartz (decreasing up-section), 0-7% microline and orthoclase, 0-4% granite and gneiss rock fragments, 0-3% chert, 0-2% metamorphic rock fragments, and 0-2% sandstone rock fragments. Sandstone channel-fills are typically well-cemented by carbonate (Cather, 1991). Floodplain sediment consists of claystone and siltstone in thin to thick, tabular beds that are locally internally horizontal planar-laminated. Colors of clayey floodplain sediment ranges from reddish gray (2.5YR 5-6/1) to reddish brown (2.5YR 5/4). Silty floodplain sediment is reddish gray to light reddish gray (2.5YR 6-7/1). In Chaves Canyon, below the base of the lowest channel-fill is reddish brown claystone that is internally massive and has 10-15% reduced nodules (very fine to very coarse pebble size); this is suggestive of a short hiatus in deposition between the Cub Mountain and Sanders Canyon Formation but more investigation is needed to address this issue. About 120 m of this unit is exposed on the Cub Mountain quadrangle. Total thickness may be as much as 400 m.

Tscf **Sanders Canyon Formation, fine-grained (lower to middle Eocene) --**Light gray to maroon mudstone that is locally reduced and generally massive. Interpreted to lie near the top of the Sanders Canyon Formation. 50-100 m thick.

Tcm **Cub Mountain Formation (lower to middle Eocene) --** White to pale yellow to light reddish gray, channel-fill sandstones interbedded with reddish floodplain deposits of mudstone and very fine- to fine-grained sandstone. The slightly coarser texture of the sand (mostly medium-grained) and reddish fine-grained sandstone beds serve to distinguish this unit from the underlying Crevasse Canyon Formation. Channel-fill sandstones are tangentially cross-stratified (foresets up to 50 cm-thick) or horizontal-planar-bedded (mostly laminated to very thin). Sandstones are moderately to strongly cemented by carbonate and lesser amounts of clay and quartz (Cather, 1991). Sand is fine- to coarse-grained (mostly medium-grained), subrounded to subangular, moderately to well-sorted, locally glauconitic, and composed of quartz with subordinate feldspar and 3-15% mafic and lithic grains that include volcanic grains (field estimates). Sandstone petrologic study by Cather (1991) for the Cub Mountain Formation give ranges of: 50-70% quartz, 3-15% microline and orthoclase, 2-16% granite and gneiss rock fragments, 5-11% volcanic rock fragments, 1-9% chert, 0-9% metamorphic rock fragments, 0.5-6% twinned plagioclase, and 0-3% sandstone rock fragments. Locally, very coarse sand and pebbles are present in the channel-fills; gravel are subrounded, moderately sorted, and composed of quartz + quartzite, rhyolite, and chert. Pebbles are 2-10 mm in length. Sand matrix of conglomerate beds consists of medium- to very coarse-grained sand. Floodplain deposits consist of claystone, mudstone, siltstone, and very fine- to fine-grained sandstone. Claystone is weak red (2.5YR 5/2 and 10R 5/3) to reddish brown (2.5YR 5/3) to reddish gray (10R 6/1) and in thin to thick, tabular beds. Mudstone is pale red to purplish red (2.5YR 6/2-10R 6/1-2). Siltstone is reddish brown (2.5YR 5/3) and horizontal planar-laminated to ripple-marked. Very fine- to fine-grained sandstone is pinkish gray to lght gray (5YR 6/1-2) and in laminated to very thin, tabular beds. The fine-grained, floodplain sandstone is subangular (minor subrounded), well-sorted, and composed of quartz and feldspar(?) with 20-35% lithic and mafic grains (half of which are volcanic?). Locally, beds of light gray, fine- to medium-grained sandstone are present in this formation; these look similar to the sands in the Sanders Canyon Formation and have 20% lithic (including abundant biotite) + mafic grains. Strata are interpreted as a fluvial deposit. Definition of the base of this unit differs from that of Cather (1991). We define the base of the Cub Mountain Formation at the top of the mottled, MnO(?) concretion-bearing paleosol at the top of the Crevasse Canyon Formation. This gives a thickness range of 370-570 m.

MESOZOIC STRATA

Kcc **Crevasse Canyon Formation, undivided (Upper Cretaceous) --** Units **Kccu**, **Kccl**, **Kccda**, and **Kccdi**, which are described in more detail below.

Kccu **Crevasse Canyon Formation, upper part (Upper Cretaceous) --** Intercalated channel-fill sandstones and floodplain deposits. This fluvial sediment differs from the overlying Cub Mountain Formation by its yellowish-greenish floodplain deposits and its slightly finer sand sizes in the channel-fills. Sandstone channel-fills commonly occur in stacked complexes 1-10(?) m in thickness. Individual channel-fills are very thin to thick, tabular bedded (locally internally planar-horizontal- to cross-laminated) or tangentially cross-stratified (laminated to thinly-bedded). Fresh colors are generally white to pale yellow to olive yellow to light gray, commonly weathering to pale yellow or yellow or brownish yellow. Sand is fine- to medium-grained, subrounded to subangular, well-sorted, and composed of quartz, 5-15% feldspar, and 1-15% gray to very dark gray lithic grains and black mafic grains (field estimates). Sandstone petrologic study by Cather (1991) for the upper Crevasse Canyon Formation give ranges of: 50-80% quartz, generally 4-10% microline and orthoclase, 2-9% granite and gneiss rock fragments, 0-14% volcanic rock fragments, 5-8% chert, 0-4% metamorphic rock fragments, 0.4-2.5% twinned plagioclase, and 0-1% sandstone rock fragments. Sand is variably glauconitic and generally cemented (mostly by carbonate; Cather, 1991). Floodplain sediment consists of mudstone, siltstone, and very fine-to fine-grained sandstone in laminated to thin (less commonly, medium), tabular beds; coal seams are locally common and generally up to 30 cm-thick (although uncommon, thicker coal beds are also present). Colors for floodplain strata are light olive gray to pale olive (5Y 6/2-3) to light brownish gray (2.5Y 6/2) to gray (2.5-5Y 5-6/1) to light greenish gray (10GY 8/1). Pebbles are found in channel-fills in the upper part of the unit, in association with thicker foresets (up to 1 m-thick). Cobbles are relatively sparse, with the largest clasts being 11x6 cm. Gravel are scattered or in very thin to thick, lenticular beds. Gravel are rounded, moderately sorted, and composed of rhyolite, felsic intrusive clasts, quartzite, and chert. One cobble of a rhyodacite-dacite was noted. The gravelly upper interval of the Crevasse Canyon Formation likely corresponds to the Ash Canyon Member. The upper contact of the Crevasse Canyon Formation is mapped at the top of a distinctive, 6-8 m-thick paleosol. This paleosol is composed of a light gray, fine- to medium-grained sandstone with 15% dark purple concretions that are ~3-10 cm diameter and inferred to be cemented by manganese oxides. The sand in the paleosol is massive and likely bioturbated, subangular to subrounded, well-sorted, and composed of quartz, minor feldspar, and 3-10% lithic grains. Unit is approximately 260 m thick in the vicinity of the coal mines at Willow Draw.

Kccl **Crevasse Canyon Formation, lower part (Upper Cretaceous, Coniacian? North American Stage) –** Mudstone and shale floodplain deposits interbedded with minor sandstone channel-fills. The floodplain deposits consist of gray to dark gray to greenish gray, fissile to blocky shale and mudstone. Estimate 1-3% coal beds or organic-rich mudstone beds that are generally less than 1 m-thick. Locally, iron oxide (siderite?) concretions are present. Sandstone channel-fills are 1-5 m-thick, pale yellow to yellow, and contain a variety of bedding: mostly laminated to thick and tabular to cross-stratified. Sand is subrounded to subangular, well-sorted, and composed of quartz, 10-20% feldspar, and 3-10% lithic and mafic grains. Contact between this unit and the upper part of the Crevasse Canyon Formation (unit **Kccu**) is gradational and placed at the base of the first laterally extensive sandstone interval that is ~10 m thick or more. Unit is approximately 290 m thick in the vicinity of the coal mines at Willow Draw.

Kccda **Crevasse Canyon Formation, Dalton Sandstone(?) (Upper Cretaceous, Coniacian North American Stage) –** Primarily sandstone that locally contains marine invertebrate fossils (including oysters). Sandstone is in very thin to medium, tabular beds that are internally planar-horizontal laminated to tangential cross-laminated (up to 30 cm-thick). Base of unit contains hummocky cross-stratification (1 m thick or less) underlain by ~1 m of bioturbated sandstone. Sand is pale yellow and fine- to medium-grained, subrounded to subangular, well sorted, and composed of quartz, 15-25% feldspar, and 15-20% lithic and mafic grains. Shale partings locally are present between tabular sandstone beds, suggesting local tidal channel or tidal bar deposition. Top contact drawn at a thick, calcareous, orangish sandstone bed with trace to very minor shell fossils(including oysters); lower part of this fine-grained sandstone bed may be planar-horizontal laminated and upper part may be a sandy limestone. 25-45 m-thick.

Kccdi **Crevasse Canyon Formation, Dilco Member (Upper Cretaceous, Coniacian North American Stage) –** Interbedded gray shale and minor yellow sandstone beds. Coal bed(s) observed in unit on west slope of Willow Hill. Sandstone is in very thin to thick, tabular beds that are internally horizontal planar-laminated to cross-laminated. Strata interpreted to be a mix of fluvial and lagoonal facies. Approximately 18-28 m-thick.

Kgs **Gallup Sandstone (Upper Cretaceous, lower Coniacian Stage) --** Sandstone tongues interbedded with light gray to gray shale intervals. Unit interpreted to have been deposited in a nearshore to offshore marine environment. In a given sandstone tongue, strata progress upwards from 1-2 m of bioturbated sand to 1-2 m of hummocky cross-stratified sand to several meters of tangential cross-stratified (up to 30 cm-thick foresets) and horizontal-planar laminated sand. The latter may be within medium to very thick, tabular beds. This cycle represents shallowing of water depth from below wave base to the swash zone on the beach. Sand is white to pale yellow to yellow, fine- to medium-grained, subrounded to subangular, well sorted, and composed of quartz with 1-10% feldspar and 3-10% lithic and mafic grains. Top of sandstone beds locally contain paleo-burrows. Shales represent offshore, deep-water facies and are fissile. Oyster shells are abundant locally. The top of the Gallup Sandstone is placed at the top of the sandstone tongue below the coal-bearing Dilco Member of the Crevasse Canyon Formation. The top bed of the upper tongue is generally thick, tabular, and composed of a distinctive fine- to medium-grained, bioturbated, quartzose sandstone. On the west slopes of Willow Hill, this bioturbated, quartzose sandstone bed commonly overlies a thick sandstone bed containing abundant, large oyster fossils. Base of unit placed at the bottom of the lowest 2-m thick (or greater) sandstone tongue displaying the aforementioned shallowing upward cycle. Sandstone is well-cemented by large intrusions near Cub Mountain and Willow Hill, but the degree of cementation appears to decrease to the west. Unit is 100-110 m-thick.

Kmd **Mancos Shale, D-Cross Member (Upper Cretaceous, middle Turonian to lowest Coniacian Stage) --** Dark gray to greenish gray, fissile shale. This unit is yellow and relatively sandy-silty near the western boundary of the quadrangle, where it is in laminated to medium, tabular to wavy beds. Shale is planar-horizontal laminated or very thinly bedded, and commonly silty. Towards top of unit, green to brown beds of siltstone and very fine- to fine-grained sandstone become progressively more common. Sandstone beds are very thin to medium and tabular. Unit erodes readily and tends to be exposed only in recently cut arroyos. Approximately 90 m-thick.

SUBSURFACE UNITS DEPICTED ONLY IN CROSS-SECTION A-A'

Km+Kth **Mancos Shale and Tres Hermanos Formation, undivided (Upper Cretaceous) –** Upper part includes the D-Cross Member. This is underlain by ~30 m of sandstone of the Tres Hermanos Formation, followed by more gray, marine shale.

Kd **Dakota Formation (upper Cretaceous) –** Fine- to medium-grained sandstone, with local pebbles. Sandstone is tangential- to planar- cross-stratified or in medium to thick, tabular beds. Deposited in a fluvial environment.

Trm **Moenkopi Formation (middle Triassic) –** Interbedded sandstone and pebbly sandstone channel-fills and floodplain deposits that were deposited in a fluvial setting. Sand is typically light purplish white, red, reddish gray, or light gray (weathering to light brownish gray) and fine- to medium-grained. Floodplain deposits are composed of weak red to red to reddish brown mudstone, siltstone, and very fine- to fine-grained sandstone. About 100 m thick in adjoining quadrangle to the west (Zeigler and Allen, 2010). [Description summarized from Koning et al., 2010].

Psa **Sand Andres Formation (lower to upper Permian) –** Light gray limestone and tannish dolomite that grade upward into interbedded carbonate and gypsum beds. 250-270 m-thick. [Description summarized from Koning et al., 2010].

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

ACKNOWLEDGMENTS

We sincerely thank Mark Hendrix for allowing us to map on the Bar X Ranch and Kenneth Owens for enthusiastically granting permission to map his land to the north. John Hemphill allowed access to his land on the Polly Hills and Kathy MacDonald gave permission to map her land south of Steele Hill. Steve Hook and Greg Mack generously shared their expertise in Gallup Sandstone fossils and sequence stratigraphy. The shallowing-upward trends in the Gallup Sandstones were recognized and studied by Greg Mack.

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Cub_Mtn_photo caption: Ruin associated with coal mining in Willow Draw. The coal seams are located in the lower Crevasse Canyon Formation. This unit is dominated by floodplain deposits of gray to greenish gray shale and mudstone. Within these fine-grained, fluvial and paludal strata are an estimated 1-3% beds of coal or organic-rich mudstone. A coal mine dump can be seen to the right of the ruin. In the background is Cub Mountain, the namesake of the quadrangle. The upper part of this mountain is composed of a stock of porphyritic syenite.

Gallup SS photo caption: The upper sandstone tongue of the Gallup Sandstone, which represents nearshore and foreshore deposition during a sea level regression. In background is Willow Hill. This hill is formed by exhumation of a syenitic sill.

Kccu_top_soil photo caption: The top of the Crevasse Canyon Formation was mapped at the top of the paleosol depicted here. This paleosol is composed of a light gray, fine- to medium-grained sandstone. The sandstone is massive and probably thoroughly bioturbated. Note the dark purple concretions that are ~3-10 cm diameter and inferred to be cemented by manganese oxides.