

Preliminary Geologic Map of the Ghost Ranch Quadrangle, Rio Arriba County, New Mexico (Year 1 of 1-Year)

By

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May 2006

**New Mexico Bureau of Geology and Mineral Resources
*Open-file Digital Geologic Map OF-GM 127***

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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GEOLOGIC MAP OF THE GHOST RANCH 7.5- MINUTE QUADRANGLE, RIO ARRIBA COUNTY, NEW MEXICO

BY

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May, 2006

Revised June, 2012

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EXECUTIVE SUMMARY

The Ghost Ranch quadrangle offers beautiful exposures of sedimentary rocks that are 300 and 100 million years old. These sedimentary rocks are predominantly sandstones, siltstones, and mudstones deposited by various rivers systems (e.g., Burro Canyon, Summerville and Morrison formations together with the Cutler and Chinle groups). However, there are also formations deposited by wind-blown sand dunes (Entrada and Bluff sandstones), sedimentation in a hyper-saline inland lake (Todilto Formation), and sedimentation along the coast of an interior seaway (Dakota Formation). These rocks reveal a story of progressive environmental changes during an exciting time period while dinosaurs and their immediate predecessors roamed the area. Vast river systems and associated floodplain swamps were characteristic of the area during the Permian and Triassic periods, and they drained either southward (Permian) or westward (Triassic). During the middle part of the Jurassic, increased aridity likely accompanied the arrival of an extensive wind-blown sand sea and later a hypersaline lake and sabkha. Deposition by river systems again became the dominant depositional environment through the later part of the Jurassic. In the Cretaceous, coastal sedimentation indicates the presence of an interior seaway to the east, which periodically extended and retreated across the area.

These sedimentary rocks are generally tilted a few degrees to the southwest to northwest, except in the southwest corner of the quadrangle. Faulting and folding affected these strata following approximately 70 million years ago. Most of the faults observed on this quadrangle are related to extension that formed the Rio Grande rift immediately to the east (30 million years ago to the present). This extension created faults that trend predominately northeast (with minor north or slightly northwest trends). Movement along these faults was mostly vertical (i.e., normal dip-slip). However, slickenside lineation data indicate some horizontal slip as well -- a component of left-lateral slip along northeast-trending faults, and a component of right-lateral slip along some faults that trend N-NW. Joint data are usually in conjugate pairs whose orientations generally fall in the range of: 1) 030-060° and 2) 330-005°. Such data are consistent with an overall WNW extension direction during Rio Grande rift dilation.

Between approximately 30 and 70 million years ago, tectonic strain was marked by contraction during uplift associated with the Laramide orogeny. Structures on the quadrangle dating from this time period are more difficult to recognize than later extensional structures, but include high-angle reverse faults that trend N-NW and locally minor NW-trending folds. Near the eastern quadrangle boundary is a prominent structural high marked by predominantly southwest to west dips. We infer that this structural high may be a remnant of a Laramide monocline that was later modified by rift-related normal faults because: 1) stratal strikes parallel the trend of interpreted Laramide structures on this quadrangle and in the Arroyo del Agua quadrangle to the southwest, and 2) these strikes are discordant with predominantly NE-orientated extensional fault systems on this quadrangle and in the Rio Grande rift proper immediately to the east. If that interpretation is correct,

it suggests that very little rift flank uplift occurred on the immediate western side of the Rio Grande rift in this area.

The Chama basin is primarily an erosional geomorphic feature, but erosion was greatly influenced by the relative arrangement of harder (more erosion resistant) and softer (less erosion resistant) formations; this arrangement in turn has been affected by vertical movement of blocks during extensional faulting. Muddy formations erode readily to form low badlands, while formations composed predominately of resistant sandstone form cliffs. These cliffs primarily erode by parallel slope retreat and mass-wasting associated with landslides. Stream systems over the past 1 million years have been characterized by two types of behavior: one in which there was sufficient discharge available to carry much gravel (probably associated with glacial climates), and one in which presumably lesser discharge resulted in mainly sandy alluvium (associated with the Holocene and probably previous interglacials). Terrace deposits along the Rio Chama and Canjilon Creek (the latter is called Arroyo Seco on older maps) are characterized by sandy gravel overlain by sandier sediment. A landslide deposit immediately west of Ghost Ranch (unit Qlsig) overlies the sandy sediment of a terrace deposit having numerous soils near its upper contact. Such a relationship raises the possibility that after a prolonged period of sand deposition during an interglacial, a return to a wetter, glacial climate and associated increased incision may have facilitated slope failure of the adjacent hillslope. Across these cyclical glacial and interglacial climate shifts, incision rates are on the order of 0.1 mm/year for the past 600,000 years.

Based on limited well data, exploited aquifers on this quadrangle are found primarily in the Cutler Group, with the Poleo Formation and the Entrada Sandstone locally saturated in the western part of the quadrangle.

DESCRIPTION OF MAP UNITS

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. Clast percentages are based on counts of 100-150 clasts at a given locality. Descriptions of bedding thickness follow Ingram (1954). Colors of unconsolidated sediment are based on visual comparison of dry samples to the Munsell Soil Color Charts (Munsell Color, 1994). Surficial units are only delineated on the map if estimated to be at least 0.5 m thick. Soil horizon designations and descriptive terms follow those of the Soil Survey Staff (1992) and Birkeland (1999). Stages of pedogenic calcium carbonate morphology follow those of Gile et al. (1966) and Birkeland (1999). **More detailed descriptions are provided in the accompanying map report.**

Mapping of geologic features was accomplished using field traverses, close inspection of numerous outcrops across the quadrangle, and aerial photographs. The map was compiled by Daniel Koning, and the area covered by each respective worker is shown in **Figure 1**. Map units are correlated in **Figure 2**. Two stratigraphic sections of Cretaceous strata north of Ghost Ranch are shown in **Figure 3**.

QUATERNARY EOLIAN AND SLOPEWASH DEPOSITS

Qes **Eolian silty-clayey sand, reworked as or mixed with sheetflood deposits of sand and minor pebbly sand (Holocene to latest Pleistocene)** – Light brown to light yellowish brown, silty-clayey, very fine- to fine-grained sand, with minor medium-grained sand; generally massive; moderately to well consolidated and very weakly cemented by calcium carbonate. Very minor, very thin to thin lenses of clast-supported, poorly sorted, sandy pebbles (locally minor cobbles) derived from local sources. Soil developed on surface has a calcic horizon(s) possessing a 10-40 cm-thick stage I (most common) to stage II carbonate morphology. Buried soils may be present but are less developed than surface soil. Unit has developed on relatively higher interfluvial surfaces and over terrace deposits, and is interpreted to reflect cumulative aggradation of eolian deposits that have generally been reworked by slope wash processes. 0.5 to 5(?) m-thick.

Qes/Qao **Eolian silty-clayey sand, reworked as or mixed with sheetflood deposits of sand and minor pebbly sand, overlying older alluvium** – See descriptions of units **Qes** and **Qao**.

Qes/Qtca1 **Eolian silty-clayey sand, reworked as or mixed with sheetflood deposits of sand and minor pebbly sand, overlying the uppermost terrace deposit of Canjilon Creek** – See descriptions of units **Qes** and **Qtca1**.

- Qes/Qtca2** Eolian silty-clayey sand, reworked as or mixed with sheetflood deposits of sand and minor pebbly sand, overlying the upper middle terrace deposit of Canjilon Creek – See descriptions of units **Qes** and **Qtca2**.
- Qes/Qtca3** Eolian silty-clayey sand, reworked as or mixed with sheetflood deposits of sand and minor pebbly sand, overlying the middle terrace deposit of Canjilon Creek – See descriptions of units **Qes** and **Qtca3**.
- Qes/Qtca4** Eolian silty-clayey sand, reworked as or mixed with sheetflood deposits of sand and minor pebbly sand, overlying the lower middle terrace deposit of Canjilon Creek – See descriptions of units **Qes** and **Qtca4**.
- Qes/Qtca5** Eolian silty-clayey sand, reworked as or mixed with sheetflood deposits of sand and minor pebbly sand, overlying the lower terrace deposit of Canjilon Creek – See descriptions of units **Qes** and **Qtca5**.
- Qes/Qtcau** Eolian silty-clayey sand, reworked as or mixed with sheetflood deposits of sand and minor pebbly sand, overlying an undifferentiated terrace deposit of Canjilon Creek – See descriptions of units **Qes** and **Qtcau**.
- Qes/Qtch1** Eolian silty-clayey sand, reworked as or mixed with sheetflood deposits of sand and minor pebbly sand, overlying the highest terrace deposit of the Rio Chama – See descriptions of units **Qes** and **Qtch1**.
- Qes/Qtg** Eolian silty-clayey sand, reworked as or mixed with sheetflood deposits of sand and minor pebbly sand, overlying a gravelly terrace deposit – See descriptions of units **Qes** and **Qtg**.
- Qes/Qtgh** Eolian silty-clayey sand, reworked as or mixed with sheetflood deposits of sand and minor pebbly sand, overlying a high-level gravelly terrace deposit – See descriptions of units **Qes** and **Qtgh**.
- Qes/TrCpo** Eolian silty-clayey sand, reworked as or mixed with sheetflood deposits of sand and minor pebbly sand, overlying the Poleo Formation of the Chinle Group – See descriptions of units **Qes** and **TrCpo**.

- Qs Slopewash deposits (Holocene)** – Sand, mud, and/or gravel deposited as a sheet-like deposit at the foot of steep slopes; planar-bedded or else massive, with minor lenticular beds of coarser material. 0.5 to 2(?) m-thick

QUATERNARY COLLUVIUM AND LANDSLIDE DEPOSITS

- Qct Colluvium and talus (Holocene to Pleistocene)** – Generally massive deposits consisting of very poorly sorted gravel, sand, and mud. Gravel ranges in size from pebbles to boulders and consists of locally derived, very poorly sorted, angular to subangular blocks of Mesozoic strata (particularly cemented sandstone). Deposit found on moderate to steep slopes of buttes and the flanks of Mesa Montosa and Mesa del Yeso. Moderately to well consolidated. 1 to 30 m-thick.

- Qct/TrCcp Colluvium and talus overlying the Painted Desert Member of the Petrified Forest Formation** – See descriptions of units **Qct** and **TRCcp**.

- Qlsu Undifferentiated landslide deposits (Pleistocene)** – Landslide deposits consisting of a chaotic, non-bedded assemblage of very poorly sorted gravel, sand, and mud. Gravel contains large, boulder-size, angular to subangular blocks of Jurassic or Cretaceous strata (particularly cemented sandstone). Also present are meter-scale blocks of Jurassic and Cretaceous strata that have been displaced more or less together but are mangled, contorted, and brecciated. Deposit found along the flanks of Mesa Montosa and Mesa del Yeso. Moderately to well consolidated. 10 m to greater than 40 m-thick.

- Qlsi Individual landslide complex (Pleistocene)** – Similar to unit **Qlsu**, but consisting of a single landslide complex that is inferred to have moved, more or less, as one deformed body. Deposits occur as large lobate geomorphic features along the flanks of Mesa Montosa and Mesa del Yeso. Moderately to well consolidated. 10 m to greater than 50 m-thick.

- Qlsig Ghost Ranch landslide complex (Pleistocene)** – Prominent landslide deposit immediately west of Ghost Ranch. The Chimney Rock trail ascends this landslide. 30-60 m thick.

QUATERNARY ALLUVIAL DEPOSITS

- Qay Younger alluvium (Holocene)** – Sand -- with subordinate pebbly sand, clay-silt, and gravel beds -- occupying valley bottoms. Gravel consists of pebbles

with minor cobbles and boulders. Color and composition of sand and gravel depends on the source area of a particular drainage. The gravel is dominated by Mesozoic sandstone, but locally limestone, gypsum, or quartzite is common. Loose to weakly consolidated. Lower contact has up to 2 m of relief. Deposit is overall finer-grained than Pleistocene terrace gravel deposits (such as **Qtg**) but similar in texture to many older alluvial deposits (**Qao**). 1 m to 10 m-thick.

Qay/TRCpo Younger alluvium overlying the Poleo Formation of the Chinle Group
– See descriptions of units **Qay** and **TRCpo**.

Qao Older alluvium in tributaries to Canjilon Creek and the Rio Chama (Pleistocene) – Sand and gravel, along with very minor clay-silt beds, preserved as terrace deposits along smaller drainages draining the flanks of Mesa Montosa and Mesa del Yeso. Gravel consists of pebbles through boulders that are dominated by Mesozoic detritus (sandstone, limestone, and gypsum) and locally minor quartzite. Sand is very fine- to very coarse-grained but mostly very fine- to coarse-grained. Deposits commonly fine-upwards (and silt or clay content increases) and buried soils become more common up-section. These buried soils are typified by Bt soil horizons (horizons marked by transported clay) overlying whiter calcic horizons possessing stage I to II+ carbonate morphologies. Along Arroyo del Yeso, the aforementioned sediment commonly overlies a sandy gravel that is 2-6 m-thick. Weakly to well consolidated and non-cemented. 2 m to 20 m-thick. **Note: We use the name of Canjilon Creek for the major southeast-flowing stream in the western part of the quadrangle; in older maps (including the base map for this geologic map) this drainage has been referred to as Arroyo Seco but we elect to use the more recent name of Canjilon Creek.**

Qao/Qtca4 Older alluvium overlying the lower middle terrace deposit of Canjilon Creek – See descriptions of units **Qao** and **Qtca4**.

Qtg Gravelly terrace deposits (upper to middle Pleistocene) – Sandy gravel dominated by quartzite clasts that flanks the courses of modern-day streams. Gravel is composed of pebbles through boulders (mostly pebbles). In addition to quartzite, there are subordinate clasts of Mesozoic sedimentary rocks and lesser metarhyolite clasts. These terrace deposits are generally found along drainages in the eastern part of the quadrangle, including Comanche Canyon and Bull Canyon. Loose and 1-9 m-thick.

Qtgh High-level gravelly terrace deposits (lower Pleistocene to Pliocene) – Sandy gravel dominated by quartzite clasts that is present at relatively high topographic levels and not clearly associated with modern-day streams. Gravel consists of pebbles through boulders. In addition to quartzite, there are

subordinate clasts of Mesozoic sedimentary rocks and ~1% granite clasts. In the southwest corner of the quadrangle, clasts are composed of quartzite with trace-2% basalt. The straths (bases) of these terrace deposits are found at several different relative heights above modern stream grade. Loose and 1-2 m-thick.

Qtgh/TrCpm High-level gravel overlying the Montosa Mesa Member of the Petrified Forest Formation -- See descriptions of units Qtgh and TRCpm.

Qtuw Undifferentiated terraces in the western part of the quadrangle (Pleistocene) – Sandy gravel, reworked from Canjilon Creek terraces, near the western border of the quadrangle. Not described in detail. 1-10 m thick.

Sandy gravel deposited by Canjilon Creek (Pleistocene) -- Terrace deposits of sandy gravel deposited by Canjilon Creek during the Pleistocene. The gravel is clast-supported and consists of pebbles, subordinate cobbles, and lesser boulders. Clasts are composed of quartzite and Mesozoic sandstone; only 1-5% limestone + siltstone clasts and trace-2% red-orange metarhyolite clasts. Sand is fine- to very coarse-grained. The sandy gravel is generally overlain by thin (about 1 m or less) eolian and slopewash deposits of silt and very fine- to fine-grained sand; the underlying gravel may be mixed with this fine sediment due to bioturbation. Clast imbrication indicates a south-to-southeast paleoflow direction, consistent with the flow direction of the modern Canjilon Creek. Weakly consolidated. Commonly 1 m to 2 m-thick, but locally as thick as 3 m.

These terrace deposits are generally in five main levels, so we have subdivided this deposit into six map units representing these five main levels plus a unit that includes undifferentiated terrace levels. No age control of this unit is available on this quadrangle, but we assign tentative ages by inferring that the five main terrace levels here correlate to the five main terraces present along the lower Rio Chama and Rio Ojo Caliente (units Qt7 through Qtc3 of Koning et al., 2004), whose ages have been constrained by Dethier and McCoy (1993), Dethier and Reneau (1995), and Koning et al. (2011). A terrace profile between this area and the lower Rio Chama would test our preliminary correlations and age estimates.

Note: We use the name of Canjilon Creek for the major southeast-flowing stream in the western part of the quadrangle; in older maps (including the base map for this geologic map) this drainage has been referred to as Arroyo Seco but we elect to use the more recent name of Canjilon Creek.

Qtcau Undifferentiated terrace deposit of Canjilon Creek

- Qtca2 Upper middle terrace deposit of Canjilon Creek** – Strath is located approximately 50 m above the modern stream grade. Relatively extensive deposit. Comparison of this strath height with Koning et al. (2011, table 3 and figures 5-6) and correlations of Gonzales (1993) suggest an age range of 200-380? ka. This terrace correlates with unit **Qtch2**.
- Qtca3 Middle terrace deposit of Canjilon Creek** – Strath is located 22-27 m above the modern stream grade. Comparison of this strath height with Koning et al. (2011, table 3 and figures 5-6) and correlations of Gonzales (1993) suggest an age range of 100-280? ka. This terrace probably correlates with unit **Qtch3**.
- Qtca4 Lower middle terrace deposit of Canjilon Creek** – Strath is located 15-22 m above the modern stream grade near Highway 84, but this height increases to 27 m near the confluence with the Rio Chama. Relatively extensive deposit and overlain by thick **Qao** in the center of the quadrangle. Correlated to the 20-40 m terrace deposit of Koning et al. (2011), which has an age of 100-160 ka. This terrace correlates with unit **Qtch5 or Qtch4**.
- Qtca5 Lower terrace deposit of Canjilon Creek** – Strath is located 13-17 m above the modern stream grade. Comparison of this strath height with Koning et al. (2011, text, table 3 and figures 5-6) suggests an age range of 20-100 ka. This terrace correlates with unit **Qtch5**.

Sandy gravel deposited by the Rio Chama (Pleistocene) – High-level terrace deposits of sandy gravel deposited by the Rio Chama during the Pleistocene. The gravel is clast-supported and consists of pebbles and cobbles with very minor boulders. Gravel is composed of quartzite and volcanic rocks (intermediate to basaltic) with subordinate (estimate 5-25%) clasts of Mesozoic sandstone, 1% granite + metarhyolite clasts, and trace to 1% chert clasts. The presence of volcanic rocks serves as a convenient way to distinguish the Rio Chama gravel from gravel deposited by Canjilon Creek. Sand is fine- to very coarse-grained. Minor medium, tabular beds of reddish gravelly sand. Loose. 1 m to 9 m-thick.

These terrace deposits are generally in five main levels, so we have subdivided this deposit into six map units representing these five main levels plus a unit that includes undifferentiated terrace levels. One level (**Qtch3**) grades into terrace deposit **Qtca3** deposited by the Canjilon Creek. Other terrace levels of the Rio Chama also appear to correlate with various terrace deposits associated with the Canjilon Creek, as noted below. No age control of this unit is available on this quadrangle, but we assign tentative ages by inferring that the five main terrace levels here correlate to the five main terraces present along the lower Rio Chama and Rio Ojo Caliente (units Qt7 through Qtc3 of Koning et al., 2004), whose ages have been constrained by Dethier and McCoy (1993), Dethier and Reneau (1995), and Koning et al. (2011). A terrace profile between this area

and the lower Rio Chama would test our preliminary correlations and age estimates.

Qtchu Undifferentiated terrace deposit of the Rio Chama

Qtch1 Highest terrace deposit of the Rio Chama – Strath is located approximately 72 to 80 m above the modern stream grade. Comparison of this strath height with Koning et al. (2011, table 3 and figures 5-6) and correlations of Gonzales (1993) suggest an age range of 330-470? ka. This terrace correlates with unit **Qtca1**.

Qtch2 Upper middle terrace deposit of the Rio Chama – Strath is located 40-55 m above the modern stream grade. Comparison of this strath height with Koning et al. (2011, table 3 and figures 5-6) and correlations of Gonzales (1993) suggest an age range of 200-380? ka. This terrace correlates with unit **Qtca2**.

Qtch3 Middle terrace deposit of the Rio Chama – located 27-30 m above the modern stream grade. Grades into unit Qtca3 on the northwest shores of Lake Abiquiu. Comparison of this strath height with Koning et al. (2011, table 3 and figures 5-6) and correlations of Gonzales (1993) suggest an age range of 100-280? ka. This terrace probably correlates with unit **Qtca3**.

Qtch4 Lower middle terrace deposit of the Rio Chama – located 22-26 m above the modern stream grade. Mostly submerged by the waters of Lake Abiquiu. Based on its strath height, it may correlate to the 20-40 m terrace deposit of Koning et al. (2011) and have an age of 100-160 ka. This terrace may correlate with unit **Qtca4**.

Qtch5 Lower terrace deposit of the Rio Chama – located 16-20- m above the modern stream grade. Submerged by the waters of Lake Abiquiu. Comparison of this strath height with Koning et al. (2011, text, table 3 and figures 5-6) suggests an age range of 20-100 ka. This terrace may correlate with unit **Qtca5**.

MIXED EOLIAN AND ALLUVIAL QUATERNARY DEPOSITS

Qae Mixed eolian and alluvial deposits (Holocene to upper Pleistocene) – Sediment that is a mixture of units **Qes** and **Qay** (see descriptions for those units). Deposited in small arroyos on Mesa del Yeso and along its southern slopes. Thickness is unknown.

PLIOCENE-MIOCENE(?) ALLUVIAL DEPOSITS

- Tgly Lower gravel on Mesa del Yeso** - Boulder conglomerate composed exclusively of Proterozoic quartzite, granite, metavolcanic, and metasedimentary clasts derived from the Tusas Mountains to the northeast. The conglomerate is not cemented, and the matrix is tan colored, suggesting that these are clasts recycled out of the Eocene El Rito Formation. Rests on Dakota Sandstone. Up to 12 m thick. The base of this deposit is located about 30 m below the base of unit **Tghmy**.
- Tghmy Higher gravel on Mesa Montosa and Mesa del Yeso** - Pebbles to cobbles of rounded Mesozoic sandstone, Proterozoic quartzite and granite from the Tusas Mountains, and in places quartzite and chert recycled out of the Cretaceous Burro Canyon Formation, sitting on Dakota Sandstone, usually the Paguete Member. 1 to 2 m thick.

CRETACEOUS ROCKS

Cretaceous stratigraphy on the Ghost Ranch quadrangle follows that of Landis and Dane (1967), Saucier (1974), Owen et al. (2005), and Lucas et al. (2009). The Dakota Sandstone near Ghost Ranch consists of the following members, in ascending order: Encinal Canyon, Oak Canyon Member, Cubero, and the Paguete Sandstone. In this area, the Paguete Sandstone consists of: 1) a lower yellow sandstone-siltstone, and 2) an upper white sandstone. We chose to differentiate the medial and upper Paguete subunits in order to observe and interpret structures on top of Mesa Montosa. Other members in the Dakota Sandstone were too thin (and generally on cliff faces) to map at a scale of 1:24,000.

- Kdpu Dakota Sandstone, upper Paguete Member (Upper Cretaceous)** - White quartz sandstone; thin- to medium- beds that are internally laminated; moderately bioturbated. Coarse sandstone near base, medium grained at top. Caps the highest knobs on Mesa Montosa and Mesa del Yeso. 2 to 3 m thick.
- Kdps Dakota Sandstone, Paguete Member sandstone and siltstone (Upper Cretaceous)** - Grayish yellow, thin- bedded sandstone and siltstone. Thin (<0.1 m) sandstone beds common in the lower third of the unit; unit becomes more silty near the top. Rare pelecypod and fragmentary ammonite fossils described in report (from Lucas et al., 2009). Best exposed on the south side of Mesa Montosa; elsewhere covered by Quaternary eolian sand. Approximately 15 m thick.
- Kdeoc Dakota Sandstone - Encinal, Oak Canyon, and Cubero members (Upper Cretaceous)** - Tan to yellow-brown quartzose sandstone, dark gray and brown carbonaceous shale, and minor greenish gray mudstone and bentonite. Members include, from lowest to highest (oldest to youngest): Encinal Canyon, Oak Canyon, and Cubero. The Encinal Canyon Member is highly variable in thickness, ranging from 0 to 18 m and averaging 2 to 4 m. This tan cross-

bedded quartz sandstone, with thin to medium bedding, commonly has woody plant impressions at the upper contact. Bioturbation is not common in the Encinal Canyon Sandstone. The Oak Canyon Member is a black, muddy siltstone interbedded with thin (<1 m) beds of ledgy and often lenticular, white to orange, cross-bedded, bioturbated sandstone. Local, poorly to moderately preserved leaf and twig fossils. The Cubero Member contains three subunits. The lower subunit consists of a white, massive, thick-bedded, bioturbated sandstone that is 7-8 m thick. The middle subunit is a black sandy shale to shale with thin (2-3 cm) beds of ripple-laminated sandstone that is 1-3 m thick. The upper subunit is composed of orange to tan, fine-to medium-grained sandstone. The upper subunit is often intensely bioturbated, but in places remnant cross-bedding, ripple marks, and thin to thick bedding is preserved. The Cubero Member forms a bold cliff along exposed escarpments of Mesa Montosa that is 25-30 m thick. The entire thickness of Dakota Sandstone is 40 m to 56 m.

Kbc Burro Canyon Formation (Lower Cretaceous). White, light yellow and buff, conglomeratic sandstone with thin lenses of pale green and pink mudstone (Saucier, 1974). Small-scale trough cross-bedding is associated with the conglomeratic channels, which are more common near the base of the unit in the Ghost Ranch area. Conglomerate clasts are mostly varicolored quartzite and chert pebbles up to 2.5 cm in diameter, with minor sandstone and limestone clasts. Laminar low-angle wedge and high-angle planar wedge cross-bedding is common in the sandier portions of the unit. Chert gravel is rare near the top of the unit, but green and red mud rip-up clasts are common. Up to 40 m thick.

JURASSIC ROCKS

Jurassic stratigraphy on the Ghost Ranch quadrangle follows Lucas et al. (2005a), which is based on the regional stratigraphy of Anderson and Lucas (1992, 1994, 1995, 1996, 1997) and Lucas and Anderson (1997, 1998).

Jmb Brushy Basin Member of the Morrison Formation (Upper Jurassic) – Variegated pale greenish gray, grayish yellow green, pale olive, yellowish brown, and pale reddish brown bentonitic mudstone with a few beds of trough-crossbedded pebbly sandstone. Locally, the base of the Morrison Formation is a thin (up to 8 m thick) interval of trough-crossbedded sandstone and interbedded mudstone. Above that interval, the formation is mostly mudstone. Greenish white, medium-bedded sandstones with cross-bedding and mud-rip up clasts and thin tabular sandstones are present in a few places near the top of the unit. The basal sandy interval is likely correlative to the Salt Wash Member of the Morrison Formation to the west and south. However, this interval is neither thick enough, persistent enough, nor lithologically distinctive enough to separate from the Brushy Basin Member. 41 m to 68 m thick.

Jsb Combined Summerville Formation (Middle Jurassic) and the Bluff Sandstone (Upper Jurassic) -- The Summerville Formation is thinly and

cyclically-bedded and composed of the following: maroon, grayish red and yellowish gray siltstone, sandy siltstone, fine gypsiferous sandstone, and mudstone. In the Chama Basin, the Summerville Formation is readily divided into two informal members, lower and upper. The lower member is 12 to 15 m thick and is repetitively-bedded gypsiferous sandstone and siltstone that forms a ribbed cliff or slope. It is the same unit that Goldman and Spencer (1941) termed the “Bilk Creek Sandstone Member” in southwestern Colorado. The upper member is 61 to 96 m of siltstone and thinly-interbedded gypsiferous sandstone and mudstone that forms a thick, grayish red and white, banded slope. Strata we term Summerville Formation were assigned to the Morrison Formation by Smith et al. (1961) and Ridgley (1977), though Ridgely (1989) did assign what we term the lower member of Summerville Formation to the Wanakah Formation. 74 m to 111 m thick.

The overlying Bluff Sandstone is a light gray, very fine grained, well sorted sandstone with crossbeds in thick sets. This unit consists of two members not mapped separately. The lower, Junction Creek Member comprises most of the formation (30-40 m thick) and is mostly pale yellowish green and light olive gray, very fine grained, well sorted sandstone with crossbeds in thick sets. These are primarily eolian deposits similar to the type section of the Junction Creek Member near Durango, Colorado (Goldman and Spencer, 1941). The overlying Recapture Member is 6 to 14 m thick and is mostly maroon, pale brown, grayish red, and light greenish gray gypsiferous siltstone, fine-grained sandstone, and mudstone. Recapture strata lithologically resemble underlying Summerville strata. Their fine-grained gypsiferous lithotypes indicate that these strata do not belong to the Morrison Formation (contra Ridgely, 1977), but instead are correctly assigned to the Recapture Member of the Bluff Sandstone (Lucas and Anderson, 1997, 1998; Lucas et al., 2005). 44 m to 47 m thick.

Jt **Todilto Formation (Middle Jurassic).** The Todilto Formation consists of a lower, limestone-dominated interval (Luciano Mesa Member) overlain locally by a gypsum interval (Tonque Arroyo Member) (Lucas et al., 1985, 1995; Kirkland et al., 1995). The Luciano Mesa Member is 2 to 8 m thick and consists mostly of thinly laminated, dark gray or yellowish gray, kerogenic limestone. Beds near the base of the member are usually sandy, and microfolding of the thin limestone laminae is common. The 30 m-thick, overlying Tonque Arroyo Member consists of white to light gray gypsum interbedded with carbonate. In localized areas east and west of Chimney Rock, a thin limestone bed (<1 m) is deposited on the gypsum of the Tonque Arroyo Member. **Note that the Todilto Formation is always present between the Entrada Sandstone and Summerville Formation, but commonly is not depicted on the map because it occupies a cliff face.** Up to 38 m thick.

Jtl **Todilto Formation that is dominated by limestone (Luciana Mesa Member)** – see Todilto Formation description above.

Jtg **Todilto Formation that is dominated by gypsum (Tonque Arroyo Member)** – see Todilto Formation description above.

- Je Entrada Sandstone (Middle Jurassic).** Trough cross-bedded and cross-laminated, in addition to ripple laminated, sandstone that forms a prominent cliff in the northern part of the quadrangle. Only the Slick Rock Member is present in the Chama Basin (Lucas et al., 2005a), and consists of very fine- to medium-grained, moderately well sorted sandstone. Colors are shades of yellow, light brown, orange, and grayish orange. 60 m to 76 m thick.

TRIASSIC ROCKS

All Triassic strata on the Ghost Ranch quadrangle are assigned to the Upper Triassic Chinle Group (Lucas, 1993). Triassic stratigraphy follows Lucas and Hunt (1992) and Lucas et al. (2003, 2005b).

TrC Chinle Group (Upper Triassic)

- TrCr Rock Point Formation (Upper Triassic)** – Reddish brown to grayish red to red to reddish yellow to yellowish red beds of siltstone and very fine- to fine-grained sandstone. Subordinate reddish brown mudstone. Massive or else in thin to medium, tabular beds that are internally planar- to ripple-laminated. The interbedded sandstone and siltstone beds form a ribbed cliff where the Rock Point outcrop is not deeply weathered. Where weathered, the Rock Point Formation has an orange slope. The Rock Point base is the first persistent bed of sandstone above slope-forming mudstone of the Painted Desert Member of the Petrified Forest Formation. Locally, where sandstones are absent at the base, the contact was mapped where the mudstones and siltstone change to an orangish color and where the mudstones became less bentonitic. The top of the Rock Point is a sharp, unconformable contact with overlying eolian sandstone of the Slick Rock Member of the Jurassic Entrada Sandstone. Up to 70 m thick

- TrCpu Petrified Forest Formation, undivided (upper Triassic)** – Mostly reddish-brown bentonitic mudstone that forms extensive slopes and dissected badland areas where exposed. Lucas et al. (2003, 2005b) divided the Petrified Forest Formation in the Chama basin into two members, which are generally mapped as separate units and described separately below. However, in areas of poor exposure or for areas under Lake Abiquiu we have mapped this undivided unit. Up to 200 m-thick.

- TrCpu Painted Desert Member of the Petrified Forest Formation (upper Triassic)** – Reddish brown and weak red (hues of 2.5YR and 10R), with subordinate dark grayish brown to light reddish brown, bentonitic mudstone and claystone intercalated with minor greenish gray to light greenish gray, pebbly sandstone channel-fills. Local reduction of the mudstone (approximately 1-2% of the unit) has resulted in cm-scale streaks and meter-scale beds of light gray, greenish

gray, and light greenish gray. Locally there are minor intervals of ripple-laminated to planar-laminated, very fine- to fine-grained sandstone. The mudstone is in thick to very thick, tabular beds, with minor thin to medium, tabular beds. The greenish pebbly sandstone channel-fills occupy 1-7% of the unit, have up to 2.5 m of relief at their base, may be as much as 3 m thick, and are lenticular. The pebbles in these channel fills are composed of light gray to very dark gray limestone or calcrete pebbles with very minor mudstone-claystone rip-up clasts; these pebbles are typically up to 2 cm in diameter (locally up to 3 cm-diameter). The sand in these channel-fills is medium- to very coarse-grained and composed of the same type of limestone as the pebbles. Between the pebbles and sand grains is a greenish muddy matrix that imparts an overall greenish color to the entire channel-fill deposit. A few measured trends of the channels occupied by these fills are W-E and SW-NE. The mudstone is well consolidated but weakly cemented; the coarser channel-fills are locally cemented by calcium carbonate. The base of the unit corresponds to the highest sandstone ledge of the Mesa Montosa Member. Its top is a sharp, relatively planar contact with siltstone and sandstone of the Rock Point Formation Up to 180 m-thick.

TrCpm Mesa Montosa Member of the Petrified Forest Formation (upper Triassic)

– Very fine- to fine-grained sandstone with slightly lesser mudstone and siltstone that range in color from reddish brown (hues of 2.5-5YR) to moderate brown to light reddish brown. The unit occupies a gradation between the sandstone and pebbly sandstone of the underlying Poleo Formation and the mudstone-dominated overlying Painted Desert Member of the Petrified Forest Formation. As such, litharenite sandstone beds dominate near the lower part of the member and mudstone beds dominate in the upper part of the member. Sandstone beds are very thin to medium, tabular, and typically ripple-laminated to wavy-laminated to planar-horizontal-laminated. Ripple-marks and troughs commonly give a northwestward-to-southwestward paleoflow direction. The Mesa Montosa Member forms a ribbed slope where not covered by colluvium. The lower contact of the unit corresponds with the base of a thick bed of mudstone, siltstone, or silty fine sandstone bed associated with the reddish brown to brown, very fine- to fine sandstones that typify this unit. However, yellow to gray sandstone beds similar to those seen in the Poleo Formation are commonly found in the lower part of the Mesa Montosa Member as well. In addition, the lower 1-10 m of this unit may grade laterally into or interfinger with the uppermost Poleo Formation. 3 m to 24 m-thick.

TrCpo Poleo Formation (Upper Triassic) -- Sandstone and minor pebble-conglomerate in broadly lenticular, 0.5-4 m-thick, stacked channel-fills that are extensively cross-laminated or cross-bedded. Trough cross-stratification commonly gives a northwestward to westward paleoflow direction. Intercalated in medium to thick, tabular to broadly lenticular sandstone near the top of formation are 1-2 m-thick intervals of very thin to thin, horizontal-planar sandstone locally mined for flagstone. Poleo Formation sandstones are fine- to very coarse-grained, micaceous litharenites and are typically gray to yellow in

color. Conglomerates are either intrabasinal (composed of siltstone and nodular calccrete clasts) or extrabasinal (chert, quartz, and quartzite clasts). Strongly cemented and indurated. The Poleo Formation has a sharp, scoured contact on the underlying Salitral Formation. It grades upward into the overlying Petrified Forest Formation and forms a light-colored bench, ledge or cliff. Up to 41 m-thick.

TrCsc Combined Salitral and Shinarump formations (Upper Triassic) – The Salitral forms a bentonitic, mudstone-dominated slope between the cliff/ledge-forming sandstone of the Shinarump (below) and Poleo (above) formations. The Salitral Formation is divided into two members (Lucas et al., 2003, 2005b): a lower, Piedra Lumbre Member of reddish brown to light gray mudstone with a persistent sandstone bed (the El Cerrito Bed) at its top, and an upper, Youngsville Member, which mostly consists of reddish-brown mudstone. On this quadrangle, the El Cerrito Bed is located about 6 m above the base of the Salitral Formation, and the lower Piedra Lumbre Member may have inclusions of diagenetic, reddish chert. The El Cerrito Bed is 30-50 cm-thick bed, has a color of light gray to white to pale yellow, and consists of medium- to very coarse-grained, angular to subangular, moderately sorted sandstone composed of quartz with 1-3% possible feldspar. Other than the El Cerrito Bed, sandstone beds are generally not observed in the Salitral Formation on this quadrangle, but exposures are generally poor. The Salitral Formation contact with the underlying Shinarump Formation is a sharp surface where mudstone rests directly on sandstone or conglomeratic sandstone. The Poleo Formation contact on the Salitral Formation is a sharp, scoured surface where conglomerate/sandstone at the base of the Poleo is incised into underlying Salitral mudstone/siltstone. 1 to 11 m-thick.

The Shinarump Formation consists of quartzose sandstone and siliceous conglomerate. This formation has previously been called the Agua Zarca Formation (e.g., Wood and Northrop, 1946; Dubiel, 1989; Lucas and Hunt, 1992). It is only exposed locally near the eastern quadrangle boundary. Here, the lower 1.0-1.5 m consists of a thick bed of medium- to coarse-grained quartz sandstone with abundant matrix; white, purple, red, and pale yellow mottling is present on a large scale (mottles are laterally continuous for meters and about 20-30 cm-thick). Above this is cross-bedded sandstone, with 3-5 cm-thick beds, that appears nodular in places and is mottled yellow, orange, red, purple, and white. The upper 2 m has is also mottled but predominately white, and consists of: 1) a lower (about 1 m-thick) bed having low-angle, trough crossbedding, and 2) an upper conglomeratic sandstone interval having a vague sense of planar bedding but very nodular and bioturbated; the conglomerate consists of very fine pebbles of quartz grains hosted in a fine- to medium-grained quartz sandstone matrix. The Shinarump Formation usually forms a light-colored ledge where it is entirely exposed on a slope. Regionally, its basal contact is a sharp, erosional scour on underlying, finer-grained strata of the Cutler Group. Up to 6 to 7 m-thick.

PENNSYLVANIAN-PERMIAN ROCKS

The oldest strata exposed on the Ghost Ranch quadrangle are Pennsylvanian-Permian siliciclastic red beds of the Cutler Group (Cutler Formation of Smith et al., 1961) Stratigraphy employed here follows Lucas and Krainer (2005).

IP-PC Cutler Group (Pennsylvanian-Permian)

We assign the oldest siliciclastic red beds on the Ghost Ranch to the Cutler Group. Only the upper part of the upper formation of the Cutler Group in the Chama Basin, the Arroyo del Agua Formation of Lucas and Krainer (2005), is exposed on the Ghost Ranch quadrangle.

IPCa Arroyo del Agua Formation (Lower Permian) -- Orange sandstone, muddy sandstone, and mudstone. Minor intraformational and extraformational conglomerate has been reported in the vicinity but were not observed in the limited exposures on this quadrangle. Most of the Arroyo del Agua formation observed on this quadrangle consists of brown to yellowish brown, thick, tabular beds of clayey to slightly clayey, very fine- to fine-grained, arkosic sand. There are slightly subordinate, thick beds of yellowish red and red mudstone that are commonly bioturbated and locally reduced (cm-scale) to light greenish gray to light gray colors. There are about 10% 1-3 m-thick, lenticular beds of fine- to medium-grained, arkosic sandstone (minor coarse- and very coarse-grained sand). In the vicinity of this quadrangle, siltstones in this unit form thick, slope-forming units with abundant calcrete nodules between thin sandstone sheets that are arkosic and trough crossbedded. Up to 130 m thick, but only 1-18 m exposed on this quadrangle.

ACKNOWLEDGMENTS

We wish to thank Ghost Ranch for allowing us access to their lands, and particularly Cheryl Muceus and Alex Downs for facilitating this access and other logistics. We also thank the United States Geological Survey, in particular Mark Hudson, for funding the senior author's use of their PG-2 plotter. James Messerich set the photogrammetric models on this plotter.

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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 are based on 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.

The map has not been reviewed according to New Mexico Bureau of Mines and Mineral Resources standards. Revision of the map is likely because of the on-going nature of work in the region. The contents of the report and map should not be considered final and complete until reviewed and published by the New Mexico Bureau of Mines 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. Cross-sections are constructed based upon the interpretations of the authors made from geologic

mapping, and available geophysical (regional gravity and aeromagnetic surveys), 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.