Geologic Map of the Echo Amphitheater 7.5-Minute Quadrangle, Rio Arriba County, New Mexico

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Open-file Digital Geologic Map OF-GM 280

Scale 1:24,000

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DESCRIPTION OF MAP UNITS

Explanation of descriptive terms.

Colors (e.g. rocks, outcrops) are subjective; strength, sorting, angularity, grain/clast size, and hand-sample descriptive terms after Compton (1985); sedimentary terms after Boggs (1995). Queries (?) after descriptors indicate uncertainty in interpretation and/or identity of descriptor.

Notes to users:

Whenever possible, we have adopted the Group/Formation/Member/unit designations used on the adjacent Ghost Ranch Quadrangle Geologic Map and the following descriptions borrow heavily and freely from the Ghost Ranch quad report (Koning et al., 2006). Exceptions include the subdivision of the Paguate Member of the Dakota Sandstone, some Quaternary rock designations, and the identification of a localized sandstone body within the Petrified Forest Member of the Painted Desert Formation. Bedrock contacts and Qt and Qal deposits mapped below the level of Abiquiu Lake are inferred from the (pre-lake) topographical maps.

Formation/Member contacts were digitized onto orthophoto coverage and some topographic details may not be apparent on topographical base and/or easting and northing may not "register" perfectly on topographic base maps. Note also that many contacts on this quadrangle are mapped as 'approximately located" (dashed contact) simply because they are located in very steep areas. Units are only delineated on the map if estimated to be at least 2m thick.

QUATERNARY ROCKS

Qal

Undivided Quaternary alluvium (Holocene and/or Pleistocene)

Generally poorly exposed; light to dark brown and/or dark grey and/or orangish; loose to friable; fine to coarse-grained; poorly sorted, medium to thick bedded, sometimes weakly calcite cemented; clayey, silty, pebbly sand and sandy silt. Clasts are composed mostly of local Triassic through Cretaceous rocks sometimes with variable amounts of quartzite clasts. Pebbles and small cobbles of gypsum are particularly distinctive downstream of Todilto Formation outcrops. Includes sediment in active channels and valley bottoms, adjacent 'valley fill', tributary alluvium graded to within ~2m of present river level, and active stream terraces and gravel bars. On this quadrangle Qal also includes some areas of active alluvium found at higher elevations (such as within landslides) but these are only mapped where they are particularly extensive and/or clearly active. Quaternary alluvium is only mapped where it is clearly >2m thick and/or it obscures large areas of bedrock units and/or unit contacts. Chestnut (written communication, 2020) obtained a calibrated radiocarbon age of 978 +/ 39 ybp for a terrace 1.4 m above the Rio Chama on the Luguna Peak Quadrangle (immediately to the West of the Echo Amphitheatre Quad). Generally 1 to 10 m-thick but possibly thicker beneath the Rio Chama and Canjilon Creek.

Qf
Quaternary fans
Poorly exposed; light to dark brown and/or blackish or orangish; loose to friable; fine to coarse-grained; poorly sorted; medium to thick bedded; sometimes weakly calcite cemented; clayey, silty, pebbly-to-cobbly sand and sandy silt. This unit includes Quaternary fans of multiple ages/heights above grade. These fans likely have a similar origin to Qal/Qf but base level fall and subsequent incision has left them above current grade. Some sub-map scale (generally <~75m wide) fans and fan remnants have not been mapped. Qf deposits sometimes grade up-slope into Qls and have often been derived from them. ~2-25(?)m thick.

Qal/Qf
Quaternary alluvium and/or Quaternary fans (Pleistocene and/or Holocene)

Light to dark brown and/or black or orangish; loose to friable; fine to coarse-grained; poorly sorted, medium to thick bedded, sometimes weakly calcite cemented; clayey, silty, pebbly sand and sandy silt. This unit represents complexes of alluvium and alluvial fans that, although mostly at a higher level than unit Qal, are still active during runoff events and that may grade to a higher level than Qal simply due to relatively recent incision of "main stem" streams such as Canjilon Creek. May include some colluvium and/or talus at base of steep slopes and in some cases may include complex surfaces of variable age that have formed from a variety of processes (stream action, mass wasting, planation of older Quaternary surfaces by sheetwash, and possibly some eolian activity). 1-25(?)m thick.

Qf/Qt Quaternary fans overlying Quaternary terraces.
See descriptions for Qf and Qt.

Qls
Landslide deposits (Pleistocene(?))
Landslide deposits consisting of a chaotic, non-bedded, friable assemblage of very poorly sorted gravel, sand, silt and clay derived mostly from Cretaceous rocks and Jurassic rocks younger than the Entrada Sandstone and semi-intact blocks of Jurassic rocks up to several tens of meters across. Terrace gravels are sometimes found on/in the lower parts of landslide deposits even when no terrace remnants are preserved. Landslides commonly have the form of Toreva blocks (rotational slumps) where they overlie Cretaceous and Jurassic Rocks above the Todilto Formation. Below the Todilto Formation, they often appear to be earthflows. The surface of the landslides is commonly littered with large blocks of Cretaceous sandstone. Earthflow(?) deposits sometimes seem to have a rough stratigraphy consisting of (from bottom to top): chaotic material occasionally including gypsum blocks and slabs up to 100m+; a middle zone of sandstone boulders and deformed-to-relatively intact masses of Jsb and Jmb, and an upper layer characterized by large boulders of Cretaceous sandstone from the Dakota and Burro Canyon Formations in a poorly sorted, tan to greyish matrix of gravel, sand, silt, and some clay. Not all of these layers are present everywhere and near the edges of mapped deposits (especially in landslides below the Todilto Formation) the uppermost layer is often the only one present

and/or exposed. Erosion of the uppermost layer often produces hoodoos (boulder-capped pedestals) between <1 and ~10m high along the margins of landslides.
It is often difficult to determine if bedrock units surrounded by landslide deposits have been displaced. For example, the Mesa Montosa Member is occasionally ‘missing’ between the Painted Desert Member and the Poleo Formation in otherwise undisturbed-looking areas and this may indicate some slumping of the otherwise apparently intact Painted Desert Member. See also description of Jtl for more information on possible relations between landslides and bedrock units.
A Radiocarbon date obtained by Chestnutt (written communication) on shells from terrace gravels buried by landslide deposits near the Big Eddy Campground indicates that at least some landslides are <~22 ka. Minimum age is not constrained.
Note that the “heads” of landslides have only been mapped where they are particularly distinct and arcuate on orthophoto coverage. Also note that the upper contact of landslides along the margin of the Mesa de los Viejos has been mapped everywhere as a ‘simple’ geologic contact even though the mesa’s edge here is, in many cases, distinctly cuspate. Qls deposits sometimes grade down-slope into Qf. ~1-40+(?)m thick.

The above observations lead us to propose a generalized model of landslide development as follows: Failures initiated at the base of, at the top of, or within the Todilto Formation lead to translational and/or rotational failure of younger Jurassic and Cretaceous rocks along with overlying Quaternary colluvium consisting largely of blocks of Cretaceous sandstone. The rocks mobilized by these failures traveled over cliffs or relatively steep slopes in the Entrada and Todilto Formations and, in many cases, became earthflows at this point. In at least one case, the Todilto Formation slid *en mass* over both the Entrada Formation and older colluvium (Figure 1). The ubiquitous, poorly sorted cover of Cretaceous sandstone blocks on landslide deposits probably represents a redistribution of extensive colluvium/talus that we infer to have buried slopes above the Todilto Formation prior to mass movements. Alternatively, abundant sandstone blocks may have been generated by ‘calving’ of large masses of Cretaceous sandstones during mass movements.

Qc
Quaternary colluvium (Holocene and/or Pleistocene)

Light tan to brownish; loose to friable; coarse to fine grained; very poorly sorted; massive(?); sometimes weakly calcite cemented; sandy, silty, pebble to boulder conglomerate and pebbly silty sand. Colluvium is mapped only where it obscures bedrock units and/or unit contacts—mostly within the drainage of the Canada Del Potrero which is at relatively high elevation and beneath Ponderosa Pine forest. Contacts between Qls and Qc in the Canada del Potrero are somewhat arbitrary as no exposures are available and these two units present very similar surfaces. Although included in Qls as mapped, colluvium/talus is fairly common along the upper contact of landslide deposits below Dakota and/or Burro Canyon outcrops and on the steep slopes above the heads of landslides.

Qg
Quaternary gravel (Pleistocene and/or Holocene)

Gravel derived from terrace deposits but found on slopes that are either steeper than terrace surfaces or in topographic positions that make an origin as true terrace gravels unlikely. This unit represents relatively large areas of regraded terrace gravel and small and/or thin, poorly preserved terrace remnants(?). Only the thickest/most extensive parts of these 'aprons' of gravel below eroding terrace gravels are shown. Not exposed. 2-10(?) m thick.

General discussion of terrace deposits on the Echo Amphitheatre Quadrangle

We have loosely correlated terraces here with those defined by Koning et al. (2006) on the adjacent Ghost Ranch Quadrangle. Note that these correlations are based solely on height of strath above stream grade and that the ranges in strath height of some different terrace levels defined by Koning et al. (2006) overlap (e.g. Qtch3 and Qtch4). Additionally, some terraces on the Ghost Ranch Quad merge downstream so that designations may be somewhat arbitrary (Koning et al., 2006).
The main control on strath height in many locations on this quadrangle is clearly the presence of sandstone beds within the sedimentary section. Terraces may therefore not correlate along stream profiles in a strict sense. Rather than erecting an entirely new terrace hierarchy on this quadrangle, we have mapped terraces with strath heights below 13m (the lowest height of the lowest terrace defined by Koning et al., (2006)) or those that fall outside the strath height ranges defined by Koning et al. (2006) as simply undivided Quaternary terraces (Qt). Queried designations (e.g. Qtch4?) may indicate that the height of a terrace strath is within the overlapping ranges of two terrace classes or that strath height is close to but not within one of the strath height ranges of Koning et al. (2006). We have used Koning et al.'s (2006) unit Qtgh (essentially undivided high-level terraces) for those above Qtch1/Qtca1 level (~80m). Some small terrace remnants (<~50m wide, or approximately 2mm at map scale) have not been mapped, particularly where many terrace remnants or other Quaternary units are found close together or where the geology is otherwise complex.

Qtp
Quaternary terrace gravel of the Rio Puerco
Terrace deposits found in southern part of map and composed of high percentage of basalt clasts and variable amounts of Pedernal Chert, indicating they are derived from within the Rio Puerco drainage (from near Cerro Pedernal) to the south.

Qt
Quaternary terrace deposits, undivided (Pleistocene)
Generally poorly exposed; loose to friable; medium to thick bedded; moderately to moderately well sorted; mostly subangular; fine to coarse grained sand, sandy gravel, and cobble conglomerate. Often includes 1-4 m of 'overbank' sand and silty sand at top of terrace deposits and clast-supported cobble conglomerate in first few meters above strath. Top of some deposits may have been reworked (by eolian(?), sheetwash, and small-scale fluvial processes). Gravel is composed of pebbles through boulders. Clasts are dominated by quartzite with variable amounts of sandstone and/or limestone, small amounts of Brazos Basalt within the Rio Chama terraces (and possibly some Jarita Basalt from the Los Pinos Formation) and metamorphic clasts. This unit includes all terraces

below 13 m and those that do not fall into the strath height ranges defined by Koning et al. (2006). ~2-10m thick.

Canjilon Creek Terraces:

Qtca1
High terrace of Canjilon Creek
Strath is located approximately 70-85 m above the modern stream grade. Koning et al. (2006) suggest a possible correlation with a high terrace along the lower Rio Chama that contains the 620 ka lava Creek B ash.

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) would suggest an age range of 200-380? ka (Koning et al., 2006).

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) would suggest an age range of 100-280? ka (Koning et al., 2006). However, Chestnut (written communication, 2020) obtained calibrated radiocarbon ages for terraces between 19 and 22 m above the Rio Chama that range from ~22-41 ka.

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. Comparison of this strath height with Koning et al. (2011, text, table 3 and figures 5-6) would suggest and age of 100-160 ka. However, Chestnut (written communication, 2020) more recently obtained calibrated radiocarbon ages for terraces between 19 and 22 m above the Rio Chama that range from ~22-41 ka.

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) would suggests an age range of 20-100 ka (Koning et al., 2006).

Chama River Terraces:

Qtch1
High level 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) would suggest an age range of 330-470? ka (Koning et al., 2006).

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) would suggest an age range of 200-380? ka (Koning et al., 2006).

Qtch3
Middle terrace deposit of the Rio Chama
Strath is located 27-30 m above the modern stream grade. Grades into unit Qtca3 on the northwest shores of Lake Abiquiu (Koning et al., 2006). Comparison of this strath height with Koning et al. (2011, table 3 and figures 5-6) and correlations of Gonzales (1993) would suggest an age range of 100-280? ka (Koning et al., 2006).

Qtch4
Lower middle terrace deposit of the Rio Chama
Strath is 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 (Koning et al., 2006). However, Chestnut (written communication, 2020) more recently obtained calibrated radiocarbon ages for terraces between 19 and 22 m above the Rio Chama that ranges from ~22-41 ka.

Qtch5
Lower terrace deposit of the Rio Chama
Strath is located 16-20 m above the modern stream grade. Comparison of this strath height with Koning et al. (2011, text, table 3 and figures 5-6) would suggests an age range of 20-100 ka. However, Chestnut (written communication, 2020) more recently obtained calibrated radiocarbon ages for terraces between 19 and 22 m above the Rio Chama that ranges from ~22-41 ka.

Qtgh High-level gravelly terrace deposits (lower Pleistocene to Pliocene)
Sandy gravel dominated by quartzite clasts that is present at several relatively high topographic levels. Rather than constructing an entirely new terrace hierarchy on this quadrangle we have mapped all terraces above Qtch1/Qtca1 level (~80m) as Qtgh. The dividing line between Qtgh gravel derived from an ancestral Rio Chama (those with basalt clasts) and that derived from an ancestral Canjilon Creek is found along the ridge that defines the northwest edge of the Llano Del Vado (in the east-central part of the quad). However, some Canjilon Creek gravel has been reworked from this ridge and redeposited as unit Qg to the west of this ridge. Gravel consists of pebbles through boulders. In addition to quartzite, there are subordinate clasts of Mesozoic sedimentary rocks and Proterozoic metamorphic clasts. In deposits derived from the Rio Chama Drainage, Brazos Basalt (and possibly some Jarita Basalt from the Los Pinos Formation) forms ~1-10% of terrace deposits. 2-10(?) m thick.

CRETACEOUS ROCKS

Cretaceous stratigraphy on the Echo Amphitheatre quadrangle follows that of Owen et al. (2005) and Koning et al. (2006). An excellent geologic history of this part of the Chama Basin has been provided by Kelley et al. (2006).

Kdpc Paguate Member of Dakota Sandstone and Clay Mesa Tongue of Mancos Shale (Upper Cretaceous)
The Paguate Member is composed of yellowish to tan; Moderately strong to strong; moderately well sorted; subrounded; medium to thick bedded; very fine to medium grained; commonly burrowed; arkosic quartz sandstone. Sandstones are mostly coarse grained near base, and medium grained at top. Rare pelecypod and fragmentary ammonite fossils have been found (Lucas et al., 2009). The Paguate is interpreted as middle and outer shoreface sands (Owen et al., 2005). Hand samples are difficult to distinguish from the Cubero Sandstone.
Some thin, loose Quaternary sand presumably derived from weathering of the Paguate Member is present on the Mesa de los Viejos but this material is nowhere exposed and seems to be generally less than 1 m thick. Very rare quartzite pebbles were observed within this loose sand in Section 1 T24N:R3E and would seem to indicate the former presence of more extensive Quaternary cover.
The underlying Clay Mesa Tongue is a very poorly exposed shale and siltstone(?) that sometimes forms a narrow bench beneath the Paguate Member. The Clay Mesa Tongue is not present in the "Highway 84 Section" of Owen, et al. (2005) a few miles north of Echo Amphitheatre (in the northeast part of this quadrangle) but is identified in the western half of this quadrangle based on uncommon exposures of shale at the base of cliffs formed by the Paguate Member and is tentatively inferred in the eastern part off the quadrangle based on a slope break at the base of the Paguate in some locations. The Clay Mesa Tongue is approximately 2-3 m thick where exposed. Total thickness of Kdpc ~18 m thick.

Kdeoc Dakota Sandstone - Encinal, Oak Canyon, and Cubero members (Upper Cretaceous)
Mostly poorly exposed; tan to yellow-brown quartzose sandstone, dark gray and brown carbonaceous shale, and minor greenish gray mudstone and bentonite. Includes, from oldest to youngest: the Encinal Canyon, Oak Canyon, and Cubero Members.
The Encinal Canyon Member is highly variable in thickness, ranging from 2-24 m and averaging 8 m regionally (Owen et al., 2005). This tan, cross-bedded quartz sandstone with thin to medium bedding sometimes contains carbonized plant fragments. 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. The "A bentonite" is found in the lower part of the Oak Canyon Member and recently provided a direct age of 98.1 +/- 2.4 Ma (Peters, 2004). Interpreted as offshore marine deposits (Owen et al., 2005). The Cubero Member is a sometimes well exposed; yellowish to tan; moderately strong to strong; moderately well to well sorted; subrounded to rounded; medium to thick bedded; very fine to fine; commonly burrowed; quartz sandstone with minor silt and shale approximately 10-15 (?) m thick. Bedding features are commonly

obliterated by burrowing. Lower contact is sharp to gradational over about 1 m. Upper contact usually sharp. The entire thickness of Kdeoc is ~40 m to 56 m.

Kbc Burro Canyon Formation (Lower Cretaceous)
Whitish to tan; moderately strong to strong; poorly to moderately sorted; subrounded; medium to thick bedded; fine to medium, sometimes pebbly; cross laminated and plane laminated; sometimes pebbly to cobbly sandstone and red and/or green; sometimes mottled; laminated or massive clay and siltstone. Small-scale trough cross-bedding is associated with the conglomeratic channels, which are more common near the base of the unit in the Echo Amphitheatre area. Conglomerate clasts are mostly varicolored quartzite and chert pebbles with less common sandstone and limestone(?) clasts. Clasts are usually < 3 cm in diameter but occasionally up to 20 cm. Laminar, low-angle wedge and high-angle planar wedge cross-bedding is common in the sandier portions of the unit regionally. This unit is only rarely exposed near the top of landslides along the edge of the Mesa de los Viejos and in a few other areas. Interpreted as coastal plain, braided stream deposits (Owen et al., 2005). Up to ~50 (?) m thick.

JURASSIC ROCKS

Jurassic stratigraphy on the Echo Amphitheatre 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). An excellent geologic history of this part of the Chama Basin has been provided by Kelley et al. (2006).

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 here. Gastroliths (belly-stones) found mostly on the surface of unit Qls are thought to be derived from this unit. 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 the lower member of the Summerville Formation to the Wanakah Formation.
It is often difficult to tell if exposed Summerville/Bluff Formation outcrops are in place or have been disrupted by landslides (see also Jtl, Jtg and Qls descriptions). Directly above the Todilto Formation, beds of the Summerville are often contorted and this may be due to mass movements. Alternatively this deformation may be related to dewatering of the gypsum in the underlying Todilto Formation (see also Todilto Formation description for other possible mass movement features) or dissolution of gypsum within the Todilto (Kelley, et al., 2006). We have included many exposures of Summerville rocks directly above the Todilto in Qls deposits. "Windows" of Summerville rocks surrounded by unit Qls have only been mapped as Jurassic bedrock where the elevation of contacts and relatively undisturbed bedding (not contorted and conformable with the low regional dip) clearly indicate they have not been displaced. Because there are multiple possible causes for deformation of these units the distinction between disturbed and undisturbed outcrops is sometimes a little arbitrary. Some 'windows' are too small to show at map scale and many are queried (i.e. Jsb?) where they may have been displaced by mass movements. 74 to 111 m thick.

The overlying Bluff Sandstone is a light gray or pinkish, very fine grained, well sorted, crossbedded sandstone. 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 Member strata resemble underlying Summerville strata (Lucas and Anderson, 1997, 1998; Lucas et al., 2005). 44 m to 47 m thick.

Jtg Todilto Formation composed mostly of gypsum* (Middle Jurassic)
The Todilto Formation consists of a lower, Luciano Mesa Member composed mostly of limestone and commonly overlain by the Tonque Arroyo Member, an interval composed mostly of gypsum (Lucas et al., 1985, 1995; Kirkland et al., 1995). The ~30 m-thick, Tonque Arroyo Member consists of white to light gray gypsum interbedded with carbonate that forms a prominent white cliff in this region. The Luciano Mesa Member is not always present in Jtg but such areas were not mapped separately. In at least one area where the Todilto Formation seems to have slid over the top of the Entrada Sandstone and buried Quaternary hillslope deposits (see below) the Luciano Mesa Member may have been removed by mass movements. Any area where gypsum is present has been mapped as Jtg (Koning et al., 2006; Kelley et al., 2006). Up to 38 m thick.
*Actually anhydrite but commonly referred to as 'gypsum' here and in the literature.

Jtl Luciano Mesa Member of the Todilto Formation (Middle Jurassic)
In some areas the Tonque Arroyo Member of the Todilto Formation is not present either due to nondeposition, erosion, or chemical dissolution (Koning et al., 2006; Kelley, et al., 2006). The Luciano Mesa Member is 1 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. Although the Luciano Mesa Member is thin and commonly exposed in steep cliffs we have sometimes exaggerated its thickness (i.e width of outcrop) in order to show its presence. Some small areas where only the Luciano Mesa Member is present have been lumped into Jtg because they are not map scale and/or relations are not clear (e.g. where the Tonque Arroyo may be present but buried by Qls).
We suspect that in some areas the Tonque Arroyo Member has been removed by mass movements (leaving only the Luciano Mesa Member) but it has not been possible to prove this. Large (up to 100m+) 'slabs' of Tonque Arroyo Member Gypsum are sometimes found within landslides and particularly near the base of landslides.
In at least one area (in the eastern half of section 11 T24N:R3E) it can be seen that the Todilto Formation has moved *en mass* downslope over Quaternary(?) hillslope deposits (Figure 1) and large slabs of gypsum are seen at the base of landslide deposits below this point. The Luciano Mesa Member is not present here and may have been removed by mass movements. This sliding of the Todilto Formation seems to have occurred over at least a half kilometer of outcrop. This leads us to believe that the base of the Tonque Arroyo Member and/or the Luciano Mesa Member may have acted as the 'breakaway' surface for some landslides in the area. If this interpretation is correct then all of the Jurassic section above the Todilto here is likely also displaced by mass movements. However, we have mapped 'windows' of the Summerville/Bluff and Morrison Formations above here as in-place bedrock because they are not obviously tilted relative to other bedrock units and are no more disturbed than many other such windows above locations where the Todilto is not obviously displaced.
*An exception to the 2m minimum thickness of units has been made for the Luciano Mesa Member in some locations.

Je Entrada Sandstone (Middle Jurassic)
Well exposed; commonly reddish and yellowish but sometimes light brown, orange, whitish or grayish orange; cross-bedded; cross-laminated; very fine- to medium-grained; moderately well sorted and ripple laminated, eolian sandstone that commonly forms a prominent cliff. Transport direction at individual outcrops is variable but the regional transport direction is toward the south and southwest (Tanner, 1965). 60 m to 76 m thick.

TRIASSIC ROCKS

All Triassic strata on the Echo Amphitheatre quadrangle are assigned to the Upper Triassic Chinle Group (Lucas, 1993). Triassic stratigraphy follows Lucas and Hunt (1992) and Lucas et al. (2003, 2005b). An excellent geologic history of this part of the Chama Basin has been provided by Kelley et al. (2006).

Chinle Group (Upper Triassic)

Trcr
Rock Point Formation (Upper Triassic)
Poorly to well exposed; reddish brown to yellowish red beds of siltstone and very fine- to fine-grained; massive or thin to medium, tabular bedded sandstone and reddish brown mudstone. Where deeply weathered(?), the Rock Point Formation forms an orange slope (slightly less red than the underlying Painted Desert Member of the Petrified Forest Formation). The lower contact of the Rock Point is mapped at the first persistent bed of sandstone above the mudstone of the Painted Desert Member or at the above noted color change. The top of the Rock Point is a sharp, unconformable contact with overlying Entrada Sandstone. Width of outcrop is sometimes exaggerated where exposed in or at the base of steep cliffs. Up to 70 m thick regionally but commonly 10-15 m on this quadrangle.

Trcpp Painted Desert Member of the Petrified Forest Formation (upper Triassic)
Poorly to well exposed; brick red to reddish brown; thin to thick bedded; bentonitic(?) mudstone and claystone intercalated with minor greenish gray to light greenish gray, pebbly sandstone. Local reduction of the mudstone has resulted in cm-to-decimeter scale mottles, fracture linings, streaks and meter-scale beds of light gray, greenish gray, and light greenish gray mudstone. Locally there are thin 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 bodies are lenticular, have up to 2.5 m of relief at their base, and may be as much as 3 m thick. The pebbles in these channel fills are composed of light gray to very dark gray limestone or calcrete(?) pebbles (or concretions?) with very minor mudstone rip-up clasts. Pebbles are up to 2 cm in diameter. Pebbles and sand grains are in a greenish, muddy matrix that imparts an overall greenish color. A few measured trends of channels in the area are W-E and SW-NE (Koning et al., 2006). The mudstone is well consolidated but weakly cemented; the coarser channel-fills are locally cemented by calcium carbonate. The base of the unit is mapped at the highest, persistent sandstone ledge of the Mesa Montosa Member although some reddish sandstone lenses(?) or beds are found in the lowest part of the Petrified Forest Member and caution must be used to distinguish these from the underlying Mesa Montosa Member. Up to 180 m-thick.

Trcpps Sandstone body within the Painted Desert Member of the Petrified Forest Formation (upper Triassic)
An isolated body of medium to coarse sandstone is found within the Painted Desert Member in the south-central part of the map. This body is approximately 25-30 m thick at its north end and seems to have a steep buttress unconformity on its eastern side. As this sandstone is traced to the south it thins and, near its southern terminus, is clearly a bed of sandstone within Trcpp. An additional bed of sandstone in a similar stratigraphic position(?) was also observed just south of the Rio Chama Campground on the Laguna Peak Quadrangle (immediately north of the Echo Amphitheatre Quad). This body may represent an ‘axial’ stream portion of the Painted Desert Member. Hand samples of this sandstone are superficially similar to the sandstone of the Mesa Montosa Member and the Poleo Formation and could be mistaken for either.

Trcpm Mesa Montosa Member of the Petrified Forest Formation (upper Triassic)
Poorly to well exposed; very fine- to fine-grained sandstone, siltstone and mudstone. Siltstone ranges in color from reddish brown to light reddish brown. Sandstone beds are very thin to medium, tabular, and ripple-laminated, wavy-laminated or planar-horizontal-laminated. Ripple-marks and troughs commonly give a northwest-to-southwest paleoflow direction (Koning et al., 2006). This unit represents a gradational facies between the Poleo Formation and the Painted Desert Member of the Petrified Forest Formation. 5-20(?) m-thick.

Trcpo Poleo Formation (Upper Triassic)
Well exposed; tan to yellowish; strong; medium to thick bedded; fine to very coarse grained; moderately well sorted; cross laminated micaceous litharenite and minor pebble-conglomerate. Trough cross-stratification commonly gives a northwestward to westward paleoflow direction (Koning et al., 2006). The Poleo Formation has a sharp, scoured contact on the underlying Salitral Formation. It grades upward into the overlying Petrified Forest Formation thru the Mesa Montosa member. Up to 41 m-thick.

Trcsc Combined Salitral and Shinarump Formations (Upper Triassic)
The Salitral Formation sometimes forms a slope between the cliff-forming sandstones of the Shinarump and Poleo Formations. The Salitral Formation has been divided into two members that are not mapped separately here (Lucas et al., 2003, 2005b). The lower, Piedra Lumbre Member is composed of reddish brown to light gray mudstone with a persistent sandstone bed (the El Cerrito Bed) at its top. The upper, Youngsville Member is mostly composed of reddish-brown mudstone. The lower contact of the Salitral Formation is a sharp surface where mudstone rests directly on sandstone or conglomeratic sandstone. The upper contact is a sharp, scoured surface where conglomerate/sandstone at the base of the Poleo is incised into the Salitral Formation. Approximately 10 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). Above this is a mottled yellow, orange, red, purple, and white; thin; cross-bedded sandstone that appears nodular in places. Conglomerate consists of pebbles of quartz in a fine- to medium-grained quartz sandstone matrix. The basal contact is a sharp, erosional scour on the underlying Cutler Group. 6 to 7 m thick.

PENNSYLVANIAN-PERMIAN ROCKS

Cutler Group (Pennsylvanian-Permian)

We assign the oldest rocks on the Echo Amphitheatre Quadrangle to the Cutler Group. Only the Arroyo del Agua Formation of the Cutler Group of Lucas and Krainer (2005), is exposed here.

Pca Arroyo del Agua Formation (Lower Permian)
Well exposed; mostly brick red; thin to thick bedded; fine to medium arkosic sandstone, muddy sandstone, and brick red mudstone Also contains some thick beds of yellowish red and red mudstone that are commonly bioturbated and locally reduced to light greenish gray to light gray colors. Up to 130 m thick regionally.

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