Geologic Map of the Heron Reservoir 7.5-Minute Quadrangle, Rio Arriba County, New Mexico

By

Scott Aby[1] and J. Michael Timmons[2]

[1]Muddy Spring Geology, P.O. Box 488, Dixon, NM 87527
muddyspringgeology@gmail.com

[2]New Mexico Bureau of Geology and Mineral Resources, 801 Leroy Place, Socorro, NM 87801
mike.timmons@nmt.edu

June, 2017

New Mexico Bureau of Geology and Mineral Resources
Open-File Geologic Map OF-GM 264
Scale 1:24,000

This work was supported by the U.S. Geological Survey, National Cooperative Geologic Mapping Program (STATEMAP) under USGS Cooperative Agreement G16AC00287 and the New Mexico Bureau of Geology and Mineral Resources.

New Mexico Bureau of Geology and Mineral Resources
801 Leroy Place, Socorro, New Mexico, 87801-4796

New Mexico's Oceans

Look out across El Vado or Heron Lake (we will call them simply "the Lakes" from here on). Imagine all of today's mountains are gone, and instead that the nearest mountains are far to the west or south. A vast, shallow, warm ocean filled with marine animals extends from beaches and river deltas somewhere in Arizona and Utah all the way across America to the Appalachian Mountains—and north and south across modern-day Canada and down to the Gulf of Mexico (Figure 1).

FIGURE 1A

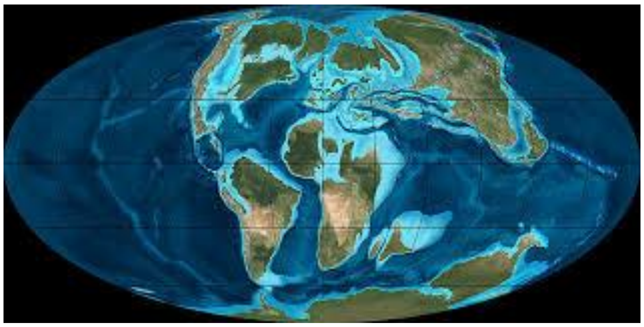

FIGURE 1B

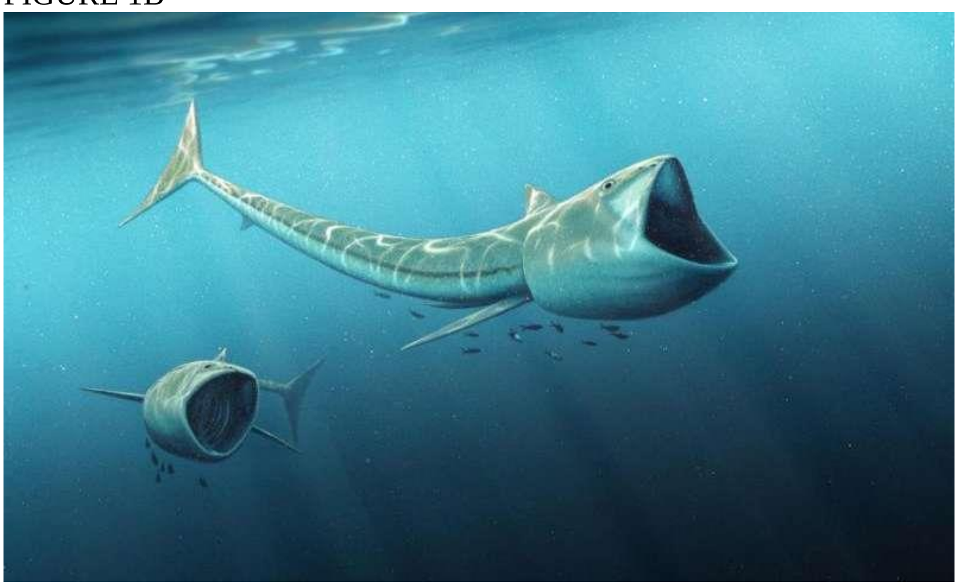

FIGURE 1C

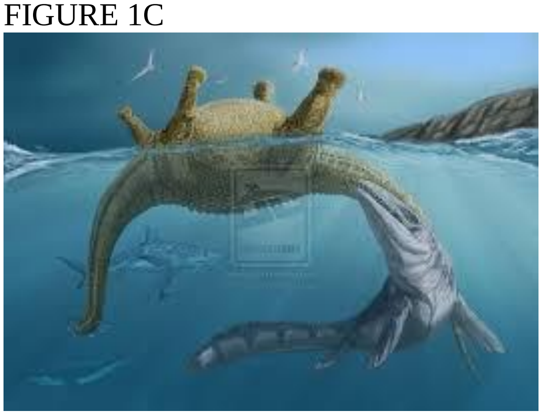

Figure 1. A. Map showing the positions of the continents and the extent of shallow oceans on the continents during deposition of many of the rock layers around Heron and El Vado Lakes. B. An example of one of the strange kinds of fish found in the Cretaceous seas. This fish was a filter feeder that lived much like today's Whale Sharks. C. A "marine reptile" eating a dinosaur that has washed out to sea.

In that ocean live hundreds of kinds of fish, many kinds of sharks, and many types of marine reptiles (some as big as some of the smaller whales alive today). The seafloor is home to trillions of clams and other bivalves. Squid-like animals with tightly coiled shells (Ammonites) propel themselves by directing jets of water through specialized organs as they wander and hunt. You can find shells in many of the rocks around the lake, and it is not uncommon to find impressions of the ribbed shells of ammonites either (Figure 2).

Figure 2. Example of an Ammonite. These coiled shells are named for the rams horns of Ammon, an Egyptian god.

Hundreds of other species of animals inhabited this ocean, and a complete compliment of plankton and seaweed must have also existed—although seaweed does not often fossilize.

So, if there was an ocean here, why do the rocks around the Lakes change from sandstone to shale to limestone? Well, different parts of a shallow ocean bordered by mountains have different types of sediment being deposited in them. Imagine again that high mountains rise in Arizona and Utah. Large and small rivers drain these mountains and form deltas and "coastal plains" (flat areas along the coast created by the sediment brought to the oceans by rivers and then reworked by the tides and coastal currents). Waves at the shoreline winnow out the fine sediment, which then moves on offshore and leaves fairly well-sorted sand behind on the beach. This sand moves in seasonal cycles.

Relatively gentle waves in the summer tend to move sediment far up the beach, while larger waves in the winter tend to erode the sand from the beach and move it into offshore "bars" that parallel the coast. This offshore sand is what is preserved as the Cubero and Paguate Members of the Dakota Sandstone exposed to the North and South of Heron Lake, east of El Vado Dam, and all along the Chama River Canyon (see map and map description).

Further offshore, the fine sediment winnowed out of the sand on the beach floats along for weeks or months and eventually comes to rest on the bottom of the sea below "wave base" (the depth to which waves can agitate the water). The finest of this sediment is composed of clay minerals which are shaped like thin plates or flakes. You can think of this as microscopic mica. These plates settle out flat and parallel to each other on the sea floor, and this platy structure is what makes the fine layers sometimes visible in the **shales** these deposits become. The platy structure is also what makes shale so slippery when wet. A tiny amount of "organic matter" (mostly small plant fragments eroded from the mountains and the remains of microscopic things) makes these rocks dark gray or black—like charcoal is black. Planktonic animals, clams, and other shell-making creatures add a certain amount of lime to these shales and larger shells or fragments of shells can sometimes be found in the shales.

Even further offshore almost no sediment from the mountains is deposited, and so shells (many of them the microscopic shells of plankton) are the only thing accumulating. Actually, shells and the feces of worms and other burrowing organisms are the only things accumulating. This feces usually forms little balls of shell fragments and "mud" that are known as "fecal pellets." In some parts of the ocean, this is the primary sand-sized particle found since virtually all of the sediment on the floor of the ocean goes through some animals' digestive system at least once. Animals that make their living burrowing through the mud on the ocean floor are known as "indiscriminate browsers" since they eat everything in front of them and simply digest the food particles out of it -- and pass the rest on in the form of fecal pellets. The deposition of shells, fecal pellets, and a few other lime-based, sand-sized materials forms **limestones (**such at the Greenhorn Limestone that is found near the lakes and especially south and east of Heron Lake and near the Heron Lake Visitor Center). They would originally have been white like the shells that form them. Around here some of the limestones are made mostly of clam shell fragments from a type of clam that was sometimes over a foot in diameter—and you can sometimes find intact shells or impressions of them in the rocks in this area. When these deposits are buried and become rock the small amount of organic matter in them turns them gray—and sometimes even black. The places where we have white sand beaches in the world today are places where no sediment is even getting to the beach—either because they are well away from the continents or because there are no rivers hitting a particular stretch of coast.

Now imagine that, over the course of a million years or so, sea level rises a hundred feet. If you were standing on the bottom of the ocean in one place that whole time, you would see that the type of sediment deposited around you would slowly change from sand to shale and finally to limestone. If sea level fell again, then you would see the shale and then the sand come back and bury the limestone. In other words, sandstones around Heron and El Vado lakes represent the shallowest parts of the ocean and limestones represent the deepest—so in any one spot sandstones represent the lowest sea level, and limestones represent the highest.

The Greenhorn limestone, as previously mentioned, can be found right near the Heron Lake Visitor Center and many other spots. This rock actually represents the highest stand of sea level on the North American Continent in at least the last 500 Million years (Nummedal, 2004). The Dakota Sandstones (Cubero and Paguate Members in this area) can be seen at both Heron and El Vado Dams and also hold up many of the large dome-shaped hills in this area. These sandstones were deposited as the shoreline of the Cretaceous Seas passed by this area as sea level was rising and falling. The shales were deposited in the “in between” times.

Concretions

Walking along the shore of the lakes you will come across some strange looking boulders, and you may wonder how in the world they formed (Figure 3).

FIGURE 3A

FIGURE 3B

FIGURE 3C

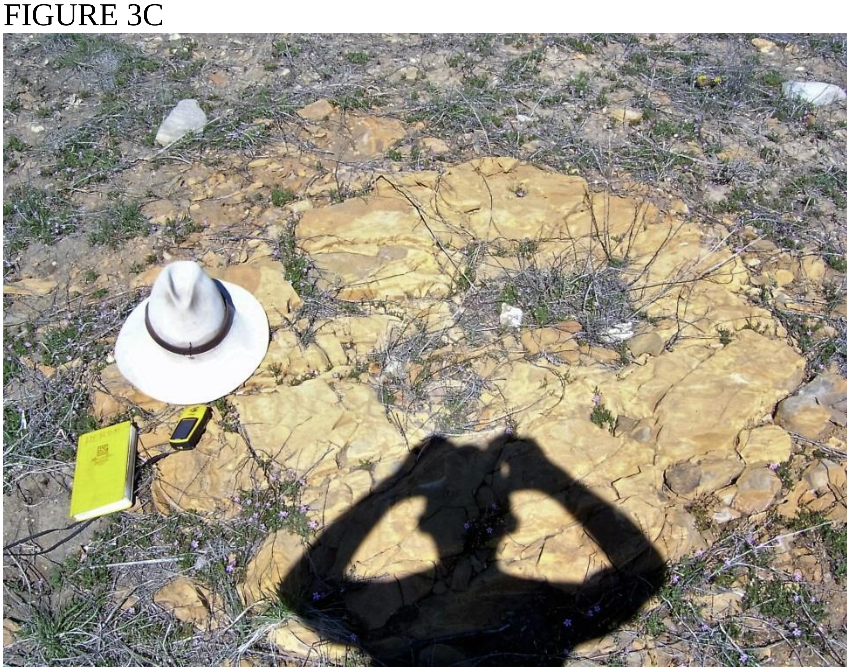

FIGURE 3D

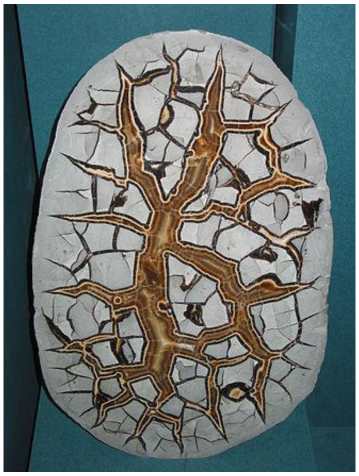

FIGURE 3. Examples of concretions found in shales near the lakes. A. A concretion still embedded in shale near the Salmon Run Campground. B. An example of a septarian concretion. The finger in picture is pointing at an individual “septa.” C. A “donut-shaped” concretion found near Reservation Site 111 in the Island View Campground. D. A slabbed and polished septarian concretion.

Geologists have also wondered about this, they have studied these boulders, and they have not been able to agree how they form. These rocks are in a general class of objects called “concretions.” This word is derived from the same root as the word “concrete” because they are both formed partly of cement. In this case “cement” means minerals that are holding small particles of rock (in this case shale) together. Remember once again that all of the rocks around the Lakes were once buried at least a half a mile deep under other, younger sediments. Rocks buried at such depths commonly have water moving very slowly through them. This water almost always has minerals dissolved in it, and as the chemistry of the water changes with time, these minerals can “precipitate out” and cement the particles of sand and shale together. One of the common minerals that form this cement is limestone (also called Calcium Carbonate, Calcite, just carbonate or sometimes simply “lime”). The precipitation of carbonate often starts on a little bit of shell—or an entire fossil—that is also made of limestone. It is easier for the cement to form on the shell because they are made of the same material. Also, if an animal is buried in the mud, the rotting of the animal can change the chemistry of the water near it and make it easier for the cement to form.

So far in this story, most geologists would agree on the general way that these concretions form. The debate concerns the formation of the internal structure of the some of the concretions you find here (Figure 3B). These particular concretions are called “septarian” concretions. The bit of cartilage that separates your two nostrils is called a “septum” and something that is full of such “walls” is similarly called “septarian.” Not all of the concretions found around the lakes—or found within individual shales are septarian (Figure 3C). If you look carefully at some of the broken septarian concretions around the lakes, you will see that the septa in them do separate little compartments of cemented shale within the concretions. The septa themselves are often filled with crystals of calcite—the mineral that forms shells and limestones. The concretions actually grew within the shale—they are not something that was deposited in the shale and buried by it. The patterns formed by the septa look very much like the kind of fractures you get when you squeeze a semi-rigid ball. The pattern leads us to believe that somehow when the concretions were not completely hard; either they were squeezed, or they shrank. Different theories for why this happened include: pressure built up from gasses formed from the rotting of animals in the center of the concretions, squeezing from the weight of sediment accumulating above and shaking from earthquakes or volcanic eruptions. Some complex chemical analysis of concretions suggests that bacteria are involved in the formation of cement within them. Surprisingly, these studies also indicate that they do not always form "from the inside out," but that all the cement can form at once or the outer layer may sometimes form first. However they form, they are often very beautiful and are commonly found in rock shops where they have been slabbed and polished (Figure 3D).

About Time

There are many ways to think about geologic time, and many analogies have been made to try and give some sense of the vastness of deep geologic time. Many people will be familiar with the image of geologic time compared to either a calendar year or to a single day—with humans always showing up on Earth in the last few seconds of the last day. The rocks around the lakes are mostly a little less than 100 million years, and so one might say that they are "not that old" geologically. Of course, this is a relative thing, 100 million years (or one hundred thousand-thousand years) is still a long time to be on hold on the telephone, for example. I find one useful way to think about geologic time is to compare the age of some particular rocks to the age of Earth herself. It is convenient to give Earth a nice round age of 4.5 billion years, and we have good radiometric dates to confirm that this is a good estimate. Four and a half billion years is then equal to 100% of the age of Earth. 2.25 Billion years is then 50%. One hundred million years ago (the general age of rocks around the Lakes) is then "only" 2.2% of Earth's age.

Faults

A fault is a place where solid rocks have been broken, and the rocks on one side have moved relative to the rock on the other side. The movement between the rocks on either side of the fault can be measured in inches, or feet, or sometimes in miles. People often think of a fault (if they think of it at all) as a single large 'crack' in the earth where earthquakes happen. However, in reality, every "big" fault is part of a system of fractures that take up the stress put on hard rocks by the motion of (and collision of) the continental plates—just like the dents in a car take up the stress of a collision. In other words, faults come in a wide variety of sizes. Imagine the complex pattern in a piece of broken glass.

The rocks around the lakes are riddled with faults of many sizes (see map). This area is not very tectonically active right now, but between about 80 and 40 million years ago this whole part of North America was being squeezed by the collision of the Pacific Plate with the North American Plate to the west. This squeezing caused the rocks here to be folded--like a rug can be folded if you slide across a wood floor in your socks and "collide" with its edge. Some of the stress of being squeezed was taken up by relatively big faults, and some of it was distributed across the rocks by literally millions of tiny faults that each moved between a fraction of inches and a few feet. If you walk across the sandstones in this area, you will see that there are often long "cracks" running more or less north to south and spaced every few feet across the rocks. Many of these would be classified as “joints” by geologists, but a joint is simply a fault that has had very little movement. Again imagine a piece of glass that has been fractured but hasn’t completely shattered. If you look carefully, you may find a spot where there has been enough movement across one of these faults to form “slickenlines” on the two sides of the crack. We use this German word to describe them because German geologists first studied them. In the area around the Lakes, these slickenlines are often on white or yellowish “faces.” They look like small grooves or groups of parallel striations scratched across the face of the rock (Figure 4 and the Map Key).

Figure 4. “Slickenlines” found in the Paguate Sandstone near the La Laja day use area.

When these faults “slip” enormous friction is generated (remember that this is all happening a few hundred or thousand feet below the surface under great pressure from the weight of the overlying rock) and that friction actually melts a little bit of rock right along the fault plane. This melted rock is what forms the white material you can find on some faults in the Dakota Sandstone.

“Hey, wait a minute, I thought faults were where earthquakes happen, and there aren’t any earthquakes around here.” Ok, true, there are not many earthquakes in New Mexico, but that is because we are not *currently* in a very tectonically active part of the continent like California. A big fault in California may have an earthquake every few decades, while an individual fault in New Mexico will only have a “big” earthquake once every few thousand years.

Ancient River Beds

All around both lakes you can find many river cobbles along the shore (Figure 5).

Figure 5. River cobbles along the Rio Chama.

This type of large rock is not found in any of the marine rocks that outcrop near the lakes. There is not one single grain of sand bigger than about 2mm in any of the sandstones found here, and the shales and limestones do not even have much sand in them at all. Every river cobble you find here was transported by the Rio Chama or its tributaries. During the most recent ice ages the Rio Chama must have been a larger river and transported more cobbles, but the present Rio Chama can move pretty big rocks when it is flooding. Some of these river cobbles are found at elevations way above the modern river (see Map). The presence of these rocks above the modern river level gives us clues as to how the present landscape has formed. There are some lava flows to the east of here that are all younger than a million years, and these lavas are found as gray cobbles in even the highest river terraces around the lakes—so all of the terraces are also less than a million years old. In other words, the entire landscape you see around you is less than one million years old. This landscape has been completely rearranged in that time. The Chama Canyon has formed in that time, as have the valleys presently flooded by Heron and El Vado Lakes.

REFERENCES

Nummedal, D., 2004, Tectonic and Eustatic Controls on Upper Cretaceous Stratigraphy of Northern New Mexico, *In*: The Geology of New Mexico: A Geologic History, New Mexico Geological Society Special Publication 11, p. 169-183.

Unit descriptions for Heron Reservoir Quadrangle
Rio Arriba County, New Mexico

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.

Note: The map of Landis and Dane (1967) was used to provide coverage of areas currently beneath Heron Lake. Mapping during 2015-17 was conducted during very low water levels, so it was possible to acquire some additional information from rocks that are normally submerged and to field check and modify some of Landis and Danes information.

QUATERNARY ROCKS

Qal

Undivided Quaternary Alluvium (Holocene and/or Pleistocene)

Light to dark brown andor dark gray 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. Composed mostly of local Cretaceous rock debris sometimes with some quartzite cobbles like those seen in Qt. Qal here represents both active upland valley-bottom alluvium and floodplain, coarse channel sediment, and river terraces and small alluvial fans within 2m of river level along the Rio Chama and Willow Creek.

Quaternary alluvium is only mapped where it is clearly >2m thick and/or it obscures large areas of bedrock units and/or unit contacts.

Qalh

Higher-level Quaternary Alluvium (Holocene and/or Pleistocene)

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. Often composed of debris from adjacent hillsides (e.g. chips of limestone from Kmgl, angular clasts derived from weathering of large concretions found in members of the Mancos shale, and platy debris from Kmjl)and sometimes containing pebbles and small cobbles of quartzite and volcanic rocks.

This unit represents Quaternary alluvium found in relatively high topographic positions. Some parts probably represent the toe of colluvial aprons that have been isolated by continued/renewed denudation. Mapped only where inferred to be >2m thick and/or they obscure bedrock units. Although found at higher topographic levels not all parts of this unit are necessarily older than Qal as some deposits show signs of active deposition.

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. Colluvium is mapped only where it obscures bedrock units and/or unit contacts.

Qt

Quaternary terrace deposits (Holocene and/or Pleistocene)

Loose to friable; poorly to moderately sorted, rounded to subrounded pebbly sand and sandy pebble to boulder conglomerate sometimes capped by 1-3 m of reddish, brownish and orangish; loose to friable; massive (?) sand, silty sand, and sandy silt. Clasts usually consist of quartzite, Tertiary intermediate to silicic volcanics, and "Brazos Basalt." Terraces of the main stem Rio Chama contain approximately 1-5% basalt cobbles presumably derived from the 0.25-1.10 Ma Brazos Basalts (Scott and Marvin, 1985). Cobbles of Cretaceous Dakota Sandstones are not found in all Qt deposits but immediately downstream of Dakota Sandstone outcrops along the Chama and in tributaries such as the Canada de la Laguna they sometimes make up more than half of the cobbles. Chips of limestone from both Kmgr and Kmjl sometimes make up significant portions of the pebbles in Qt deposits particularly downstream from outcrops of these rocks. Isolated individual pebbles and cobbles or small accumulations of Quaternary cobbles and pebbles are found over much of the quadrangle and seem to indicate that Qt deposits may have once been more extensive than at present.

CRETACEOUS MARINE AND FLUVIAL ROCKS

NOTE: We have chosen to use the nomenclature for Cretaceous rocks given by Owen et al. (2005) because this work provides a relatively recent synthesis and regional correlation (both subsurface and outcrop) based partly on stratigraphic columns within the Heron Reservoir Quadrangle.

Kmc

Carlisle Member of Mancos Shale

Very dark gray to light gray; somewhat friable laminated to thinly bedded; slope forming; sometimes limey shale. In some places, this unit contains oyster coquina beds and thin sandstone beds (Landis and Dane, 1967). Just below the Juana Lopez Member, there are often limestone concretions up to 2m diameter.

The unit is at least 450m thick regionally (excluding the interbedded Juana Lopez and Cooper Arroyo Members), although the entire thickness is not exposed on this quadrangle.

Kmcs

Cooper Arroyo Sandstone Member of Mancos Shale (Coniacian 86.3–89.8 Ma)

This thin unit found to the south on the El Vado Quadrangle is not present on the Heron Reservoir Quad.

Kmjl

Juana Lopez Member of Mancos Shale

Dark Gray, reddish-orange weathering; moderately strong; laminated to medium bedded; ripple-marked; shelly, ridge forming calcarenite interbedded with dark gray slope forming shale. Concretions up to approximately 30 cm are sometimes common. Approximately 25-40 m thick. Shale dominates the unit, but the distinctive platy-weathering calcarenites are the distinctive feature of these rocks. Individual calcarenite beds/lenses are often continuous across outcrops but seem to be discontinuous over 10's to 100's of meters commonly. Platey debris is easily transported downslope. For these reasons, the upper and lower contacts can only be approximately located. Calcarenites consist mostly of broken prisms from *Inoceramus* shells along with other bioclastic material (Landis and Dane, 1967).

Bedding attitude measurements are rare in this unit due to poor exposure.

Kmgr

Greenhorn Limestone Member of Mancos Shale

Light to dark gray, very light gray to whitish weathering; very thin to medium bedded; dense, finely crystalline, recrystallized; the ridge is forming limestone and interbedded shale. Lower contact sharp. Upper contact with overlying Carlile Shale commonly not exposed. Some small (mm-scale) fish teeth and rare shark teeth up to 2.5 cm. are found in some outcrops.

The unit is approximately 10-35 m thick in the map area, but the upper part of this resistant unit is commonly eroded away on ridge tops, and lower beds of limestone are sometimes obscured. Shale interbeds can be up to 20 m thick. Beds of Kmgr along the edges of ridges are commonly displaced by slumping of underlying shale and can give a false impression of bedding attitudes. The underlying Twowells Sandstone Tongue of the Dakota Sandstone is siltier here than to the south on the El Vado Quadrangle and can easily be mistaken for a low bed of Kmgr but the Twowells is not as reactive in hydrochloric acid, is more platey, and is usually grayer than Kmgr.

Kmg

Graneros Member of Mancos Shale (including Whitewater Arroyo Shale Tongue of the Mancos Shale and Twowells Sandstone Tongue of the Dakota Sandstone)

Dark gray to black; laminated to medium bedded; somewhat friable; slope forming shale containing locally abundant concretions.

The Twowells Sandstone Tongue of the Dakota Sandstone can be correlated in wells regionally, but in the map area, it does not contain the sandstone found in other parts of the San Juan Basin (Owen et al., 2005). The absence of this sandstone makes differentiation of the Whitewater Arroyo Shale Tongue of the Mancos Shale from the Graneros Shale impractical in the map area, so both units are here included in the Graneros Shale. The Twowells Sandstone Member is expressed in many outcrops on the

Heron Reservoir Quadrangle as a few(?) thin, limey silt intervals within the upper part of the mapped Graneros Member. The lower part (?) of the Graneros shale contains characteristic brown to red concretions up to about 2m diameter but commonly 0.50-1.0 m. These concretions are commonly botryoidal on their surface and their outer parts or usually composed of radially oriented calcite that forms abundant prismatic debris on weathering.

All three members mapped together here are interpreted as offshore marine deposits (Owen et al., 2005). 40-50m thick.

Kdp

Paguate Member of Dakota Sandstone

Yellowish to tan; Moderately strong to strong; moderately well sorted; subrounded; medium to thick bedded; very fine; commonly burrowed; arkosic quartz sandstone. 18-22m thick. In general, this sandstone is thicker on this quadrangle than on the El Vado Quadrangle to the south. On the El Vado Quadrangle the Cubero Sandstone Member is thicker than the Paguate, but on the Heron Reservoir Quadrangle the opposite is true, and exposures of the Cubero Sandstone are consequently less common on the Heron Reservoir Quadrangle. The Paguate is interpreted as middle and outer shoreface sands (Owen et al., 2005). Hand samples are difficult to distinguish from the Cubero Sandstone.

Kmcm

Clay Mesa Member of Mancos Shale

Very dark gray to light bluish gray; somewhat friable laminated to thinly bedded; poorly exposed; slope forming shale. Upper and lower contacts are sharp where exposed. Approximately 12 m thick, thinning from north to south.

Interpreted as deposits of a muddy, offshore marine environment (Owen et al., 2005).

Kdc

Cubero Member of Dakota Sandstone

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 and minor silt and shale. The lower contact is sharp to gradational over about 1 m. Upper contact usually sharp. The Cubero Sandstone in the map area consists of two fining upward sequences, the lower of which sometimes fines to silty sandstone or shale (Owen et al., 2011). Where exposed this two-part architecture is distinctive. Between 10-15(?) m thick. Bedding features are commonly obliterated by burrowing. On the El Vado Quadrangle the Cubero Sandstone Member is thicker than the Paguate, but on the Heron Reservoir Quadrangle the opposite is true, and exposures of the Cubero Sandstone are consequently less common on the Heron Reservoir Quadrangle.

Interpreted as shoreface marine sands (Owen et al., 2005).

Kdoc

Oak Canyon Member of Dakota Sandstone (Cenomanian)

Dominated by gray to blackish, sparsely fossiliferous mostly non-limey, laminated to medium bedded shale and silty shale but is characterized by a coarsening

upward sequence of yellowish to tan, moderately strong, moderately well-sorted; subrounded very thin- to medium-bedded,; very fine- to fine-grained, sometimes bioturbated, sometimes ripple laminated, quartz dominated sandstone with characteristic, sometimes very abundant plant fragments/debris. Very poorly exposed son this quadrangle. Average thickness about 15 m (Owen et al., 2005)
The "A bentonite" is found in the lower part and recently provided a direct age of 98.1 +/- 2.4 Ma (Peters, 2004). Interpreted as offshore marine deposits (Owen et al., 2005).

Kdec
Encinal Canyon Member of Dakota Sandstone.
NOTE: Mapped as a combined unit with the underlying Burro Canyon Formation.

Very light tan to whiteish; moderately strong to strong; moderately well to well sorted; subrounded; thin to thick bedded; sometimes weakly bioturbated; very fine to medium sandstone. Approximately 8vm thick. Interpreted as fluvial and tidal deposits with minor open marine sandstone (Owen et al., 2005). This unit is exposed almost exclusively in steep exposures along the canyon of the Rio Chama, and it was found impracticable to map it separately from the Burro Canyon at 1:24,000 scale.

Kbc
Burro Canyon Formation

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 sandstone and red and/or green; sometimes mottled; laminated or massive clay and siltstone. Approximately 50 m thick.
Interpreted as coastal plain braided stream deposits (Owen et al., 2005)

JURASSIC ROCKS
Jm
Morrison Formation

Poorly exposed, thin to thick bedded red and green mudstones and light gray to tannish, generally poorly sorted, medium- to thick-bedded, sub-to-moderately well-rounded sandstone and pebbly sandstone. Interpreted as fluvial sediments.

REFERENCES

Boggs, S., 1995, Principles of Sedimentology and Stratigraphy, New Jersey, Prentice-Hall 774p.

Compton, R.R., 1985, Geology in the Field: New York, John Wiley & Sons, Inc., 398 p.

Landis, E.R., and Dane, C.H., 1967, Geologic map of the Tierra Amarilla Quadrangle, Rio Arriba County, New Mexico, New Mexico Bureau of Mines and Mineral Resources Geologic Map 19, scale 1:62,500

Lucas, S.G., 2005, Cooper Arroyo Sandstone Member of the Mancos Shale (Cretaceous) of the Chama Basin, New Mexico, New Mexico Geological Society Guidebook 56, p. 64-65.

Munsell Color, 1994 edition, Munsell soil color charts: New Windsor, N.Y., Kollmorgen Corp., Macbeth Division.

Owen, D.E., Forgas, A.M., Miller, S.A., Stelly, R.J., and Owen, D.E.Jr., 2005, Surface and Subsurface Stratigraphy of the Burro Canyon Formation, Dakota Sandstone, and Intertongued Mancos Shale of the Chama Basin, New Mexico, New Mexico Geological Society 56^{th} guidebook p. 218-226.

Peters, L., 2004, 40Ar/39Ar Geochronology Results from Dakota Formation Bentonite, New Mexico geochronologic Research Laboratory Internal Report NNGRL-IR-181, 8 p.

Scott, G.R., and Melvin, R.F., 1985, Geologic Map of Surficial Deposits and Basaltic Rocks Near the Rio Chama, Rio Arriba County, New Mexico, USGS Miscellaneous Field Studies Map MF 1759.