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TAPHONOMY OF THE LOWER PERMIAN CARDILLO QUARRY, CHAMA BASIN, NORTH-CENTRAL NEW MEXICO

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ABSTRACT.—The Lower Permian Cardillo quarry is located near Arroyo del Agua, in the Chama Basin in north-central New Mexico. The quarry is stratigraphically high in the El Cobre Canyon Formation of the Cutler Group, which is Wolfcampian in age. During excavations in 1979, 1980 and 2002-2004, the remains of the labyrinthodont amphibian *Eryops*, the diadectamorph *Diadectes*, a captorhinid reptile, a varanopseid pelycosaur, and the pelycosaurs *Sphenacodon* and *Ophiacodon* were recovered from the Cardillo quarry. Taphonomic analysis reveals that this locality is an attritional fossil assemblage. The bones lie within a series of three distinct, pedogenically modified conglomerates that also include calcrete nodules, chert, quartzite and other siliceous pebbles. The skeletal material is mostly disarticulated, though two partially articulated pelycosaur skeletons were recovered from overbank sediments above the uppermost conglomerate. Isolated skeletal elements and bone fragments are in various stages of weathering and abrasion. The assemblage was not hydraulically sorted because all three Voorhies groups are well represented. The Cardillo quarry assemblage was formed by a series of crevasse splays that incorporated bones, bone fragments and basement clasts (siliceous pebbles). Thus, it is a classic example of a time-averaged vertebrate fossil assemblage.

INTRODUCTION

The Cardillo quarry is an Lower Permian bonebed that is located in Arroyo del Agua, just northwest of the town of Coyote, north-central New Mexico (Fig. 1). The quarry is located half-way up a very narrow and steep canyon that exposes both Lower Permian and Upper Triassic sedimentary rocks. Berman (1993) briefly reviewed the quarry in his summary article on Arroyo del Agua, listing the fauna and suggesting that the Cardillo quarry represents a crevasse splay deposit. In this paper, we demonstrate that this quarry, which contains the fossilized remains of early amphibians, pelycosaurs and other reptiles, is a classic example of an attritional fossil assemblage that was formed by a series of crevasse splay deposits.

HISTORY OF EXCAVATION

The Cardillo quarry was first discovered by a field party led by one of us (D. Berman) in 1979. The area had previously been visited in the 1920s and 1930s by crews working for Charles Camp of the University of California, Berkeley (Langston, 1953; Berman, 1993). Camp's crews focused their excavation efforts on several quarries at the base of the canyon, which included the Welles and Van der Hoof quarries. In 1979 and 1980, crews from the Carnegie Museum of Natural History (Pittsburgh) excavated at the Cardillo quarry, removing a number of plaster-jacketed blocks. Beginning in the summer of 2002, joint excavations led by the Carnegie Museum of Natural History and the New Mexico Museum of Natural History removed more than three dozen jackets and a variety of loose skeletal elements.

REGIONAL GEOLOGY AND STRATIGRAPHY

During the Early Permian, northern New Mexico was a fluvial landscape occupied by a broad river system (Eberth and Miall, 1991; Eberth and Berman, 1993; Lucas et al., this volume). The Cardillo quarry lies in the upper part of the El Cobre Canyon Formation of the Upper Pennsylvanian-Lower Permian Cutler Group (see Lucas and Krainer, this volume) (Fig. 1A). The El Cobre Canyon Formation is composed primarily of large, multi-storied, trough-crossbedded fluvial sandstones that are interbedded with moderately thick siltstones/mudstones. The sandstones are generally arkosic with hematitic cement. The Cardillo quarry is in a series of pedogenically modified conglomeratic sandstone stringers within floodplain siltstones (Fig. 1B). These conglomerates are reddish brown with green mottles and contain calcrete nodules, chert, quartzite and other siliceous pebbles, as well as vertebrate fossils. The quarry is just below a thick, multistoried sandstone ledge (Fig. 2A).

TAPHONOMY

Sedimentologic Data

Lithology

The Cardillo quarry bone-bearing horizons are a series of conglomeratic sandstone stringers in floodplain siltstone (Fig. 1B, 2B, C). These conglomerates are sandstone-matrix supported with siliceous extrabasinal pebbles and occur as three thin lenses. The pebbles are calcrete nodules, chert, quartzite, other siliceous pebbles and vertebrate skeletal elements and fragments. The conglomerates are reddish brown with irregularly shaped green or greenish-white mottles. Coarse-grained units in the El Cobre Canyon Formation are generally large, multistoried trough crossbedded arkosic sandstones with hematite cement, and the fine-grained units are unstratified or finely laminated siltstones/mudstones (Eberth and Berman, 1993). Thus, the conglomeratic lenses at the Cardillo quarry represent an unusual depositional event. The pebbles, bones and bone fragments indicate higher levels of energy in the depositional system than shown by the fine-grained rocks hosting these bone-bearing lenses (e.g. Voorhies, 1969).
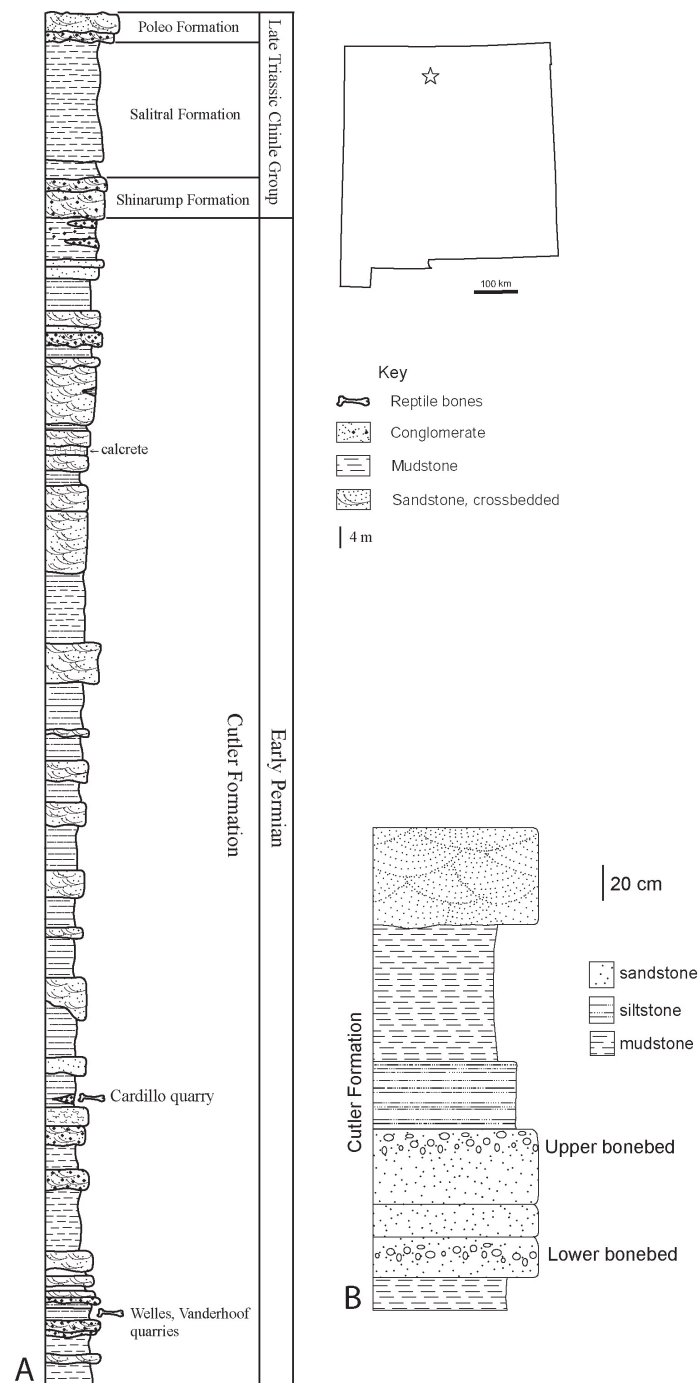
FIGURE 1. A. Stratigraphic column of the Cutler Formation at Arroyo del Agua with map of New Mexico. Star indicates location of the Cardillo quarry. B. Microstratigraphic column of the Cardillo quarry.

Bone Alignment

Bones, if transported by water, will act as sedimentary clasts (Voorhies, 1969; Aslan and Behrensmeyer, 1996) and a significant alignment of bones within water-laid sediments indicates a strong, unidirectional current (Behrensmeyer, 1988). No obvious alignment of skeletal elements was observed in the field.

Unfortunately, many of the bones are fragmentary and thus are of little use in measuring orientations. In general, though, the lack of alignment of long elements indicates that there was no strong unidirectional current interacting with the bones in the deposit (Behrensmeyer, 1988).
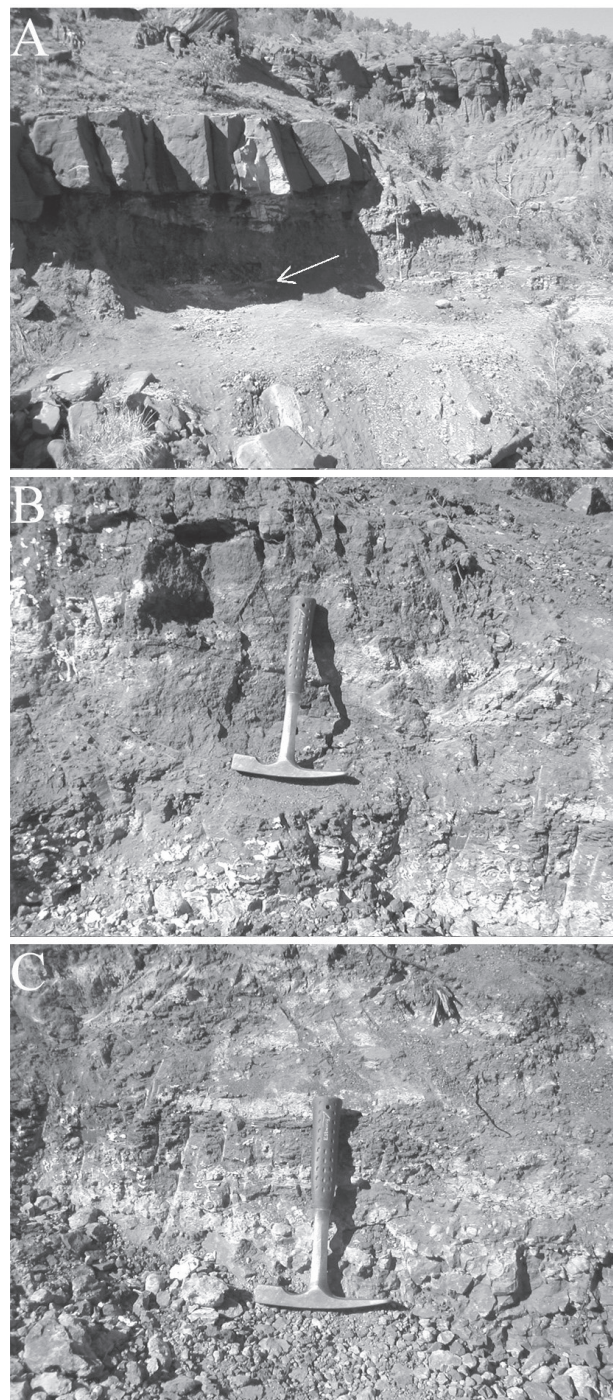

FIGURE 2. Photographs of Cardillo quarry. A. View of Cardillo quarry from across the canyon. Arrow is pointing to lower bonebed. Staff to right of arrow is 1.5 m long. Bone producing horizons are beneath sandstone ledge. B. Lower bonebed. C. Upper bonebeds.

Bone Density and Distribution

In general, the Cardillo quarry bone horizons show moderate to low densities of fossil elements within the conglomeratic lenses. The exceptions to this are the rare articulated skeletons that occur in the highest horizon, causing localized areas of high bone density. The distribution of bones in the conglomeratic lenses is patchy. The lower bonebed has more disarticulated material that is more concentrated, whereas the upper bonebed has a patchier bone distribution but contains more articulated material.

Hydraulic Sorting

All three of Voorhies' (1969) groups are present in this assemblage, ranging from vertebrae and metatarsals (Group I) through elongate limbs (Group II) to skulls and lower jaws (Group III). This indicates a lack of hydraulic sorting of the assemblage, which is consistent with the appearance of siliceous pebbles in a sandy matrix. A moderate degree of high velocity transport was necessary to entrain larger bones and articulated skeletons (including floating carcasses), but the bones, pebbles and sand did not travel far enough for energy levels to drop and elements to sort out by surface area and volume.

Abrasion

Many of the skeletal elements recovered from the Cardillo quarry are highly abraded with rounded and smoothed edges (Fig. 3C, E), but many are not abraded at all (Fig. 3B, D, F, G). This suggests that some of these bones traveled through the sedimentary system for relatively great distances prior to deposition, whereas other bones were introduced into the system from much closer sources (Shipman, 1981). Thus, this deposit represents a mixture of primary material and reworked and transported material.

Biologic Data

Articulation

In the upper bonebed, there are occasional articulated partial to complete skeletons (Fig. 4), although both the upper and the lower bonebeds are dominated by disarticulated bones and bone fragments. The presence of articulated partial and complete skeletons suggests that these individuals died very close to the depositional system and were not subjected to scavenging or decay to any substantial degree (Hill, 1979). The plethora of disarticulated bones and bone fragments indicates that the majority of the carcasses supplying skeletal elements to this deposit were in advanced stages of decay. Two complete to partially complete, articulated to associated pelycosaur skeletons were collected from the mudstone above the uppermost conglomeratic lens.

Weathering

The bones in the Cardillo quarry display a wide variety of weathering stages (Fig. 3A, C) (Behrensmeyer, 1978), although advanced levels of abrasion have obscured signs of weathering on some bones. Stage 0 bones have a smooth finish and no cracks or splintering. Stage 1-2 bones display shallow longitudinal cracking and initial splintering of the bone ends. Bones beyond stage 3 are heavily splintered at the ends and have deep cracks that reach the marrow cavity. The mixture of weathering stages present in the Cardillo quarry bones again indicates that skeletal material in various states of decay entered the depositional system from a variety of points on the landscape. For example, smooth unweathered bone material was entrained very close to where the animal died, whereas splintered and cracked bones were lying exposed to weathering processes for a longer period of time prior to being entrained (Behrensmeyer, 1978). Advanced stages of weathering will also obscure scavenging marks as the bone disintegrates.

Scavenging

No signs of scavenging, including either tooth puncture or scrape marks (Hill, 1979; Shipman, 1981), were seen on any of the material from the Cardillo quarry. However, both abrasion and advanced weathering will obscure signs of scavenging.
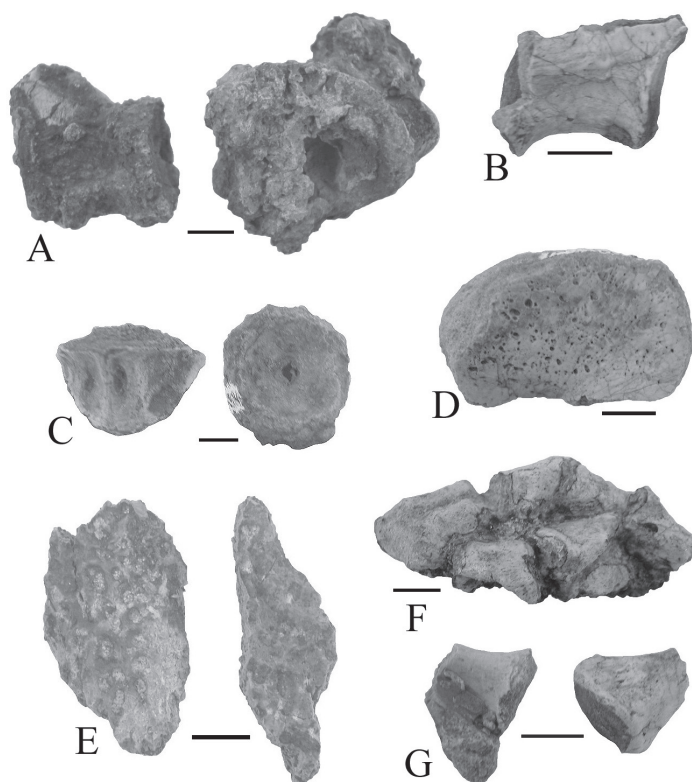

FIGURE 3. Photograph of fossil material from the Cardillo quarry. **A.** NMMNH P-34762, Amniote vertebrae encrusted with calcrete concretions. **B.** NMMNH P-34767, Amniote centrum with unweathered surface. **C.** NMMNH P-34761 and P-34764, Temnospondyl and Anthracosaur (respectively) vertebrae with mild weathering/abrasion on outer surfaces. **D.** NMMNH P-34769, Tetrapod mesopodial with unweathered surface. **E.** NMMNH P-43001, *Eryops* dermal fragments. **F.** NMMNH P-43028, *Sphenacodon* associated material. **G.** NMMNH P-34763, Tetrapod proximal rib fragments with unweathered surface and perpendicular fracture.

FIGURE 4. NMMNH P-45400, a partially prepared articulated pes in jacket

Fracture Patterns

The majority of the bones and bone fragments exhibit vertical fractures perpendicular to the long axis of the bone (Fig. 3G). Fracture surfaces are smooth planes without jagged or spiraled edges. Fresh (or "green") bone will fracture in a spiral pattern with ragged edges (Myers et al., 1980; Shipman, 1981; Fiorillo et al., 2000), whereas fossilized bone will fracture (generally due to sediment loading or excavation/preparation damage) in a vertical plane with smooth surfaces. Again, however, abrasion and weathering may have erased signs of fresh bone fracturing. The vertical fractures merely indicate post-fossilization stresses on the bones (Shipman, 1981).

Minimum Numbers of Individuals (MNI) and Age Profiles

The majority of the bones recovered are disarticulated and often too battered to identify to a generic level, making it very difficult to identify taxa. In general, the animals present in this quarry are those that should be expected for Early Permian assemblages. At least one individual each of *Eryops*, *Diadectes*, a captorhinid reptile and a varanopseid are present based upon skull material (MNI methods after Badgley, 1986). At least two individuals of *Sphenacodon* and *Ophiacodon* are present based upon skull material and partially articulated carcasses. However, the lack of positive identification of taxa does not allow us to make statements about biodiversity based on the material in this quarry. Because of the poor preservation of the material from this quarry, we did not attempt to construct age profiles for any of the positively identified genera.

DISCUSSION

There are two taphonomic end-members: the attritional assemblage and the catastrophic assemblage. An attritional assemblage is characterized by fossils that are not in ecological equilibrium (e.g., terrestrial organisms preserved in fluvial deposits) and often display variable states of weathering, abrasion and scavenging.

Thus, an attritional fossil assemblage is "the 'everyday death' within the biocoenosis…" (Holz and Barberena, 1994, p. 193) and as such, is a time-averaged sample of many animal groups (Behrensmeyer, 1982; Turnbull and Martin, 1988). In contrast, a catastrophic assemblage typically involves a geologically instantaneous event that rapidly kills and buries a fauna, thereby preserving a "snapshot" of a paleoecosystem.

In the case of the Cardillo quarry, the sedimentologic data indicate that a variety of skeletal material, both fresh and reworked, plus extrabasinal siliceous clasts, were entrained in an unsorted and unstratified flow that had moderately high energy and deposited its load quickly without orienting any of the longer skeletal elements. The biologic data show that the skeletal material entrained in this flow came from a variety of sources that ranged from fresh carcasses to weathered and decayed skeletons. The scenario that best fits the data recovered from Cardillo quarry is that a series of crevasse splays occurred, with each splay event depositing a mixture of bones, bone fragments, articulated corpses and siliceous pebbles.

There are two components to a crevasse splay system: the crevasse channel and the splay itself. In the sedimentary record, crevasse channels are commonly laterally discontinuous bodies, often termed ribbon-shaped, dominated by fine to medium grained sandstone with trough crossbedding and/or ripple cross-laminations (Miall, 1996). Usually, these crevasse channels contain material that is the same size or finer grained than the main channel. A common feature of crevasse channel deposits is coarse-grained lags that contain fossil remains and often have a pebbly sandstone component (e.g., Bown and Kraus, 1987; Eberth and Miall, 1991). There is not enough lateral exposure of the primary bone-bearing horizons to determine if they are crevasse splay deposits or crevasse channel deposits, but the coarse-grained nature of these deposits suggests that they are more likely crevasse channel deposits.

CONCLUSIONS

We conclude the following: at the Cardillo quarry, the formation of each crevasse splay deposit followed the same sequence of events:

1) Basement material in the form of extrabasinal clasts (siliceous pebbles) was incorporated into lag deposits in a stream, together with isolated bones and bone fragments from upstream and from the surrounding floodplain.

2) The lag of pebbles and bones was reworked onto the floodplain by crevasse splays during flooding of the stream. These splay events probably also incorporated additional bone material from the surrounding floodplain, which may have included partial skeletons. Partial skeletons may also represent "floaters" that were grounded when floodwaters receded.

3) The resulting mixture of bones and pebbles was buried under fine silts during overbank deposition, and was subsequently pedogenically modified.

4) Two partial to complete pelycosaur carcasses were deposited in the overbank silts after the final crevasse splay event.

Thus, the coarse-grained nature of the deposits, together with

the fragmentary nature of the fossil material and highly variable weathering and abrasion states of the bones, indicates that the Cardillo quarry was formed as an attritional assemblage over a relatively long span of time (months to years). The Cardillo quarry is thus an excellent example of a time-averaged vertebrate fossil assemblage.

ACKNOWLEDGMENTS

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