

EARLY PERMIAN VERTEBRATE ASSEMBLAGE AND ITS BIOSTRATIGRAPHIC SIGNIFICANCE, ARROYO DEL AGUA, RIO ARRIBA COUNTY, NEW MEXICO

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ABSTRACT.—Early Permian vertebrate fossils from the upper part of the El Cobre Canyon Formation of the Cutler Group in the area around Arroyo del Agua, Rio Arriba County, New Mexico, encompass an extensive assemblage of chondrichthyans, osteichthyans, temnospondyls, microsaur, a seymouriamorph, diadectomorphs, a parareptile, captorhinomorphs, an araeoscelid, and basal or pelycosaurian-grade synapsids. This long and extensively collected and studied vertebrate assemblage comes from a narrow stratigraphic interval about 50-60 m thick, and we treat it as a single biostratigraphic assemblage. The presence of *Zatrachys*, *Bolosaurus* and *Chenoprosopus* indicates correlation of this assemblage to the Bowie Group in Texas, and thus suggests an age for the upper El Cobre Canyon Formation of early Wolfcampian.

INTRODUCTION

Early Permian vertebrate fossils from the vicinity of Arroyo del Agua in the Chama Basin of northern New Mexico (Fig. 1) are among the longest known and most extensively documented Early Permian vertebrates from North America. These vertebrate fossils are of biostratigraphic value, and their correlation provides a relatively precise age for part of the Cutler Group in northern New Mexico. Here, we review the history of study, localities, and composition of the Arroyo del Agua Early Permian vertebrate fauna and place the localities into lithostratigraphic context. This allows us to discuss the biostratigraphic correlation of the Arroyo del Agua Early Permian vertebrates.

PREVIOUS STUDIES

The Lower Permian vertebrate-fossil-bearing strata surrounding the village of Arroyo del Agua, in Rio Arriba County, north-central New Mexico, have been actively prospected and excavated for more than 125 years. The nine well-collected quarries in the region (Fig. 2) have yielded extensive Lower Permian vertebrate material, which is rivaled only by the vertebrate fossil record of the Lower Permian redbeds of Texas (Berman, 1993). The Arroyo del Agua localities have been collected in three phases. The initial discovery and collection was made by David Baldwin from 1877 to 1881, followed by various university field parties intermittently collecting from 1911 to the early 1960s. From 1979 to the present, the Arroyo del Agua localities have been predominantly collected by the Carnegie Museum of Natural History and more recently by the New Mexico Museum of Natural History and Science in association with the Carnegie Museum of Natural History.

In 1877-1881, David Baldwin collected in the Arroyo del Agua region for five field seasons, initially working for O.C. Marsh and later for E. D. Cope. Subsequent researchers concluded that what is currently known as the Baldwin bonebed (Fig. 2) is where he collected the first Permian vertebrates discovered in New Mexico. This collection was sent to O.C. Marsh in 1877 (Langston, 1953).

Whereas this initial collection is seen as a key record of a Lower Permian vertebrate fauna, it produced little to no response from either Marsh or Cope, who generated only one paper each based on Baldwin's collections (Marsh, 1878; Cope, 1881).

The second phase of collecting in the region began with a field party from the University of Chicago headed by S. W. Williston in 1911. This party recollected Baldwin's locality, currently called the Baldwin bonebed. They also followed the fossiliferous horizon of that bonebed to the southeast along Mesa Montosa (called "Mesa Poleo" by them), and one of the party, P. C. Miller, discovered a new quarry, later named the Miller bonebed (Fig. 2). The resulting fauna and the stratigraphy of the quarries from which the fauna were collected resulted in several publications that characterized the Lower Permian vertebrate fauna of northern New Mexico (Case, 1907, 1910, 1911, 1915, 1916; Huene, 1911; Williston, 1911a, b, 1914a, b, 1915, 1916a, b, 1917, 1918; Williston and Case, 1912, 1913a, b, c, d; Case and Williston, 1913a, b, c; Mehl, 1913; Douthitt, 1917).

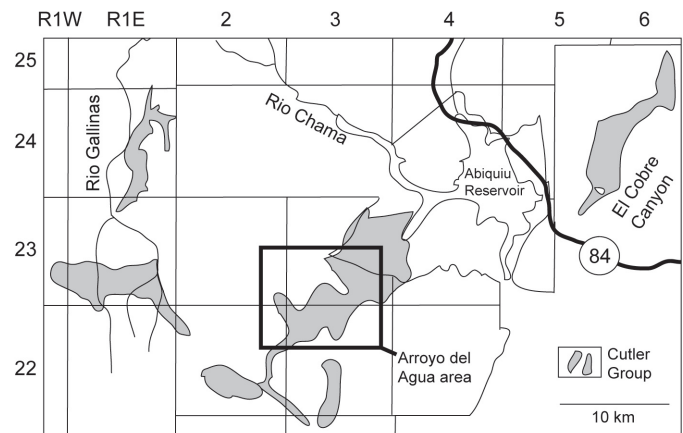


FIGURE 1. Cutler Group outcrops in the Chama Basin, northern New Mexico, showing location of the Arroyo del Agua area.

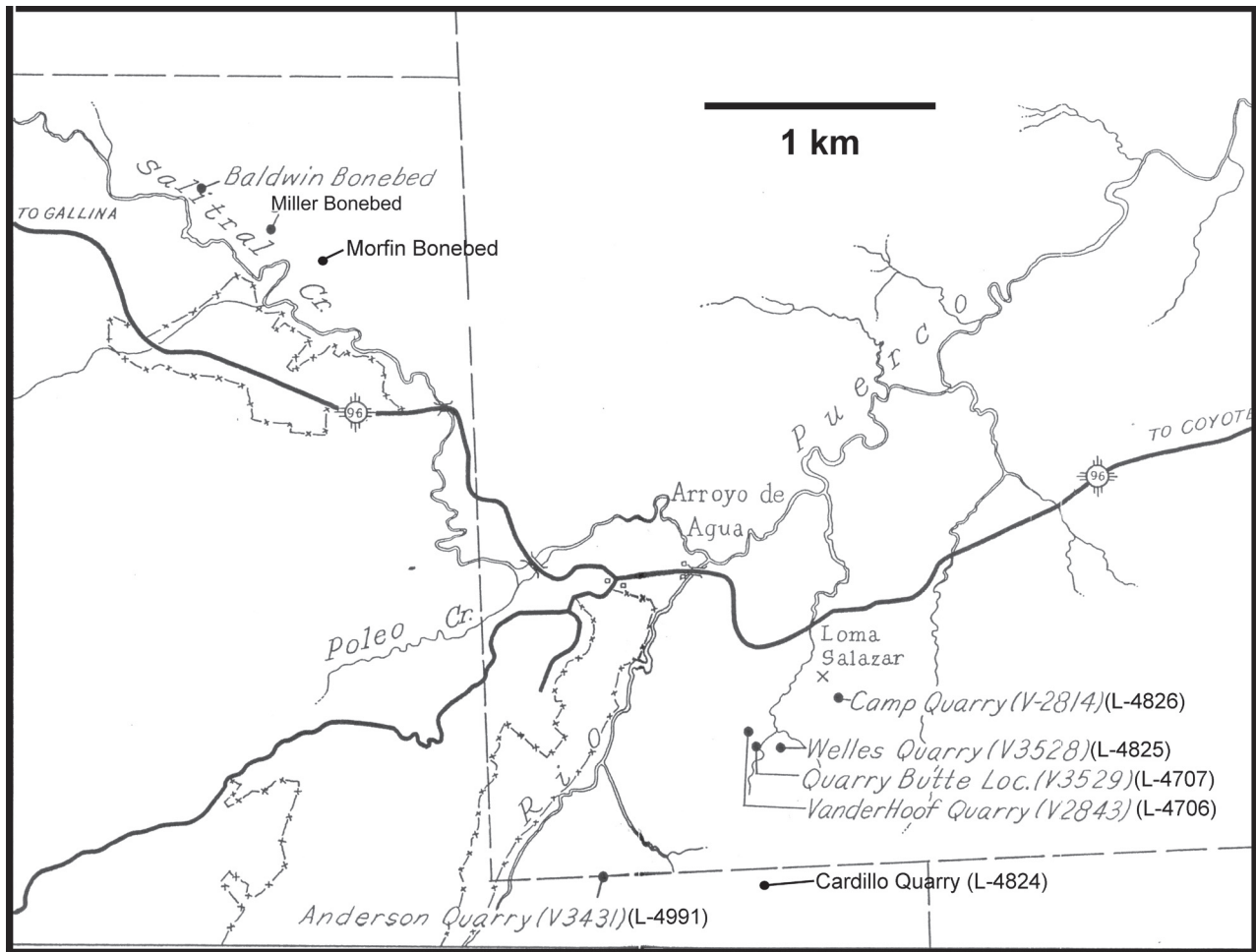


FIGURE 2. Locality map of the nine Lower Permian vertebrate fossil quarries in the vicinity of the village of Arroyo del Agua (modified from Langston, 1953). The V and L prefixes of numbers indicate specimens assigned to the quarries by the Museum of Paleontology, University of California, Berkeley, and the New Mexico Museum of Natural History and Science, respectively.

Field parties from the University of California at Berkeley began collecting in the Arroyo del Agua region in 1928. These crews were led by C. L. Camp and V. L. VanderHoof, who each discovered the quarries that bear their names (Fig. 2). Excavation of these sites was continued in 1934 and 1935, and during these field seasons the Welles, Anderson and Quarry Butte quarries (Fig. 2) were discovered. All of the Berkeley quarries are tightly clustered near the small butte that they named Loma Salazar (Fig. 2). Four important additions to the Arroyo del Agua fossil vertebrate assemblage were based on specimens from the original Camp quarry collections. These included the basal or pelycosaurian-grade synapsids, hereafter simply referred to as pelycosaurs, the eothyridid *Oedaleops campi* and varanopseid *Aerosaurus wellesi*, the diadectomorph *Limnosceloides brachycoles* and the captorhinid *Rhiodenticulatus heatoni* (Langston, 1965, 1966; Langston and Reisz, 1981; Berman and Reisz, 1986; Wideman, 2002). In addition, the University of California collection from the Anderson quarry allowed the detailed redescription of the skull of *Sphenacodon ferocior* (Eberth, 1985).

The most recent phase of collecting in the Arroyo del Agua region was begun by joint field crews from the Carnegie Museum Natural History and the University of Toronto. In 1979-1980, both the Cardillo quarry near Loma Salazar and the Morfin bonebed on the southwest flank of Mesa Montosa (Fig. 2) were discovered and partially excavated. This prompted Berman et al. (1985) to describe the Morfin bonebed and specifically record the occurrence of the rare dissorophid temnospondyl *Ecolsonia cutlerensis*, known otherwise from the VanderHoof quarry. Collecting continued until the mid-1980s, resulting in several additions to the vertebrate fossil assemblage of the Arroyo del Agua area, including the diadectomorph *Tseajaia* cf. *T. campi*, the araeoscelid *Zarcasaurus tanyderus*, the seymouriamorph *Seymouria sanjuanensis* and the microsaur *Stegotretus agyrus* (Berman and Reisz, 1980; Eberth and Berman, 1983; Brinkman et al., 1984; Berman et al., 1988).

From 2002 to 2004, the Cardillo quarry was reopened and excavated by a joint field crew from the New Mexico Museum of Natural History and Science and the Carnegie Museum of Natu-

ral History. Stratigraphic studies were also undertaken to put the Arroyo del Agua fossil vertebrate localities into a more detailed lithostratigraphic framework.

LITHOSTRATIGRAPHY

The canyon of the Rio Puerco and its tributaries around Arroyo del Agua expose a section of the Pennsylvanian-Permian Cutler Group about 220 m thick. These strata form areas of low badlands, dissected arroyo valleys and denuded escarpment slopes throughout the Arroyo del Agua area.

Lucas and Krainer (2005) divided the Cutler Group in the Chama Basin into two mappable lithostratigraphic units, a lower El Cobre Canyon Formation and an upper Arroyo del Agua Formation (Fig. 3). Approximately 90 m of the upper part of the El Cobre Canyon Formation are the oldest bedrock strata exposed in the Arroyo del Agua area. They consist of brown arkosic sandstone in multistoried beds with relatively thin brown siltstone interbeds. Extraformational conglomerates characterize the El Cobre Canyon Formation, and they are composed of clasts of Proterozoic granite, quartzite and other metamorphic rock fragments.

The overlying Arroyo del Agua Formation is about 130 m thick in the Arroyo del Agua area. It consists of thick slopes of orange-red siltstone that contain numerous horizons of pedogenic calcrete nodules. Interbedded arkosic sandstones form relatively thin sheets, and few, mostly intraformational, conglomerates are present in the Arroyo del Agua Formation. The Upper Triassic Chinle Group disconformably overlies the Arroyo del Agua Formation except where local outcrops of the De Chelly Sandstone (= Meseta Blanca Member of Yeso Formation) are present.

All but one of the Early Permian vertebrate fossil localities in the Arroyo del Agua area are in the upper part of the El Cobre Canyon Formation (Fig. 3). They are derived from an interval approximately 50-60 m thick that has its top about 20 m below the contact between the El Cobre Canyon and Arroyo del Agua formations. The overall similarity of the vertebrate fossils from the various localities (see below) and the relatively narrow stratigraphic interval lead us to treat these fossils as a single biostratigraphic assemblage, as have previous workers (e.g., Langston, 1953; Romer, 1960).

ARROYO DEL AGUA VERTEBRATE FOSSIL QUARRIES

The nine Early Permian vertebrate-fossil quarries in the Arroyo del Agua area from which extensive vertebrate collections have been made are the Baldwin bonebed, Miller bonebed, Vander-Hoof quarry, Welles quarry, Quarry Butte locality, Anderson quarry, Camp quarry, Cardillo quarry and Morfin bonebed (Fig. 2). Langston (1953) described the geological setting and fauna of most of the Arroyo del Agua quarries. Berman (1993) reviewed the studies conducted since Langston's (1953) work and noted several important additions, as well as taxonomic changes to the vertebrate assemblage list from the Arroyo del Agua localities (Table 1). The summary presented below is based on these two previous studies and new data collected by us.

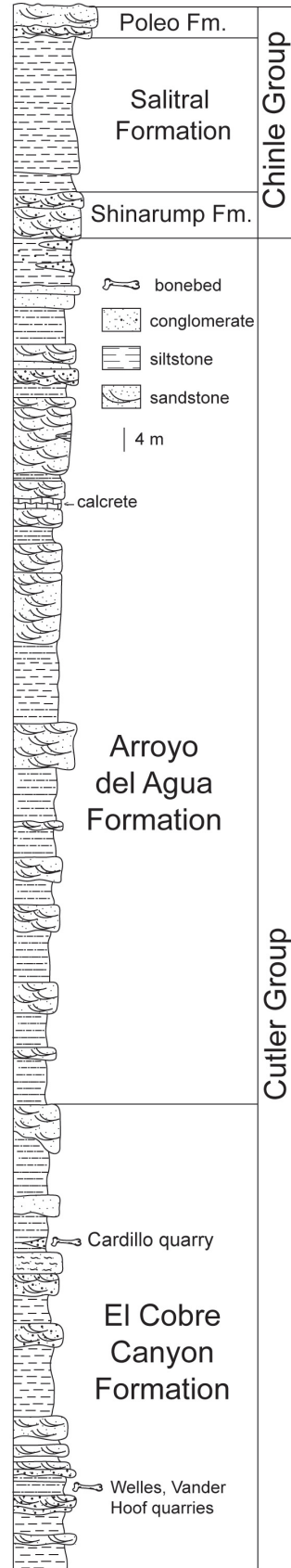


FIGURE 3. Measured stratigraphic section of the Cutler Group in the area of the Welles, VanderHoof and Cardillo quarries.

TABLE 1. Fossil vertebrate taxa from the El Cobre Canyon Formation in the Arroyo del Agua area.

Anderson quarry	Diadectomorpha
Temnospondyli	<i>Diadectes</i> sp.
<i>Eryops grandis</i>	Captorhinomorpha
Microsauria	indet. captorhinid
a pantylid?	Eupelycosauria
Diadectomorpha	<i>Ophiacodon</i> sp.
<i>Diadectes</i> sp.	<i>Sphenacodon</i> sp.
Parareptilia	a varanopseid
<i>Bolosaurus</i> sp.	Morfin bonebed
Eupelycosauria	Temnospondyli
<i>Ophiacodon</i> sp.	<i>Ecolsonia cutlerensis</i>
<i>Sphenacodon ferocior</i>	
Baldwin bonebed	Quarry butte
Temnospondyli	Elasmobranchii
<i>Chenoprosopus milleri</i>	<i>Xenacanthus</i> sp.
<i>Eryops grandis</i>	Palaeoniscoidea
<i>Zatrachys serratus</i>	<i>Progyrolepis</i> sp.
<i>Platyhystrix rugosus</i>	Temnospondyli
Diadectomorpha	<i>Chenoprosopus milleri</i>
<i>Diadectes lentus</i>	<i>Eryops grandis</i>
Captorhinomorpha	<i>Platyhystrix rugosus</i>
<i>Rhiodenticulatus heatoni</i>	Diadectomorpha
Eupelycosauria	<i>Diadectes lentus</i>
<i>Ophiacodon mirus</i>	Eupelycosauria
<i>Sphenacodon ferox</i>	<i>Ophiacodon mirus</i>
	<i>Sphenacodon ferox</i>
Camp quarry	VanderHoof quarry
Temnospondyli	Elasmobranchii
<i>Eryops grandis</i>	<i>Xenacanthus</i> sp.
<i>Zatrachys serratus</i>	Palaeoniscoidea
<i>Broiliellus novomexicanus</i>	<i>Progyrolepis</i> sp.
Diadectomorpha	Temnospondyli
<i>Diadectes</i> sp.	<i>Chenoprosopus milleri</i>
<i>Limnosceloides brachycoles</i>	<i>Eryops grandis</i>
Captorhinomorpha	<i>Zatrachys serratus</i>
<i>Rhiodenticulatus heatoni</i>	<i>Platyhystrix rugosus</i>
Caseasauria	<i>Ecolsonia cutlerensis</i>
<i>Oedaleops campi</i>	Diadectomorpha
Eupelycosauria	<i>Diadectes lentus</i>
<i>Aerosaurus wellsi</i>	Eupelycosauria
<i>Ophiacodon mirus</i>	<i>Ophiacodon mirus</i>
<i>Edaphosaurus novomexicanus</i>	<i>Sphenacodon ferox</i>
<i>Sphenacodon ferox</i>	
Valley floor east of Camp quarry	Welles quarry
Temnospondyli	Elasmobranchii
<i>Ecolsonia cutlerensis</i>	<i>Xenacanthus</i> sp.
Microsauria	Palaeoniscoidea
<i>Stegotretus agyrus</i>	<i>Progyrolepis</i> sp.
Diadectomorpha	Temnospondyli
<i>Tseajaia</i> cf. <i>T. campi</i>	<i>Chenoprosopus milleri</i>
Araeoscelida	<i>Eryops grandis</i>
<i>Zarcasaurus tanyderus</i>	<i>Zatrachys serratus</i>
	<i>Platyhystrix rugosus</i>
Cardillo quarry	Lepospondyli
Temnospondyli	an ophiderpetontid?
<i>Eryops</i> sp.	Diadectomorpha
Anthracosauria	<i>Diadectes lentus</i>
an embolomere	Eupelycosauria
	<i>Ophiacodon mirus</i>
	<i>Sphenacodon ferox</i>

Baldwin Bonebed

The Baldwin bonebed is in a claystone that overlies a thin-bedded sandstone, which is underlain by a light-colored sandstone interbedded with red shale. The claystone containing the quarry

laterally grades into red-brown shale. In addition to vertebrate material, the bonebed contains charcoal and spiral coprolites. The vertebrate assemblage consists of the temnospondyl amphibians *Chenoprosopus milleri* Mehl, *Eryops grandis* Marsh, *Zatrachys serratus* Cope, and *Platyhystrix rugosus* Case; the diadectomorph

amphibian *Diadectes lentus* Marsh; the captorhinomorph reptile *Rhiodenticulatus heatoni* Berman and Reisz (= *Puercosaurus obtusidens* Williston); and the pelycosaur reptiles *Sphenacodon ferox* Marsh and *Ophiacodon mirus* Marsh (type locality of both). This assemblage is most similar to that of the Quarry Butte locality.

Miller Bonebed

The Miller bonebed is similar in lithology (though slightly more sandy) and vertebrate composition to the Baldwin bonebed. The two quarries also are at approximately the same stratigraphic level, both being underlain by the same laterally continuous sandstone. The vertebrate assemblage from the Miller bonebed is identical to that of the Baldwin bonebed, although the Miller deposit contains fewer, but better preserved, specimens. Also, the type locality of *Chenoprosopus milleri* is within a few meters of the quarry, though it was collected from the sandstone slightly below that of the main quarry horizon.

VanderHoof Quarry

The VanderHoof quarry is in green and brown micaceous clay and siltstone that progressively becomes lighter colored towards its top. These clays and siltstones are capped by a medium-grained crossbedded sandstone and underlain by a layer of marl and spherical carbonate concretions. The VanderHoof quarry is best known as the type locality of the dissorophid amphibian *Ecolsonia cutlerensis*, described by Vaughn (1969) from a partial skull. The vertebrate assemblage from the VanderHoof quarry consists of the elasmobranch fish *Xenacanthus* sp.; the palaeoniscoid fish *Progyrolepis* sp.; the temnospondyl amphibians *Chenoprosopus milleri* Mehl, *Eryops grandis* Marsh, *Zatrachys serratus* Cope and *Platyhystrix rugosus* Case; the diadectomorph amphibian *Diadectes lentus* Marsh; and the pelycosaur *Sphenacodon ferox* Marsh and *Ophiacodon mirus* Marsh. The VanderHoof quarry is distinguished from the similar Welles quarry by the presence of a small but diverse flora, listed by Langston (1953) as *Pecopteris arborescens*, *P. bredovi*, *Odontopteris genuina*, *Taeniopteris* sp., *Daubreea* sp., *Calamites*, *Lobatannularia* sp., *Dicranophyllum?*, *Cordaites?*, and *Cardiocarpus?*

Welles Quarry

As noted above, the Welles quarry is similar lithologically to the VanderHoof quarry, and both quarries preserve a similar assemblage. Unique to the Welles quarry is a probable aistopod collected by Vaughn (1963) and later named *Vaughniella urodeloides* by Kuhn (1964). Most notably, the Welles quarry produced numerous specimens of the temnospondyls *Zatrachys serratus* (Fig. 5C) and *Chenoprosopus milleri* (Fig. 4C) (Langston, 1953), as well as a rich assemblage of nonmarine bivalves assigned to *Palaeonodonta* (Rinehart et al., 2003). The Welles quarry is lithologically distinct from the Vanderhoof quarry due to its lack of a capping sandstone and a thicker underlying concretionary layer. The main quarry level typically contains isolated cranial elements and axial skeletal elements; associated or articulated elements are

rare. The marl layer underlying the principal quarry level is also fossiliferous, containing isolated and heavily concreted postcranial elements.

Quarry Butte Locality

The Quarry Butte locality occurs geographically between the VanderHoof and Welles quarries. Lithologically, the Quarry Butte locality consists of shale similar to those of the two nearby quarries, which are capped by crossbedded sandstones and underlain by marls. The only lithologically distinct characteristic of the site is a series of hard, lenticular, calcareous lenses in the shale. Skull elements are rare at this locality, but the vertebrate remains in the marl are well preserved. All tetrapod species from the neighboring quarries are found in the Quarry Butte locality (e.g., Fig. 5B), with exceptions being *Zatrachys*, *Ecolsonia cutlerensis* and the aistopod. The Welles quarry, VanderHoof quarry and Quarry Butte locality were interpreted by Langston (1953) as belonging to a single large lake deposit, due to their similar lithologies and vertebrate assemblages. However, Berman et al. (1988) interpreted the quarries as ephemeral crevasse channels that were temporary sites of standing water within a locally anastomosed river system.

Anderson Quarry

The Anderson quarry consists of light gray shale with lenses of crossbedded sandstone capped by numerous, light-colored marl layers. These shales contain numerous small elements and partial, articulated skeletons of larger animals. The marls overlying the shales contain heavily encrusted pelycosaur elements. The vertebrate assemblage of the Anderson quarry includes the temnospondyl *Eryops grandis* Marsh (Fig. 4G), the microsauro *Pantylus* sp., the diadectomorph *Diadectes lentus* Marsh (Fig. 4D), the parareptile *Bolosaurus* sp. and the pelycosaur *Ophiacodon* sp. and *Sphenacodon ferocior* Romer (Fig. 5D-E). *Sphenacodon* remains dominate the quarry; with no less than 35 partial skeletons of individuals having been collected. Langston (1953) interpreted this deposit as belonging to a nearshore lake deposit, but Eberth (1985) interpreted it as a crevasse-channel deposit similar to the VanderHoof, Quarry Butte and Welles quarries.

Camp Quarry

The Camp quarry is in a soft red siltstone composed of sub-angular quartz and hematitic clay, with occasional mica flakes and smaller dark minerals. Vertebrate remains from this quarry are well preserved and include articulated skeletons, but some specimens have been plastically deformed. The vertebrate assemblage consists of the temnospondyl amphibians *Eryops grandis* Marsh, *Zatrachys serratus* Cope and *Broiliellus novomexicanus* Williston (Fig. 4B); the holotype of the diadectomorph *Limnosceloides brachycoles* Langston; the holotype of the captorhinid *Rhiodenticulatus heatoni* and the pelycosaur *Sphenacodon ferox* Marsh, *Ophiacodon mirus* Marsh, *Aerosaurus wellsi*, Langston and Reisz (holotype) (Fig. 4A), *Edaphosaurus novomexicanus* Williston and Case and *Oedaleops campi*, Langston (holotype)

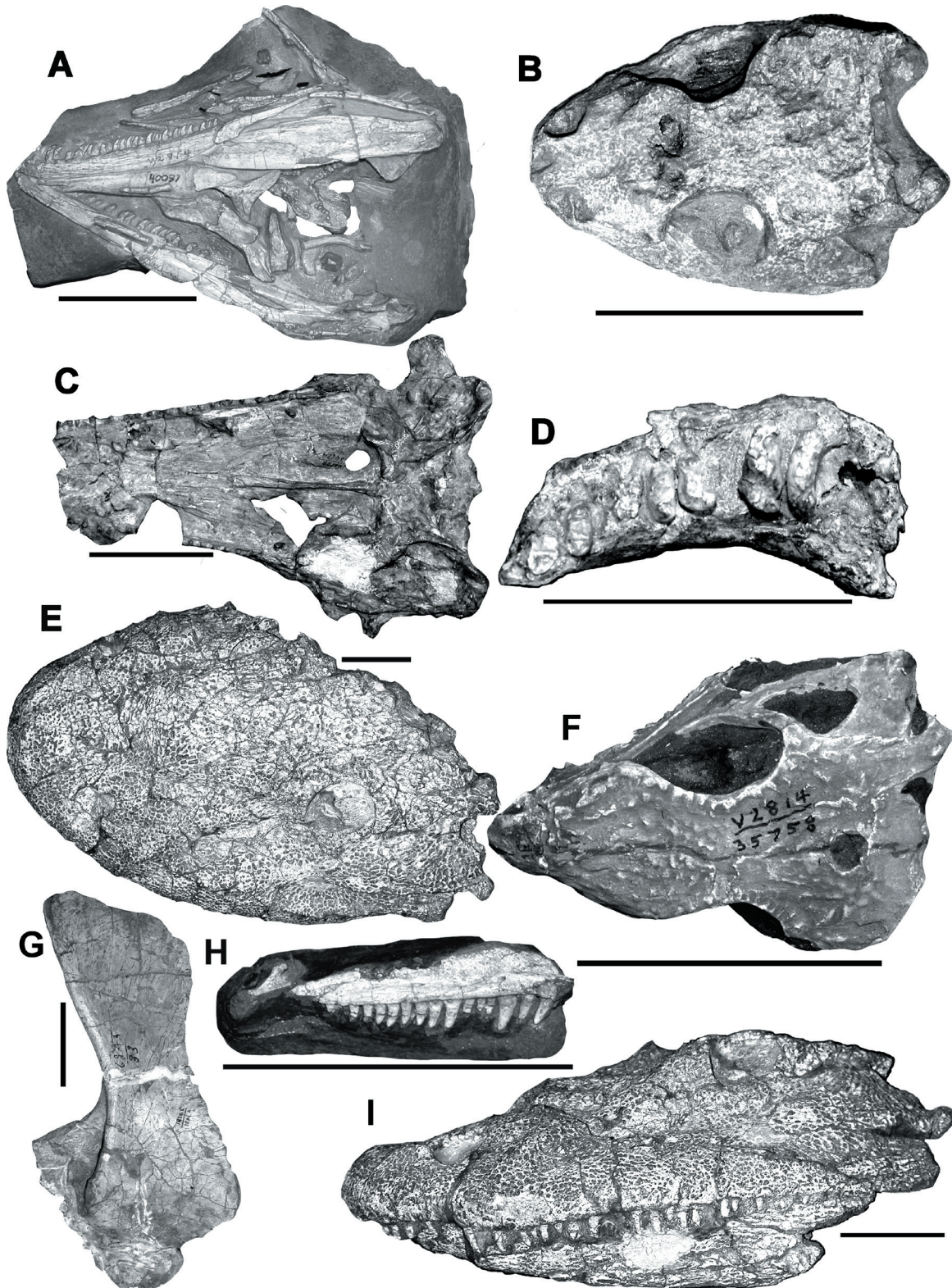


FIGURE 4. Selected fossil vertebrates from the various Arroyo del Agua quarries. **A.** Skull of the pelycosaur *Aerosaurus wellesi* (UCMP 40087) in ventral view, collected from the Camp quarry. **B.** Skull of the temnospondyl *Broiliellus novomexicanus* (UCMP 40103) in dorsal view, collected from the Camp quarry. **C.** Partial skull of the temnospondyl *Chenoprosopus milleri* (UCMP 34174) in ventral view, collected from the Welles quarry. **D.** Nearly complete dentary of the diadectomorph *Diadectes lentus* (UCMP 125584) in occlusal view, collected from the Anderson quarry. **E. I.** Partial skull of the temnospondyl *Eryops* sp. (CMNH 34906) in dorsal (**E**) and lateral (**I**) views, collected 1.6 km northwest of Arroyo de Agua, west side of Rio Puerco, CM locality 1070. **F.** Nearly complete skull of the pelycosaur *Oedaleops campi* (UCMP 35758) in dorsal view, collected from the Camp quarry. **G.** Complete left scapula of the temnospondyl *Eryops grandis* (UCMP 39181) in lateral view, collected from the Anderson quarry. **H.** Complete right maxilla of the pelycosaur *Oedaleops campi* (UCMP 35758) in lateral view, collected from the Camp quarry. All scale bars equal 5 cm.

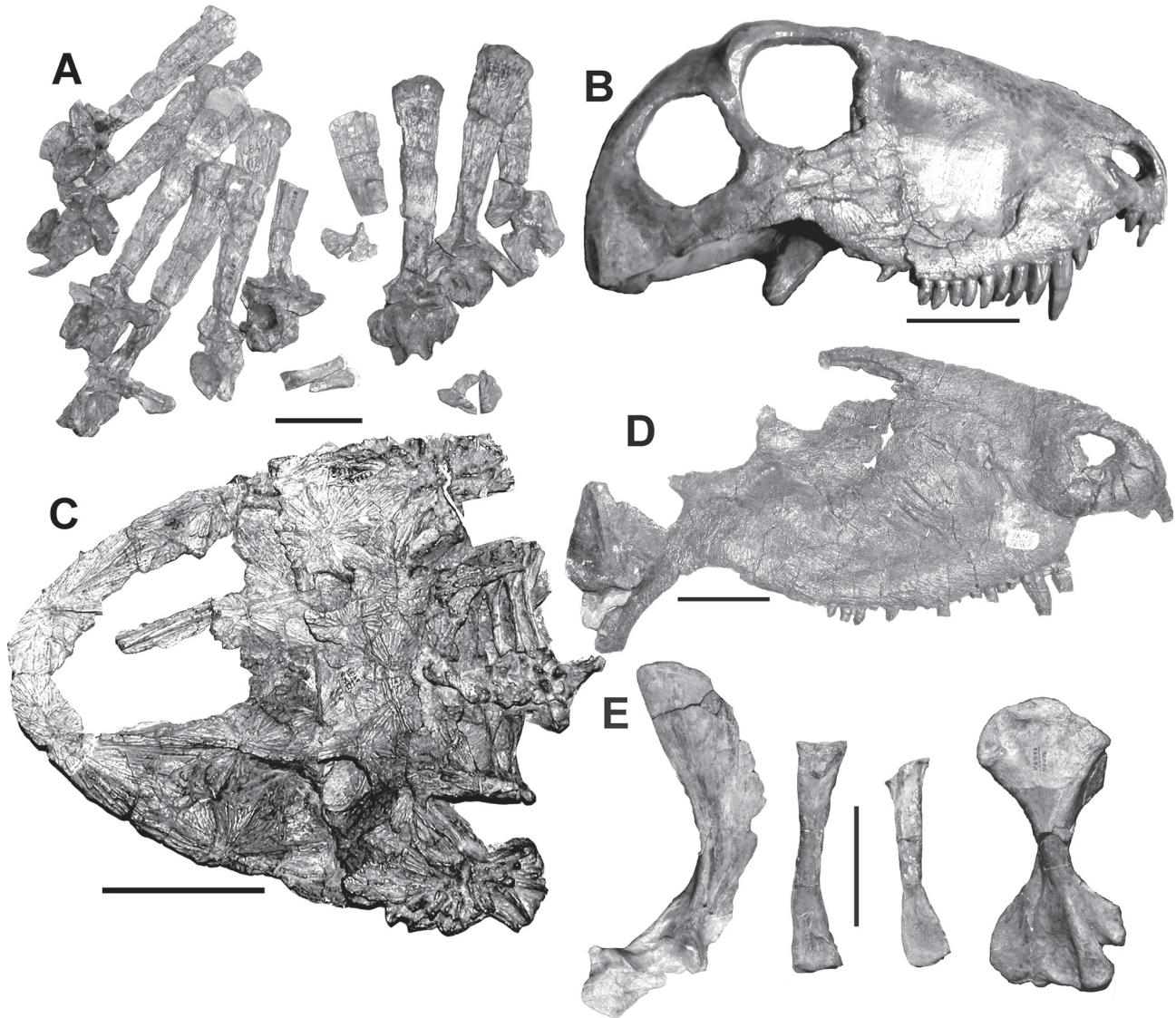


FIGURE 5. Selected fossil vertebrates from the various Arroyo del Agua quarries. **A.** Series of dorsal vertebrae in lateral view and associated fragments of *Sphenacodon* (UCMP 34218), collected from the Arroyo del Agua area. **B.** Reconstructed partial skull of the pelycosaur *Sphenacodon ferox* (UCMP 34226) in right lateral view, collected from the Quarry Butte locality. **C.** Nearly complete skull of the temnospondyl *Zatrachys serratus* (UCMP 34157) in dorsal view, collected from the Welles quarry. **D.** Partial skull of the pelycosaur *Sphenacodon ferocior* (UCMP 34196) in right lateral view, collected from the Anderson quarry. **E.** Associated right forelimb of the pelycosaur *Sphenacodon ferocior* (UCMP 40076), including from left to right, the scapula, radius, ulna and humerus, collected from the Anderson quarry. All scale bars equal 5 cm.

(Fig. 4F, H). Langston (1953) interpreted this deposit as a floodplain deposit, thus differing considerably from the other quarries. Berman et al. (1988) and Eberth and Miall (1991) interpret the strata at and around the Camp quarry as a complexly intercalated succession of crevasse splay and overbank suspension deposits that were deposited in relatively distal portions of the floodplain of an anastomosed river system.

Cardillo Quarry

The Cardillo quarry is in a reduced mudstone that is overlain by a fine-grained sandstone. The material collected from the quarry ranges from isolated elements to articulated skeletons.

The vertebrate assemblage of the quarry consists of the temnospondyl *Eryops* sp., an embolomere, the diadectomorph reptile *Diadectes* sp., an indeterminate captorhinid reptile and the pelycosaurian reptiles *Ophiacodon* sp., *Sphenacodon ferox* Marsh and a varanopseid. Berman (1993) interpreted the site as being a crevasse-splay or channel deposit, and we also identify it as a crevasse-splay deposit.

Morfin Bonebed

The Morfin bonebed lies geographically near the Baldwin and Miller bonebeds (Fig. 2). These sites are at approximately the same stratigraphic level as the VanderHoof quarry, Welles quarry,

Quarry Butte and Camp quarry. Lithologically, the bonebed exhibits a sequence of sandstone lenses and sheets with interbedded siltstones and mudstones. This is indicative of repeated cycles of shallow, ephemeral flow and deposition from suspension characteristic of a crevasse-splay deposit. Most elements recovered from this quarry are isolated, especially those from the underlying limestone-pebble conglomerate. However, articulated and associated elements, including skulls and large portions of the postcrania of the rare temnospondyl amphibian *Ecolsonia cutlerensis* Vaughn, are found in the sandy shale and siltstone (Berman et al., 1985).

Other Localities

Numerous articulated specimens have been collected from the valley floor immediately east of the Camp quarry. These include the dissorophid *Ecolsonia cutlerensis* Vaughn, the holotype of the microsauro *Stegotretus agyrus* Berman et al., the diadectomorph *Tseajaia* cf. *T. campi* Vaughn and the holotype of the araeoscelid *Zarcasaurus tanyderus* Brinkman et al. An incomplete skull of *Eryops* sp. (Fig. 4E, I) was collected 1 km northwest of Arroyo del Agua, and vertebrae of *Sphenacodon* (Fig. 5A) are from an unspecified site in the Arroyo del Agua area.

Another locality about 13 km northeast of Arroyo del Agua yielded six partial to complete specimens of *Seymouria sanjuanensis* Vaughn from sediments deposited in an overbank floodplain environment (Eberth and Berman, 1983; Berman et al., 1987). This locality, on the northern flank of the Rio Puerco north of Youngsville, is stratigraphically high in the Arroyo del Agua Formation, not in the underlying El Cobre Canyon Formation. Therefore, it is younger than all of the Arroyo del Agua quarries.

CORRELATION

Lucas (2002) proposed an informal tetrapod biochronology of the Permian, and the Lower Permian assemblage of the Arroyo del Agua region can be placed in this biochronological framework (Fig. 6). Thus, Lucas (2002) defined three vertebrate faunachrons based on the tetrapod assemblages of the Bowie and Wichita Groups of Texas: faunachron A equates to the lower Wolfcampian Markley and Archer City Formations; faunachron B equates to the upper Wolfcampian Nocona Formation and the lower Leonardian Petrolia Formation; and faunachron C equates to the middle Leonardian Waggoner Ranch/Lueders Formations.

When comparing these Texas vertebrate faunas to the vertebrate fauna of the Arroyo del Agua region, key genera appear in both, allowing for biostratigraphic correlation. The presence of numerous temnospondyls (especially *Eryops* and *Zatrachys*), few microsaurs and aistopods, anthracosaurs, the diadectomorph *Diadectes* and diverse pelycosauria suggests a correlation to faunachron A of Lucas (2002). Furthermore, *Chenoprosopus lewisi* from the Markley Formation described by Hook (1993) is of faunachron A age, and Reisz et al. (2005) believe it is a junior synonym of *C. milleri* known from the Arroyo del Agua quarries. These occurrences, and the absence of *Seymouria*, indicate the fossil localities in the El Cobre Canyon Formation near Arroyo del Agua are of faunachron

A age, which means they are correlative to the Bowie Group of Texas and are of early Wolfcampian age (Fig. 6).

A key tetrapod to Early Permian tetrapod biochronology is the seymouriamorph *Seymouria*, due to it being limited solely to faunachron B. Its presence at one locality north of Youngsville, in strata higher than the Arroyo del Agua bonebeds, indicates that the Arroyo del Agua Formation should be correlated to faunachron B of Lucas (2002).

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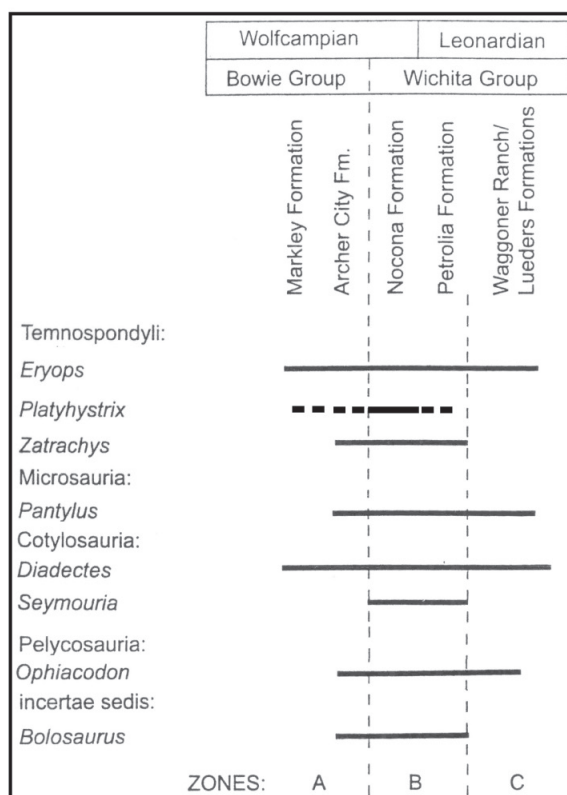


FIGURE 6. The biostratigraphic ranges of selected taxa from the Arroyo del Agua fauna in the Texas section (modified from Lucas, 2002).

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