

LITHOSTRATIGRAPHY, PALEONTOLOGY, BIOSTRATIGRAPHY,  
AND AGE OF THE UPPER PALEOZOIC ABO FORMATION NEAR  
JEMEZ SPRINGS, NORTHERN NEW MEXICO, USA

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## ABSTRACT

In the Jemez Springs area of Sandoval County, northern New Mexico, siliciclastic red beds of the upper Paleozoic Abo Formation are well exposed and yield fossil plants and vertebrates. The local Abo Formation section is more than 190 m thick and rests disconformably on the Upper Pennsylvanian Guadalupe Box Formation and is conformably overlain by the Lower Permian DeChelly Sandstone (Yeso Group). Abo sandstone sheets are low sinuosity river deposits, and intercalated sandstone beds and lenses represent sheet splays and minor channel fills that formed during overbank flooding. The dominant Abo lithofacies is mudstone, which represents floodplain deposits, many with calcareous paleosols. Fossils are present in three stratigraphic intervals of the lower to middle Abo Formation. All three intervals yield eupelycosaur-dominated vertebrate fossil assemblages of Coyotean age (Coyotean = late Virgilian-Wolfcampian on the North American provincial marine timescale; Lucas 2006). The lowest interval also yields the Spanish Queen Mine paleoflora of pteridosperms and conifers. Strata of the Guadalupe Box Formation disconformably below the Abo Formation contain late Virgilian fusulinids. We correlate the Abo Formation fossil assemblages in the Jemez Springs area to the Coyotean-age fossil assemblages in the upper part of the El Cobre Canyon Formation in the Arroyo del Agua area and in the Cañon del Cobre in the Chama basin of northern New Mexico. This suggests a middle Wolfcampian age for the Jemez Springs area fossil assemblages, an age very close to the Pennsylvanian-Permian boundary.

KEY WORDS: Coyotean, Early Permian, paleoflora, vertebrate fossils, Wolfcampian

## INTRODUCTION

In northern New Mexico the Jemez Mountains are an immense late Cenozoic volcanic edifice located on the western edge of the Rio Grande rift. This edifice separates the southeastern edge of the San Juan Basin to the west and southwest from the Chama River basin to the north (Fig. 1). Along the southern edge of the Jemez Mountains, the Jemez River and its tributaries are cut into bedrock canyons that expose sedimentary rocks as old as Mississippian (e.g., Wood and Northrop 1946; Woodward et al. 1977; Woodward 1987; Osburn et al. 2002; Kelley et al. 2003). Particularly well-exposed outcrops of the Lower Permian Abo Formation are present along the Jemez River south of Jemez Springs (Cañon de San Diego) and along the canyon of the Guadalupe River near Gilman. Fossil vertebrates were discovered in these Abo Formation red beds during the 1930s, and in the 1950s fossil plants were recognized at one locality south of Jemez Springs. During the last 80 years, the paleontology of the Abo Formation in the Jemez Springs area has been intermittently studied, most recently by field crews from the Carnegie Museum of Natural History and the New Mexico Museum of Natural History. Here, we synthesize the results of this research to provide documentation of the paleoflora and fossil vertebrate assemblages from the Abo Formation in the Jemez Springs area. We also place these fossil assemblages into a detailed lithostratigraphic framework and interpret the age and correlation of the Abo Formation in the vicinity of Jemez Springs.

## Institutional Abbreviations

<b>CM</b>	Carnegie Museum of Natural History, Pittsburgh, PA.
<b>MCZ</b>	Museum of Comparative Zoology, Harvard University, Cambridge, MA.
<b>NMMNH</b>	New Mexico Museum of Natural History, Albuquerque, NM.
<b>UCMP</b>	University of California Museum of Paleontology, Berkeley, CA.
<b>USGS</b>	U.S. Geological Survey, Washington, D.C.

<b>USNM</b>	National Museum of Natural History, Smithsonian Institution, Washington, D.C.
<b>WM</b>	Walker Museum, fossils now in collection of the Field Museum of Natural History, Chicago, IL.
<b>YPM</b>	Peabody Museum of Natural History, Yale University, New Haven, CT.

## HISTORY OF FOSSIL COLLECTING

Of the three principal Upper Pennsylvanian-Lower Permian vertebrate body fossil collecting areas in north-central New Mexico, the Jemez Springs area (sometimes referred to as the “Cañon [Canyon] de San Diego” locality) has received the least attention from vertebrate paleontologists. Whereas the Arroyo del Agua and Cañon del Cobre localities (Fig. 1) were originally collected in the late 1870s by David Baldwin, discovery of vertebrate fossils in the Jemez Springs area was not made until more than half a century later, in the 1930s.

In 1931, A.S. Romer of Harvard University reasoned that conditions of deposition similar to those of the nearby Arroyo del Agua locality might exist in the Abo Formation sediments of the Jemez Springs area (Fig. 2). Consequently, he prospected the walls of Cañon de San Diego and met with quick success, discovering numerous fossil vertebrate sites that yielded bones of pelycosaur and temnospondyls (Romer 1960). From one of these sites, Romer (1937) described the well-preserved partial skeleton of a new, large species of the eupelycosaur *Sphenacodon* Marsh, 1878, *S. ferocior*. Seven years later, unaware of Romer's brief, but productive trip to the Jemez Springs area, a field party from the University of California at Berkeley led by S.P. Welles also prospected the walls of Cañon de San Diego. They collected their most significant find, a partial embolomeres vertebral column described by Langston (1953a) as possibly pertaining to *Archeria* Case, 1918, from the same site that yielded *S. ferocior*, referred to as the Spanish Queen Mine locality (Berman 1993). Approximately 3 km north of this locality, and 90 m north of the copper mine itself, the University of California field party also discovered a fossil vertebrate site stratigraphically low in

the Abo section, which they named the Johnson locality, that yielded bones referable to small diadectids and “sphenacodonts” (Langston 1953a, 1953b; Berman and Reisz 1980; Berman 1993; Eberth and Berman 1993).

A hiatus of nearly four decades ensued before collecting in the Jemez Springs area began anew with field parties from the Carnegie Museum of Natural History under the direction of D. S. Berman from 1975 to 1978. Like Romer, the Carnegie Museum parties discovered multiple vertebrate fossil localities at various intervals in the lower part of the Abo Formation section. Their discovery of a partial, articulated sail and lower jaw elements of a new, small species of *Dimetrodon* Cope, 1878, *D. occidentalis*, marked the first recorded co-occurrence of the eupelycosaur genera *Dimetrodon* and *Sphenacodon* (Berman 1977). Another site, just north of the confluence of the Guadalupe and Jemez rivers, yielded a nearly complete skull and postcrania described by Berman and Reisz (1980) as a new species of *Trimerorhachis* Cope, 1878, *T. sandovalensis*. Additional finds of mostly isolated, though diagnostic, elements pertaining to *Xenacanthus* Beyrich, 1848, *Eryops* Cope, 1877, *Zatrachys* Cope, 1878, *Platyhystrix* Williston, 1911, *Diplocaulus* Cope, 1877, and *Diadectes* Cope, 1878, more than doubled the number of vertebrate taxa known from the Jemez Springs area (Berman and Reisz 1980; Berman 1993).

From 2003 through 2007, joint parties from the Carnegie Museum of Natural History and New Mexico Museum of Natural History revisited the known localities mentioned above in order to establish their stratigraphic context within the Abo Formation section near Jemez Springs. During the last decade, New Mexico Museum of Natural History field crews discovered several new sites from which small quantities of surface-collected fossils were recovered. At present, we are aware of 18 discrete vertebrate fossil localities in the Abo Formation in the Jemez Springs area that we can place into a detailed stratigraphic context (Fig. 2).

During the 1950s, Sergius Mamay and Ellis Yochelson, both of the U.S. Geological Survey, collected a small paleoflora at the Spanish Queen Mine, south of Jemez Springs (Fig. 2).

#### GEOLOGY AND STRATIGRAPHIC CONTEXT

In the Jemez Springs area the Abo Formation is extensively exposed along canyon walls, terraces, and tributary arroyos of the Jemez and Guadalupe rivers (Fig. 3). We measured eight stratigraphic sections in the Abo Formation in the Jemez Springs area to establish the stratigraphic distribution of the 18 vertebrate fossil localities and the one fossil plant locality that we can locate in the local Abo section (Fig. 4; Appendices 1–2).

Along the Jemez River, the maximum measured thickness of the Abo Formation is 190 m, but the base of the Abo Formation is not exposed south of Jemez Springs.

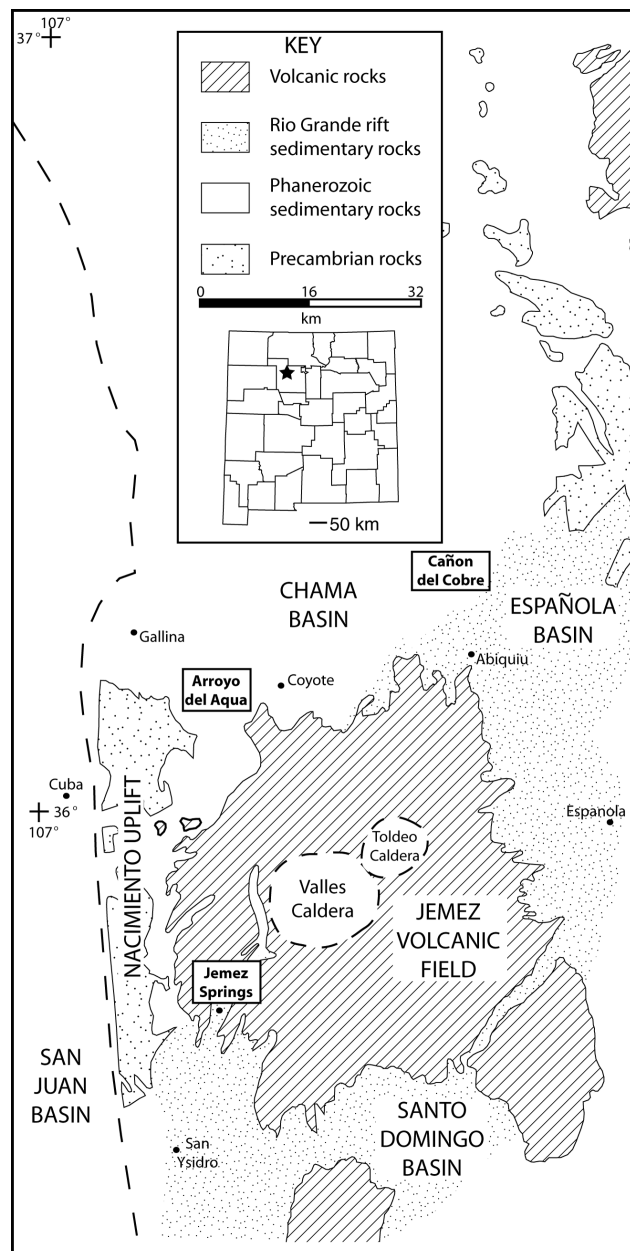


Fig 1.—Index map of northern New Mexico showing location of principal Pennsylvanian-Permian fossil collecting areas in Chama River basin (Cañon del Cobre, Arroyo del Agua) and in Jemez Springs area. Modified from Woodward (1974).

The Abo red beds along the Jemez River are overlain by eolian sandstone of the DeChelly Sandstone of the Yeso Group (formerly called the “Meseta Blanca Sandstone Member of the Yeso Formation.” Lucas et al. 2005a). Along the Guadalupe River at Gilman, the Abo Formation is completely exposed. Here the measured thickness is 131 m, and the Abo Formation is underlain by the Upper Pennsylvanian Guadalupe Box Formation (Krainer et al. 2005) and overlain by a few meters of Yeso Group red beds and

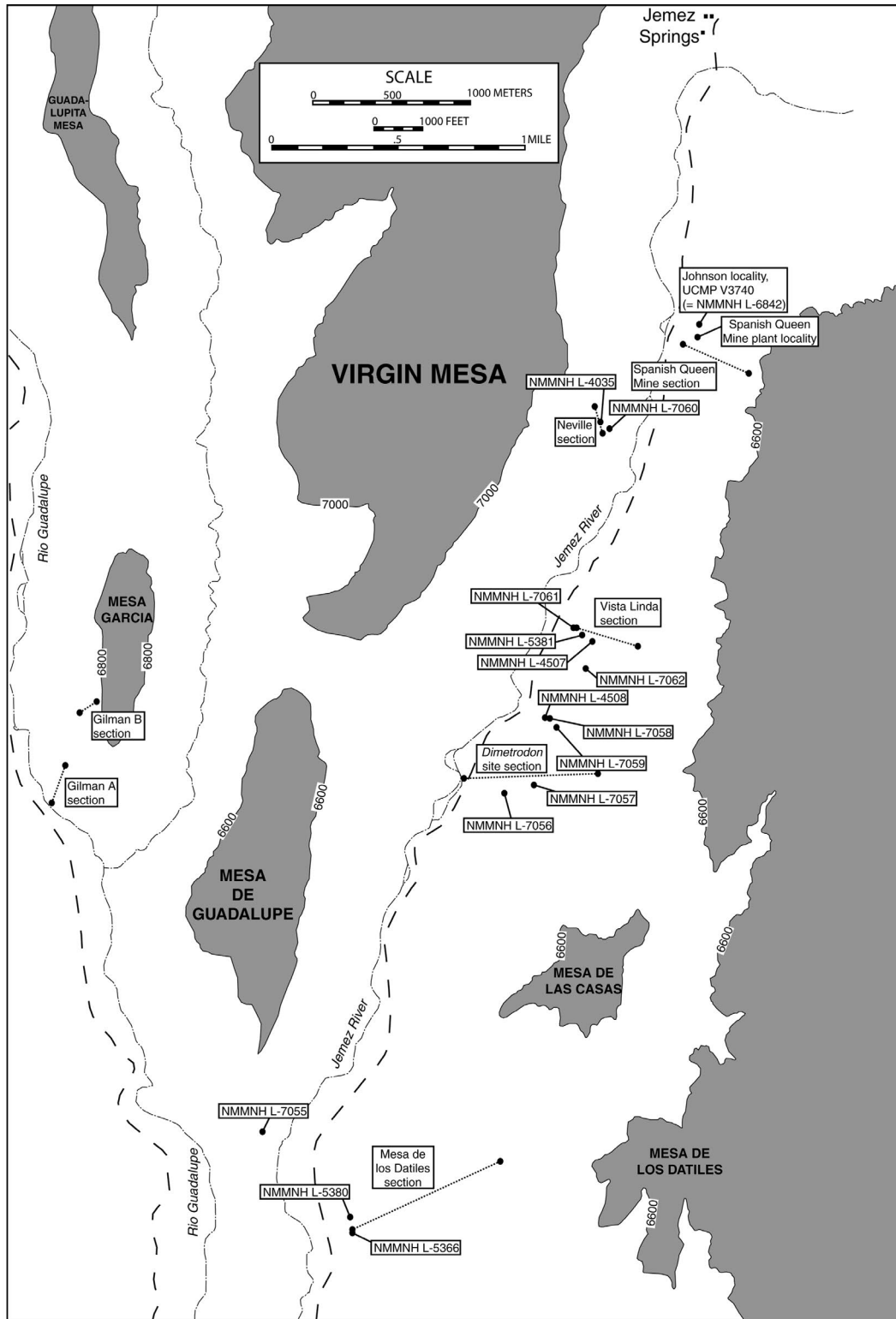


Fig. 2.—Map of the Jemez Springs area showing fossil localities and locations of measured stratigraphic sections in the Abo Formation. Precise map coordinates for all fossil localities are on file at the CM, NMMNH, and USNM.

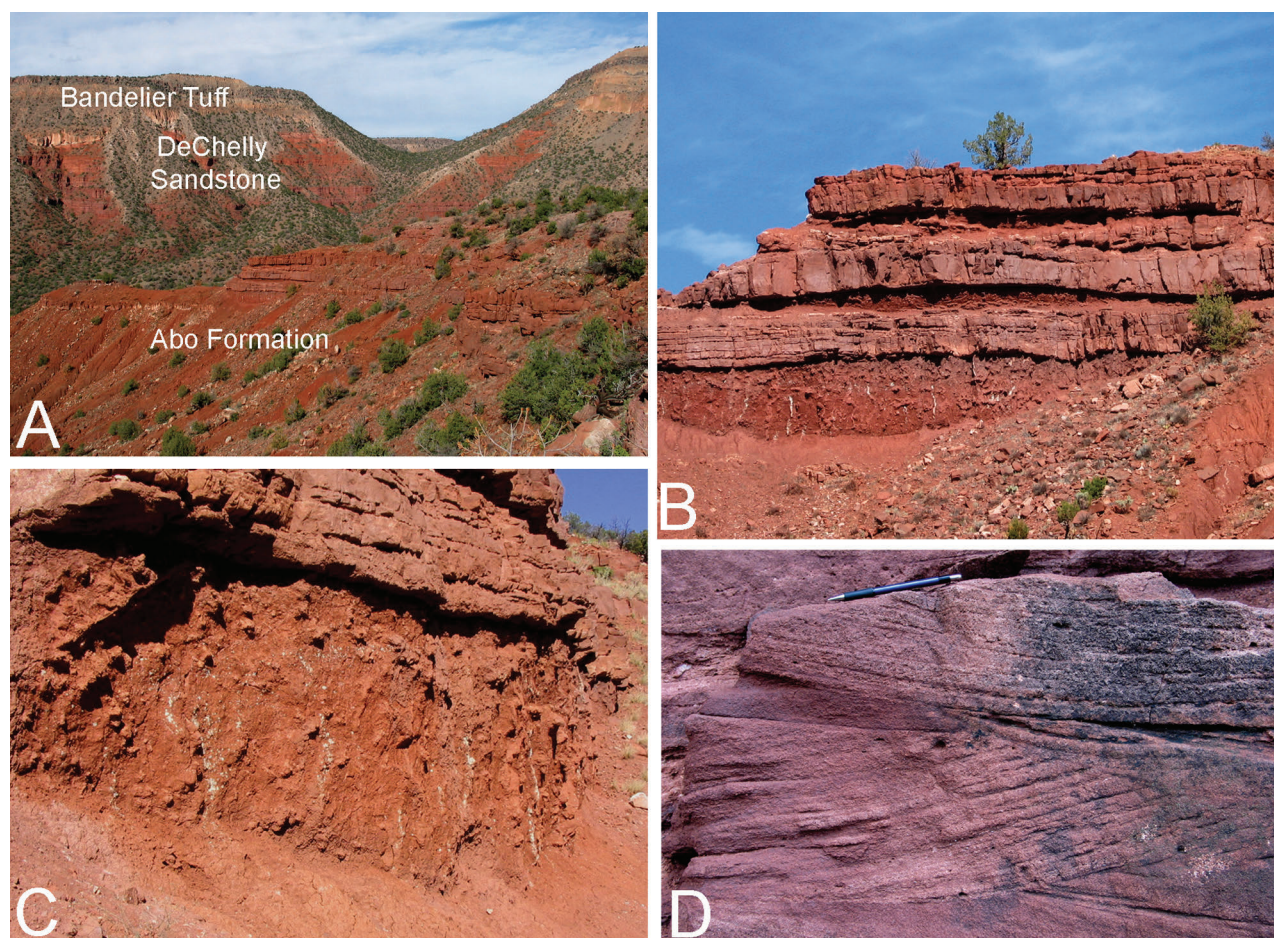


Fig. 3.—Photographs of selected Abo Formation outcrops in the Jemez Springs area. **A**, view looking west from *Dimetrodon* site section. The saddle on the skyline is between Mesa de Guadalupe (on the left) and Virgin Mesa (on the right). Both mesas are capped by Pleistocene Bandelier Tuff overlying cliff- and ledge-forming sandstone beds of the Lower Permian DeChelly Sandstone (Yeso Group) above slopes of Abo Formation. **B**, characteristic sheet sandstone of Abo Formation in *Dimetrodon* site section. **C**, calcrete nodules and rhizoliths in Abo Formation mudstone. **D**, trough crossbedded, pebbly sandstone of Abo Formation.

lower Pleistocene Bandelier Tuff (Fig. 4).

Throughout the Jemez Springs area, the Abo Formation can be divided into lower and upper members (Fig. 4). The lower member is dominated by mudstone and siltstone that constitute 69–72% of the Abo section. In the upper member, mudstone and siltstone constitute much less (25–41%) of the Abo section. The thickness of the lower member is variable, at least 115 m thick along the Jemez River and about 90 m thick at Gilman, whereas the upper member is more uniform and about 60 m thick along the Jemez River and at Gilman. These members probably are homotaxial to the Scholle Member (lower) and Cañon de Espinosa Member (upper) of the Abo type section in central New Mexico (Lucas et al. 2005a).

Fossil localities in the Abo Formation in the Jemez Springs area can be assigned to three stratigraphic intervals (Fig. 4):

1. Assemblage A is the lowest stratigraphic interval,

at least 20 m above the local base of the Abo Formation. It encompasses the UCMP Johnson locality, the USNM Spanish Queen Mine locality, and NMMNH Locality 7661.

2. Assemblage B consists of two NMMNH vertebrate fossil localities (4507 and 5381) at least 40 m above the base of the local Abo section (Fig. 4).

3. Assemblage C encompasses most of the Abo Formation vertebrate fossil localities in the Jemez Springs area (CM localities: 999, 1000 [= NMMNH Locality 7056], 1001 [= NMMNH Locality 5380], 1002 [= NMMNH Locality 7055], 1003, 4047, 4048, 4049, 4050; NMMNH localities: 4035, 4508, 5366, 7057, 7060, 7061, 7062; YPM lungfish locality) and is from an ~30-m-thick interval that begins about 90 m above the base of the local Abo section (Fig. 4). In other words, it is in about the middle of the local Abo section and straddles the boundary between the lower and upper members of the Abo Formation.

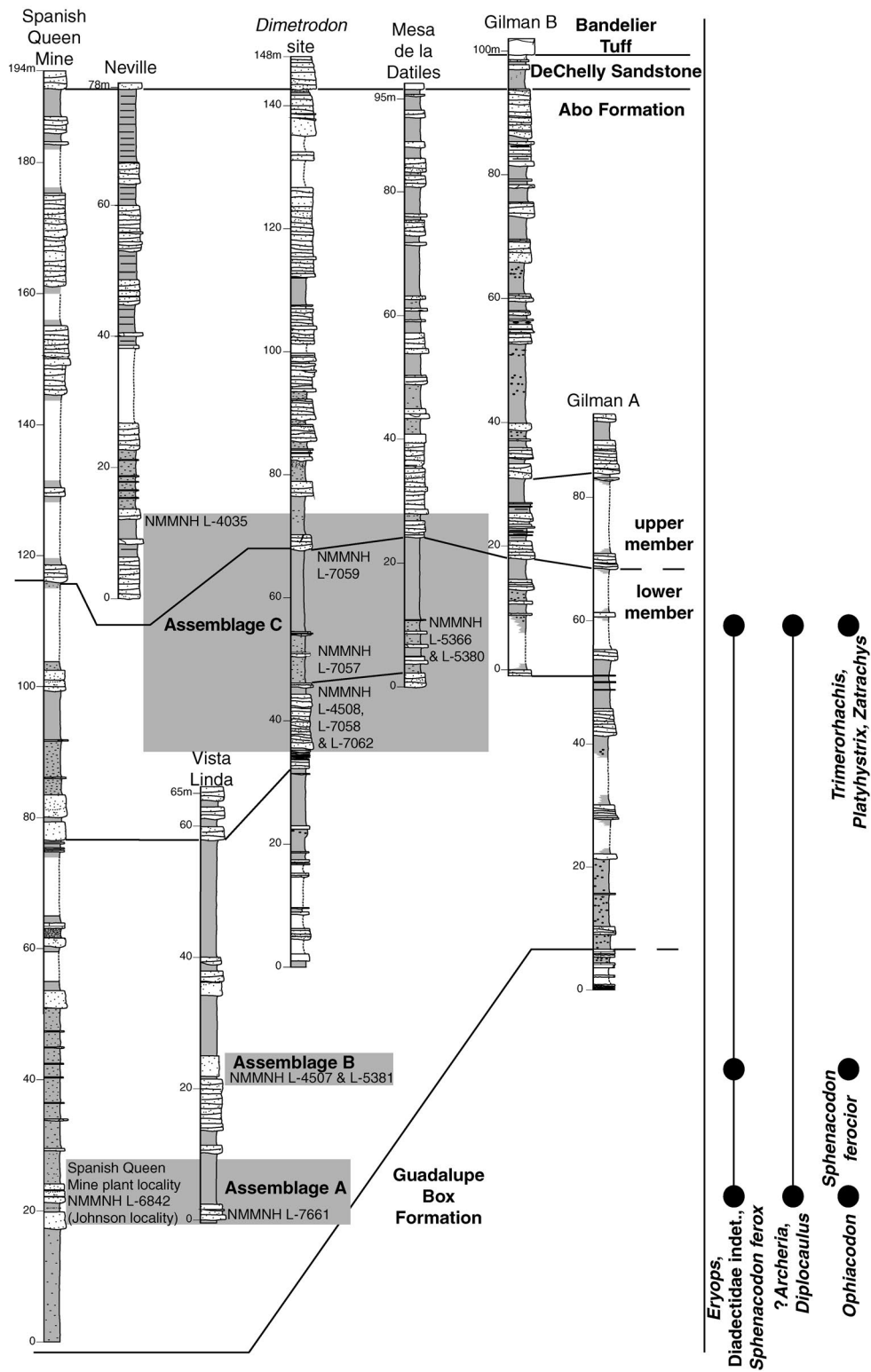


Fig. 4.—Measured stratigraphic sections of the Abo Formation in the Jemez Springs area showing stratigraphic distribution of fossil localities. See Appendix 1 for map coordinates of the measured sections and Appendix 2 for a list of fossil localities and taxa.

Romer's (1937, 1960) term "Spanish Queen Mine locality" does not indicate the same stratigraphic level as the actual mine, which is the site of the fossil plant collection. Romer used the nearest distinctive geographic place name for the collections he made, which, in this instance, were not right at the mine (Langston 1953b; Berman 1993; Hunt and Lucas 1996). Indeed, Langston (1953b: fig. 4) located the Spanish Queen Mine (vertebrate) locality (presumably based on information provided to him by Romer) about 3 km south-southwest of the Johnson locality in the vicinity of our *Dimetrodon* site section (Fig. 2). As this is the most fossiliferous Abo outcrop area, with most of the localities relatively high stratigraphically, in our assemblage C, we conclude that Romer's collections came from the stratigraphic level of assemblage C.

Note that assemblages A and B encompass only a few localities over a short stratigraphic interval (Fig. 4). So, they could be combined to form one assemblage. However, we recognize three stratigraphically-separated fossil assemblages in the Abo Formation in the Jemez Springs area, simply because this is the most precise way to depict the distribution of fossils in the section.

Loeff (1987), Eberth and Miall (1991), Eberth and Berman (1993), and Krainer and Lucas (2010) studied the sedimentology of the Abo Formation in the Jemez Springs area. Krainer and Lucas (2010) concluded that sandstone sheets in the Abo were deposited by low sinuosity river channels. More lenticular sandstone beds represent minor channel fills and crevasse splay deposits. Most of the Abo Formation in the Jemez Springs area consists of mudstone. Many mudstone beds contain calcrete nodules and rhizoliths (e.g., Fig. 3C) indicative of the development of calcareous paleosols. The mudstone lithofacies of the Abo Formation is interpreted as floodplain deposits. No pond or lake deposits have been identified in the Abo Formation in the Jemez Springs area.

According to Miall (1985, 1992, 1996), architectural elements of depositional systems are characterized by a distinctive facies assemblage, internal geometry, external form and, partly, by a distinct vertical profile. Each type represents a particular process occurring within a depositional system. Within the Abo Formation, Krainer and Lucas (2010) identified three architectural elements—sandstone sheets, intercalated sandstone beds and lenses, and siltstone-mudstone.

The most characteristic and distinct facies assemblages in the Abo Formation are sandstone sheets (e.g., Fig. 3B), which correspond to the architectural element CH (channel). Sandstone sheets are characterized by width-to-depth ratios greater than 15:1, whereas sandstone ribbons also corresponding to the element CH, have ratios smaller than 15:1. Within the Abo Formation in the Jemez Springs area, sandstone sheets form prominent, resistant ledges that can be traced laterally over long distances (commonly more than 100 m, up to several hundred meters). The base of any given sandstone body is generally erosive. Sublithofacies within the sandstone bodies commonly show an up-

ward decrease in bed thickness and grain size. Common lithofacies are clast-supported conglomerates at the base, grading into multistoried, trough-crossbedded sandstone, which in the upper part may be associated with horizontally laminated, massive, low-angle crossbedded or trough-crossbedded sandstone (e.g., Fig. 3D). Sometimes in the uppermost part of the fine-grained sandstone, the strata are bioturbated, and synsedimentary deformation structures are rarely observed. Sandstone ribbons have not been observed at Jemez Springs Abo Formation outcrops, suggesting that such channelized deposits were rare in this area (Eberth and Miall 1991; Eberth and Berman 1993).

The abundance of internal scours and erosional surfaces, presence of conglomeratic lags at the base, variation in grain size, and poorly- to well-developed fining-upward sequences are indicative of ephemeral fluvial regimes (e.g., Picard and High 1973; Tunbridge 1981, 1984; Miall 1996). Sheet sandstones are interpreted as deposits of broad, shallow channels of a probable braided river system. The lack of lateral accretion deposits indicates that the channels were shallow, so that large macroform bars could not develop. The sandstone sheets are very similar to the "major sandstone sheets" of the Cutler Group described in detail by Eberth and Miall (1991). These authors compared the sheet sandstones to those of the modern Platte River (model 9 of Miall 1985).

In the Abo Formation near Jemez Springs, thin intercalated sandstone beds and lenses are mostly 10 to 30 cm, rarely up to 50 cm thick. They occur as single sandstone beds that are laminated, massive, or crossbedded. Stacked sandstone units are up to 1 m thick. The sandstone beds occur as tabular or lens-shaped bodies; their bases may be erosive. Rarely, sandstone sheets are bioturbated. This architectural element is similar to the "minor sandstone sheets and lenses" that Eberth and Miall (1991) described from the Cutler Group red beds in the Chama basin to the north.

Intercalated, laterally-restricted sheet sands and lenses are characteristic of overbank flooding, particularly in ephemeral systems (e.g., Williams 1971; Picard and High 1973; Tunbridge 1981). The tabular sandstone beds are probably sheet splays. Basal erosional surfaces with mudstone rip-up clasts and reworked pedogenic carbonate clasts indicate high-energy transport. Lack of internal erosion and reactivation surfaces within the intercalated sandstone beds is typical of sheet flow. Sandstone lenses represent minor channel fills and may represent the feeder channels (crevasse channels) of the sheet splays.

Siltstone and mudstone units are the dominant lithofacies of the Abo Formation in the Jemez Springs area, occurring as massive or laminated beds, some with desiccation cracks and/or rhizoliths. A few pedogenic carbonate nodular zones are present. The siltstone-mudstone facies that forms sheet-like units extending laterally over at least hundreds of meters belongs to element FF (floodplain fine) of Miall (1996) and is interpreted as floodplain deposits formed by settling from sheetfloods. The presence of

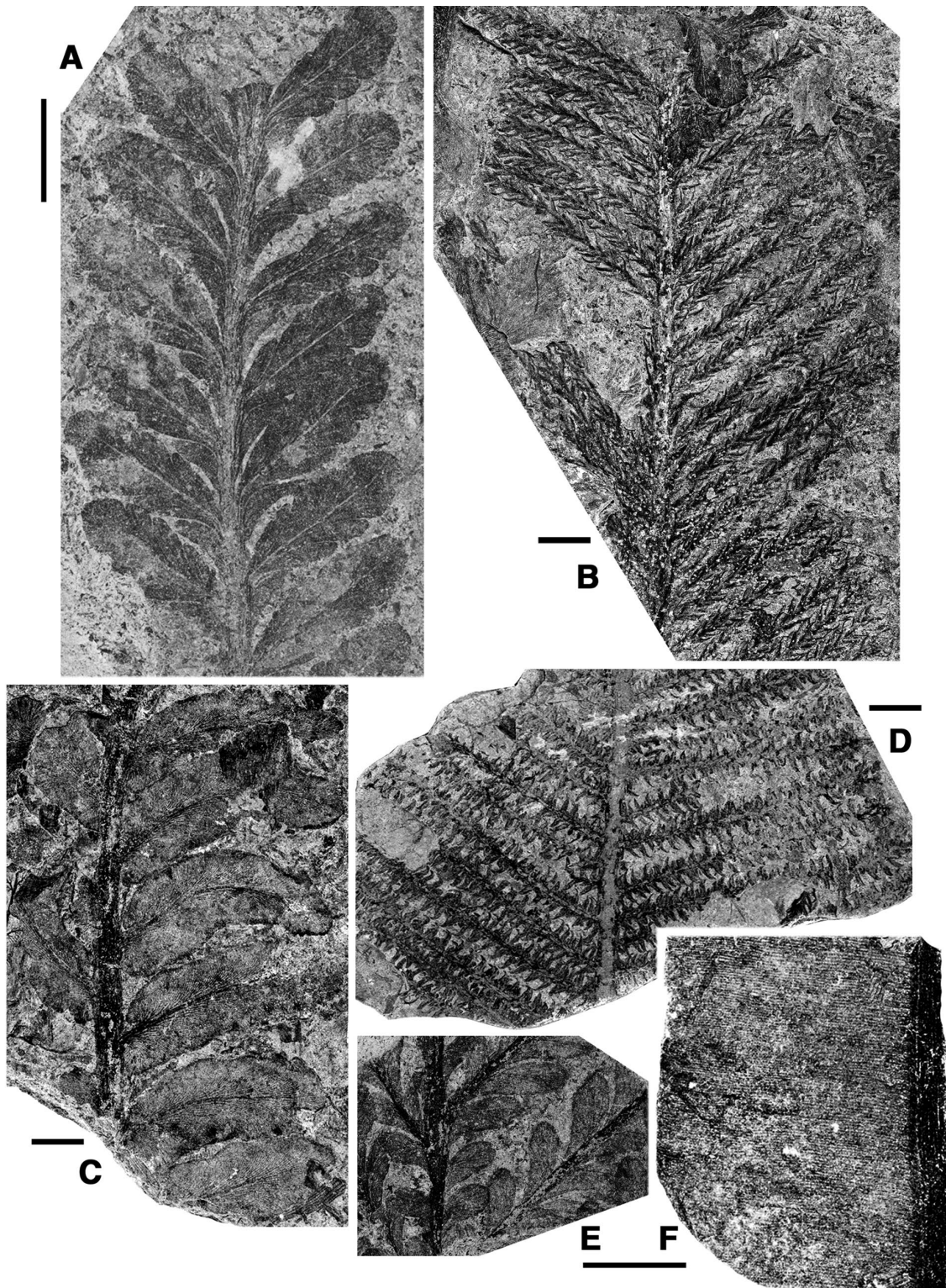


Fig. 5.—Selected fossil plants from the Spanish Queen Mine paleoflora. **A**, *Autunia naumanii*, USNM 539289, nearly complete pinna. **B**, *Walchia piniformis*, USNM 539299, branch fragment. **C**, *Neurodopteris auriculata*, USNM 538957, pinna fragment. **D**, *Ernestiodendron filiciforme*, USNM 539292, branch fragment. **E**, *Rhachiphyllum schenkii*, USNM 539314, frond segment with several partial pinnae. Note flatness of pinnule laminae, which contrasts with *Autunia conferta*, wherein the laminae are vaulted and much more robust. **F**, *Taeniopteris* sp., USNM 539308, one-half of lamina showing midrib on right side. Scale bars = 1 cm.



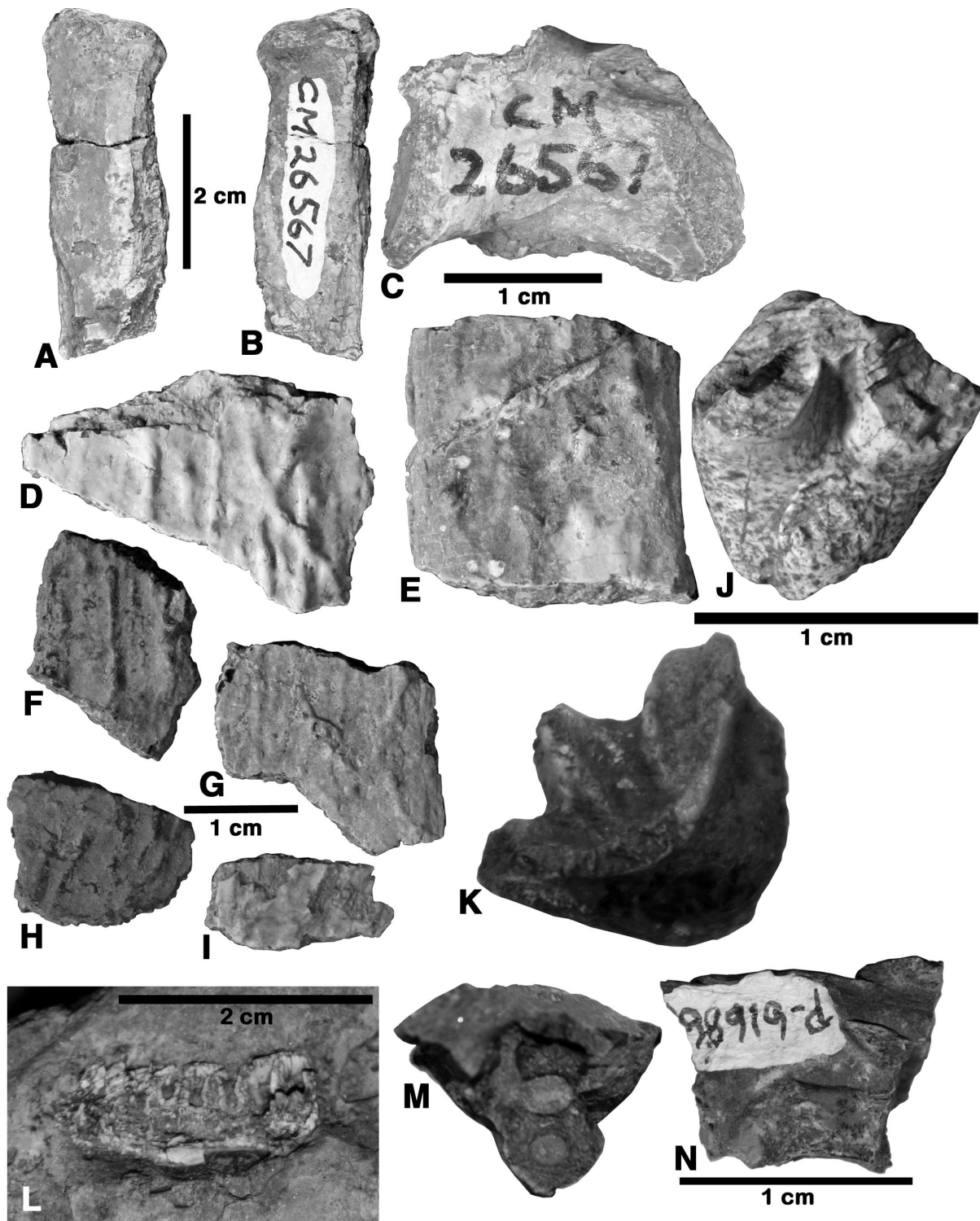


Fig. 6.—*Xenacanthus*, *Gnathorhiza*, *Eryops*, *Diplocaulus*, and *Platyhystrix* from the Abo Formation in the Jemez Springs area. A-C, *Eryops* sp., CM 26567, A-B, neural spine in lateral views and C, intercentrum, from NMMNH Locality 7056. D-I, *Platyhystrix* sp., CM 38029, neural spine fragments, from CM Locality 5, in lateral view. J, *Xenacanthus* sp., CM 38026, tooth base, from CM Locality 1, in apical view. K, *Gnathorhiza* sp., YPM 8636, tooth plate, from “east of highway 4 and south of Jemez Springs,” in occlusal view (photograph courtesy of Chris Norris). L, Diadectidae, NMMNH P-51876, partial maxilla, from NMMNH Locality 6842, in lateral view. M-N, *Diplocaulus* sp., NMMNH P-61686, vertebra, from NMMNH Locality 6842, in M, anterior and N, lateral views. Scale bars: A-B, upper left; C-E, upper right; F-I, middle left; J-K, middle right; L, lower left; and M-N, lower right.

**TABLE 1.** Plant taxa from the Spanish Queen Mine paleoflora.

Sphenopsids:	<i>Annularia spicata</i> <i>Calamostachys spicata</i>
Ferns:	<i>Asterotheca</i> sp. <i>Polymorphopteris</i> sp. <i>Pecopteris bredovii</i>
Pteridosperms:	<i>Alethopteris schneideri</i> <i>Callipteridium gigas</i> <i>Neurodopteris auriculata</i>
Callipterids:	<i>Autunia naumanii</i> <i>Dichophyllum flabellifera</i> <i>Dichophyllum moorei</i> <i>Rhachiphyllum schenkii</i>
Conifers:	<i>Culmitzschia/Lebachia speciosa</i> <i>Ernestiodendron filiciforme</i> <i>Walchia piniformis</i> <i>Gomphostrobus bifidus</i>
Incertae sedis:	<i>Taeniopteris</i> sp.

lamination indicates deposition from suspension. However, stratification is mostly absent, probably due to the presence of organisms (bioturbation or pedoturbation). Desiccation cracks, particularly in the finer-grained facies, indicate periodic drying. A strong seasonal moisture regime with a period of high evapo-transpiration facilitated the formation of calcic paleosols.

The average petrographic composition of the Abo Formation at the Jemez River and Gilman is very similar to that of the Cutler Group at Cañon del Cobre and Arroyo del Agua in the Chama basin to the north (Krainer and Lucas 2010). Sandstones are dominantly arkoses and lithic arenites, subordinately subarkoses. The main source rock type is granite, from which the majority of mono- and polycrystalline quartz, almost all detrital feldspars and micas, and all granitic rock fragments were derived. Metamorphic rocks provided a few mono- and polycrystalline quartz, and metamorphic rock fragments. Most sedimentary rock fragments were derived from the reworking of pedogenic carbonate; subordinately, reworked mudstone and siltstone grains are present. Sandstone is commonly cemented by coarse, blocky calcite; quartz cement may also be present.

#### PALEOBOTANY-FLORA OF THE SPANISH QUEEN MINE LOCALITY

The Spanish Queen Mine fossil plant locality (USGS Locality 8936 and USNM Locality 43566) is at a long-closed copper mine located approximately 2 km southwest of Jemez Springs (Read and Mamay 1964), on the eastern side of the Cañon de San Diego, through which the Jemez

River flows (Fig. 2). Fossil plants collected from this mine (Fig. 5) by Mamay and Yochelson are in the USNM collection and have not previously been documented. They occur in light to medium gray, micaceous sediment that grades from siltstone to fine sandstone. Plant fossil remains range from large portions of fronds to organic hash, the latter being abundant. The siltstone contains mm-scale laminations with occasional thicker lenses. Organic remains are found on most bedding surfaces. Preservation detail is good, but the cuticle appears to be preserved only on the most robust remains, such as conifer foliage.

The late S. Mamay (personal communication to W. DiMichele 1995) reported that the fossil plant collection from the Spanish Queen Mine came from inside one of the larger mine adits and was taken either directly from the roof or from roof falls not far from the adit entrance. Over the intervening years, the adits have become inaccessible, making it impossible to relocate the exact spot from which the fossil plant collection was made. However, fossil-plant-bearing siltstones of the same character as those collected by Mamay and Yochelson are present in the strata observable in the rock faces between the old adits. Thus, the fossil-plant-bearing beds occur within a widespread sandstone body, up to 4 m thick, consisting of scours and lenses of finely laminated micaceous siltstone. The organic-rich laminated beds are tens of cms thick and appear to represent bars within a braided stream channel system. The large amount of highly comminuted plant remains indicates some degree of destruction of plant material either by grinding in bed load or by the sweeping of partially decayed material by runoff from the paleosol surfaces surrounding the active channel (e.g., Gastaldo 1991).

The elements of the paleoflora are summarized in Table 1. The most abundant of these elements, based on an assessment of this small collection, are the pteridosperm *Neurodopteris auriculata* Potonié, 1893, callipterids, particularly *Autunia naumanii* (Gutbier) Schimper, 1869, and conifers, particularly *Culmitzschia/Lebachia speciosa* (Florin) Clenent-Westerhof, 1984. Several taxa are present in low numbers but are common enough to be present consistently throughout the collection, including *Rhachiphyllum schenkii* (Heyer) Kerp, 1988, *Ernestiodendron filiciforme* (Sternberg) Florin, 1934, and laminae of several different sizes of *Taeniopteris* Brongniart, 1828. Lower vascular plants, the sphenopsids and ferns, are exceedingly rare, represented only by small numbers of fragmentary specimens.

#### VERTEBRATE PALEONTOLOGY

We provide a comprehensive review of the vertebrate fossils collected from the Abo Formation in the Jemez Springs area. Taxa discussed include a chondrichthyan, a dipnoan, four temnospondyl amphibian taxa, an anthracosaur, a neotridean, a diadectomorph, and four eupelycosaur taxa.

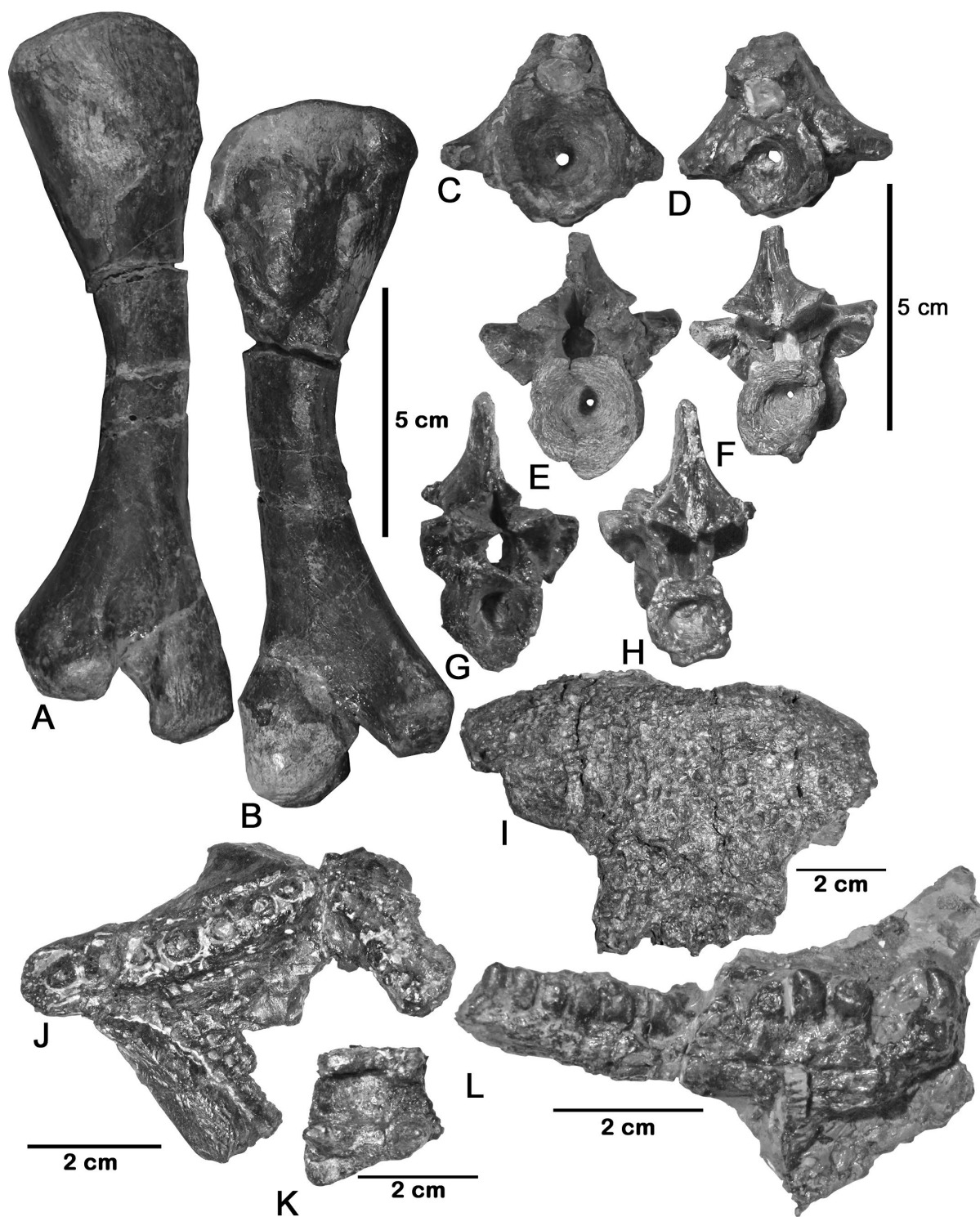


Fig. 7.—UCMP Johnson locality (UCMP Locality V3740) specimens from the Abo Formation of the Jemez Springs area. A-B, UCMP 195504, Sphenacodontidae indet., right femur in A, dorsal and B, ventral views. C-H, *Ophiacodon* sp., three dorsal vertebrae in C (UCMP 195505), E (UCMP 195506), G (UCMP 195507), anterior and D (UCMP 195505), F (UCMP 195506), H (UCMP 195507), posterior views. I-K, *Eryops* sp., I, UCMP 195508, ornamented dermal bone, J, UCMP 195509, partial palate with teeth, K, UCMP 195510, premaxilla with two large teeth. L, UCMP 195511, Diadectidae indet., right mandible in lateral view. Photographs courtesy of P. Holroyd.

SYSTEMATIC PALEONTOLOGY  
 Class Chondrichthyes Huxley, 1880  
 Order Elasmobranchii Bonaparte, 1838  
*Xenacanthus* Beyrich, 1848

*Xenacanthus* sp.  
 (Fig. 6J)

**Referred specimen.**—From CM Locality 999: CM 38026, tooth (Fig. 6J).

**Discussion.**—A single, incomplete tooth with both crowns broken off is referable to the freshwater shark *Xenacanthus* (Berman and Reisz 1980; Berman 1993).

Class Osteichthyes Huxley, 1880  
 Order Dipnoi Müller, 1844  
*Gnathorhiza* Cope, 1883

*Gnathorhiza* sp.  
 (Fig. 6K)

**Referred specimens.**—From a locality east of the highway and south of Jemez Springs in Cañon de San Diego: YPM 8636 (Fig. 6K), 8637, tooth plates.

**Discussion.**—Two tooth plates of the aestivating lungfish *Gnathorhiza* were collected from a locality in Cañon de San Diego by M. Fraccasso and S.G. Lucas while students at Yale University (Berman and Reisz 1980; Berman 1993).

Class Amphibia Linnaeus, 1758  
 Order Temnospondyli Zittel, 1888  
 Family Eryopidae Cope, 1882  
*Eryops* Cope, 1877

*Eryops* sp.  
 (Figs. 6A–C, 7I–K, 8A–F)

**Referred specimens.**—From CM Locality 1000: CM 26567, vertebral intercentrum and neural spine (Figs. 6A–C) and CM 86177, jaw fragments. From CM Locality 4048: CM 86170, neural spine. From NMMNH Locality 4507: NMMNH P-32230, vertebral intercentrum (Figs. 8C–D). From NMMNH Locality 5381: NMMNH P-61641, vertebral intercentrum (Figs. 8A–B). From NMMNH Locality 7062: NMMNH P-61672, vertebral pleuracentrum (Figs. 8E–F). From the Johnson locality, UCMP Locality V3740: UCMP 195508, ornamented dermal bone (Fig. 7I); UCMP 195509, partial palate with teeth (Fig. 7J); and UCMP 195510, premaxilla with two large teeth (Fig. 7K). From Spanish Queen Mine locality, UCMP V3855: UCMP 39179, small, fragmentary skull.

**Discussion.**—Prior to this article, only one specimen, a single vertebral intercentrum and neural spine (Figs. 6A–C), from CM Locality 1000, had been identified with confidence as pertaining to the semi-terrestrial eryopid

*Eryops* (Berman and Reisz 1980). Further, Berman and Reisz noted the probable assignment of isolated rhachitinous vertebrae collected in 1938 from the Johnson locality by the University of California (Langston 1953b) to the genus *Eryops*. Additional temnospondyl amphibian material recovered from the Johnson locality (UCMP Locality V3740) in the UCMP collection that we assign to *Eryops* includes a partial palate with teeth (Fig. 7J), a premaxilla with two large teeth (Fig. 7K), and dermal bone with pit-and-ridge ornamentation (Fig. 7I).

Three additional sites (NMMNH L-5381, 4507, and 7062) in Cañon de San Diego have yielded single, isolated rhachitinous vertebral elements possibly pertaining to *Eryops* (Figs. 8A–F). Langston (1953b) collected a small, poorly preserved amphibian skull (UCMP 39179) from the Spanish Queen Mine vertebrate locality (UCMP V3855) in the same matrix block from which he recovered articulated, embolomeric vertebrae possibly pertaining to *Archieria* (see below). Although Langston (1953b:377) noted the skull has “no particularly diagnostic characters,” he provisionally assigned it to *Eryops grandis* (Marsh, 1878), based on the marginal and palatal teeth.

Family Trimerorhachidae Cope, 1878  
*Trimerorhachis* Cope, 1878

*Trimerorhachis sandovalensis* Berman and Reisz, 1980

**Referred specimens.**—From CM Locality 1001: CM 38027, partial skull with postcranial elements. From CM Locality 1002: CM 38025, holotype, partial articulated skeleton (Berman and Reisz 1980: figs. 1–8).

**Discussion.**—Berman and Reisz (1980) described a new trimerorhachid species, *Trimerorhachis sandovalensis*, based on a nearly complete skull and large portion of an articulated postcranial skeleton. The specimen was preserved on three separate matrix blocks collected from a thick sequence of light red mudstones directly surrounded by poorly consolidated, coarse-grained, light gray sediments of a very small stream channel lens.

Superfamily Dissorophoidea Bolt, 1969  
 Family Dissorophidae Boulenger, 1902  
*Platyhystrix* Williston, 1911

*Platyhystrix* sp.  
 (Figs. 6D–I)

**Referred specimens.**—From CM Locality 1003: CM 38029, neural spine fragments (Figs. 6D–I).

**Discussion.**—Several neural spine fragments of the dissorophid *Platyhystrix* were recovered from a single locality in the Jemez Springs area. The distinctive, pustulose patterning along the neural spines identifies them as *Platyhystrix* (Berman and Reisz 1980; Berman 1993).

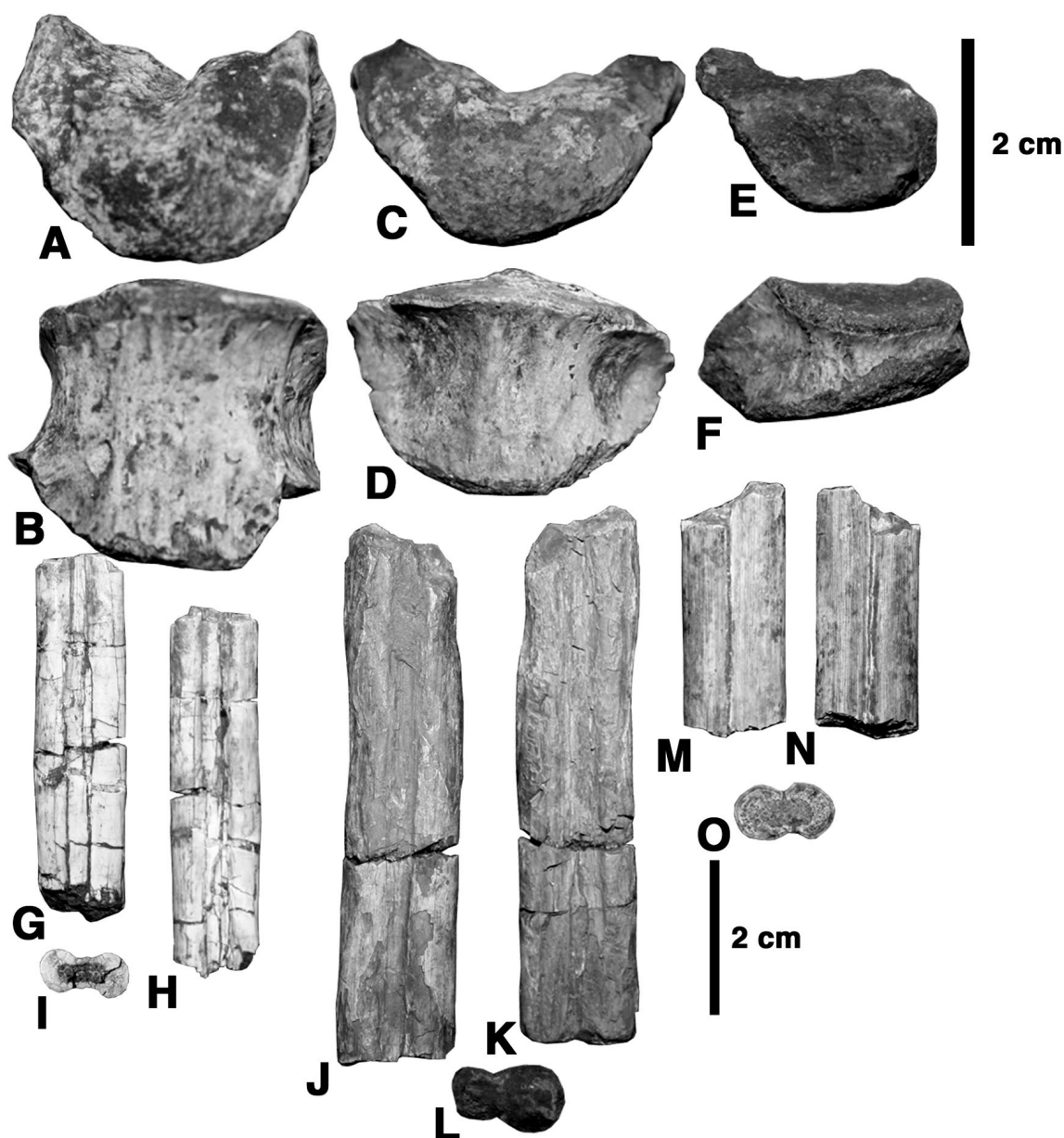


Fig. 8.— Amphibia and Sphenacodontidae from the Abo Formation in the Jemez Springs area. **A-F**, Amphibia. **A-B**, NMMNH P-61641, *Eryops* sp., intercentrum, from NMMNH Locality 5381, in **A**, anterior/posterior and **B**, ventral views. **C-D**, NMMNH P-32230, Temnospondyli, rhachitomous intercentrum, from NMMNH Locality 4507, in **C**, anterior/posterior and **D**, ventral views. **E-F**, NMMNH P-61672, *Eryops* sp., pleurocentrum, from NMMNH Locality 7062, in **E**, anterior/posterior and **F**, ventral views. **G-O**, *Dimetrodon* sp., **G-I**, NMMNH P-61635, three neural spines, from NMMNH Locality 5366, in **G-H**, **J-K**, **M-N**, lateral and **I**, **L**, **O**, cross sectional views.

Family Zatrachyidae Cope, 1878  
*Zatrachys* Cope 1878

*Zatrachys* sp.

**Referred specimen.**—From CM Locality 1000: CM 41706, tabular.

**Discussion.**—The presence of *Zatrachys* is known in the Jemez Springs vertebrate assemblage based on a single well-preserved tabular bone whose distinctive shape and

sculpturing clearly identifies it (Berman 1993).

Order Anthracosauria Säve-Söderbergh, 1937  
Family Archeriidae Kuhn, 1965  
*Archeria* Case, 1918

?*Archeria* sp.

**Referred specimens.**—From the Spanish Queen Mine vertebrate locality, UCMP V3855: UCMP 39179, articulated

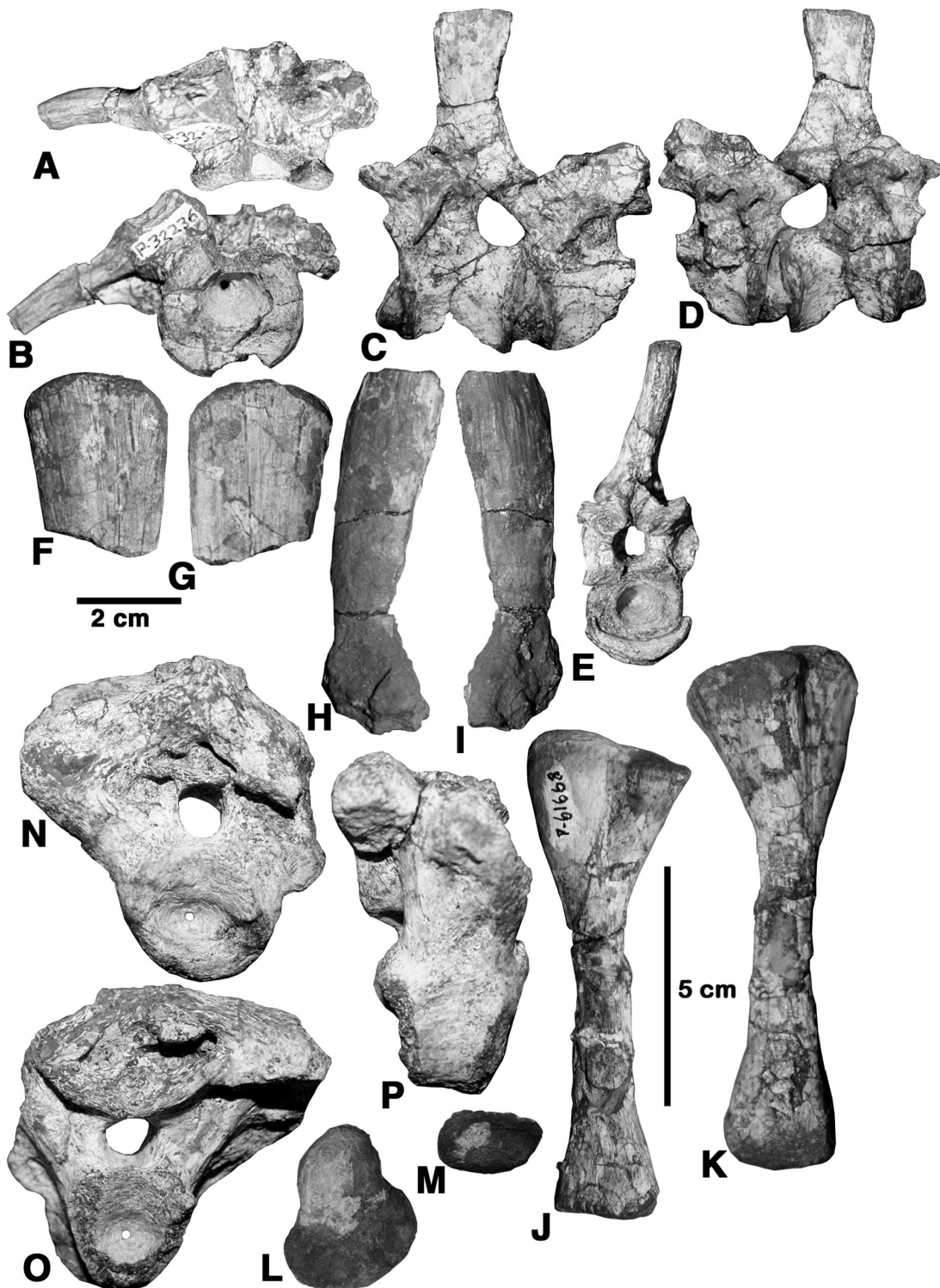


Fig. 9.—Sphenacodontidae and Diadectidae from the Abo Formation in the Jemez Springs area. A-I. Sphenacodontidae. A-B, NMMNH P-32236, Sphenacodontidae, vertebral centrum and rib fragment, from NMMNH Locality 4507, in A, dorsal and B, posterior views. C-E, NMMNH P-61669, *Sphenacodon* sp., C-E, one complete and one incomplete dorsal vertebra in C, left lateral, D, right lateral and E, anterior views, and H-I, neural spine, in H, left lateral and I, right lateral views, from NMMNH Locality 7060. F-G, NMMNH P-32233, Sphenacodontidae, one neural spine fragment, from NMMNH Locality 4507, in F, right lateral and G, left lateral views. J-M, NMMNH P-61668, Sphenacodontidae indet., left tibia, from NMMNH Locality 7057, in J, lateral, K, medial, L, proximal and M, distal views. N-P, NMMNH P-61607, Diadectidae indet., incomplete vertebra, from NMMNH Locality 4035, in N, anterior, O, posterior and P, right lateral views. Scale bars = A-G, N-P, upper left and H-M, lower right.

vertebrae, associated ribs and unidentified fragments (Langston 1953a: fig. 1). From UCMP V3740, the Johnson locality: UCMP 42158, caudal intercentrum.

**Discussion.**—Langston (1953a: fig. 1) described and illustrated six articulated embolomeres, dorsal vertebrae preserved together with their displaced ribs in a matrix block of red-mottled micaceous arkose collected from the Spanish Queen Mine vertebrate locality. Although Langston believed UCMP 39179, as well as a small, embolomeric caudal intercentrum from the Johnson locality (UCMP V3740), to be generically indeterminate, he suggested their close relationship to *Archeria*.

Order Nectridea Miall, 1875  
Family Diplocaulidae Cope, 1881  
*Diplocaulus* Cope, 1877

*Diplocaulus* sp.  
(Figs. 6M–N)

**Referred specimens.**—From CM 1000: CM 38028, vertebra. From UCMP V3740, the Johnson locality: NMMNH P-51883, P-61686, vertebrae (Figs. 6M–N).

**Discussion.**—Until recently, the only specimen diagnostic of the nectridean genus *Diplocaulus* recovered from the Abo Formation near Jemez Springs was a single vertebra (CM 38028) reported, but not illustrated, by Berman and Reisz (1980) and Berman (1993). This specimen was collected from CM Locality 1000 in stratigraphic interval C of the local Abo Formation section. Recent processing of heavily indurated limestone matrix from the stratigraphically lowest fossil vertebrate locality in Cañon de San Diego (UCMP V3740, the Johnson locality) has produced two additional *Diplocaulus* vertebrae (Figs. 6M–N). These small, holospondylous vertebrae are characterized by an elongate spool-shaped centrum, and a low, rounded neural spine, features diagnostic of the nectridean genus *Diplocaulus* (Case 1911; Mehl 1926; Milner 1996; Harris et al. 2005).

Order Diadectomorpha Watson, 1917  
Family Diadectidae Cope, 1880

*Diadectidae* indet. genus and species  
(Figs. 6L, 7L, 9N–P)

**Referred specimens.**—From CM Locality 1000: CM 86173, vertebra. From CM Locality 1001: CM 38041, postcranial skeleton. From CM Locality 4050: CM 86167, concretion postcrania. From NMMNH Locality 4035: NMMNH P-61607, 12 associated vertebrae and scrap (Figs. 9N–P); NMMNH P-61608, scapular blade. From NMMNH Locality 4507: NMMNH P-32241, ungual phalanx; NMMNH P-32235, two zygapophyses; NMMNH P-32234, centrum fragment; NMMNH P-32243, jaw fragment; NMMNH P-61612, neural spine fragment. From

NMMNH Locality 5381: NMMNH P-61642, 7 cranial fragments; NMMNH P-61643, sacral vertebra fragment; NMMNH P-61644, 4 zygapophyses; NMMNH P-61645, two metapodial fragments. From NMMNH Locality 7062: NMMNH P-61673, zygapophyses; NMMNH P-61674, ungual phalanx. From UCMP V3740, the Johnson locality: NMMNH P-51876, jaw fragment in matrix block (Fig. 6L), UCMP 195511, right mandible (Fig. 7L).

**Discussion.**—Second only to sphenacodontid specimens in numerical abundance, fossils diagnostic of the herbivorous family Diadectidae are present at seven fossil vertebrate localities near Jemez Springs, and are present in all three vertebrate fossil assemblages of the local Abo Formation section. These specimens included isolated, associated, and articulated postcrania and demonstrate a general pattern of size increase stratigraphically, with the smallest specimens from assemblage A and the largest from assemblage C. Further preparation and study of this material will allow us to determine with confidence the number of diadectid taxa present in these assemblages.

Order Synapsida Osborn, 1903  
Suborder Eupelycosauria Kemp, 1982  
Family Ophiacodontidae Nopsca, 1923  
*Ophiacodon* Marsh, 1878

*Ophiacodon* sp.  
(Figs. 7C–H)

**Referred specimen.**—From UCMP Locality V3740, the Johnson locality: UCMP 195505, 195506, 195507, dorsal vertebrae (Figs. 7C–H).

**Discussion.**—The Johnson locality is the only site in the Abo Formation near Jemez Springs from which specimens of the eupelycosaur genus *Ophiacodon* have been recovered. This material consists of small vertebrae with characteristic wing-like transverse processes (Figs. 7C–H) that were collected, but not reported, by a party from the University of California in 1937 (Langston 1953b).

Family Sphenacodontidae Williston, 1912  
Genus *Sphenacodon* Marsh, 1878

*Sphenacodon ferox* Marsh, 1878  
(Figs. 10–11)

**Referred specimens.**—From NMMNH Locality 4507: NMMNH P-61689, neural spine segment. From NMMNH Locality 4035: NMMNH P-27474, partial skull; NMMNH P-61610, 11 associated vertebrae and six neural spines; NMMNH P-61611, numerous associated bone fragments. From NMMNH Locality 5366: NMMNH P-61630, neural spine segment; NMMNH P-61631, eight neural spine fragments. From NMMNH Locality 5381: NMMNH P-61660, P-61661, P-61662, P-61663, P-61664, P-61665, neural spine segments; NMMNH P-61666, eight neural spine fragments.

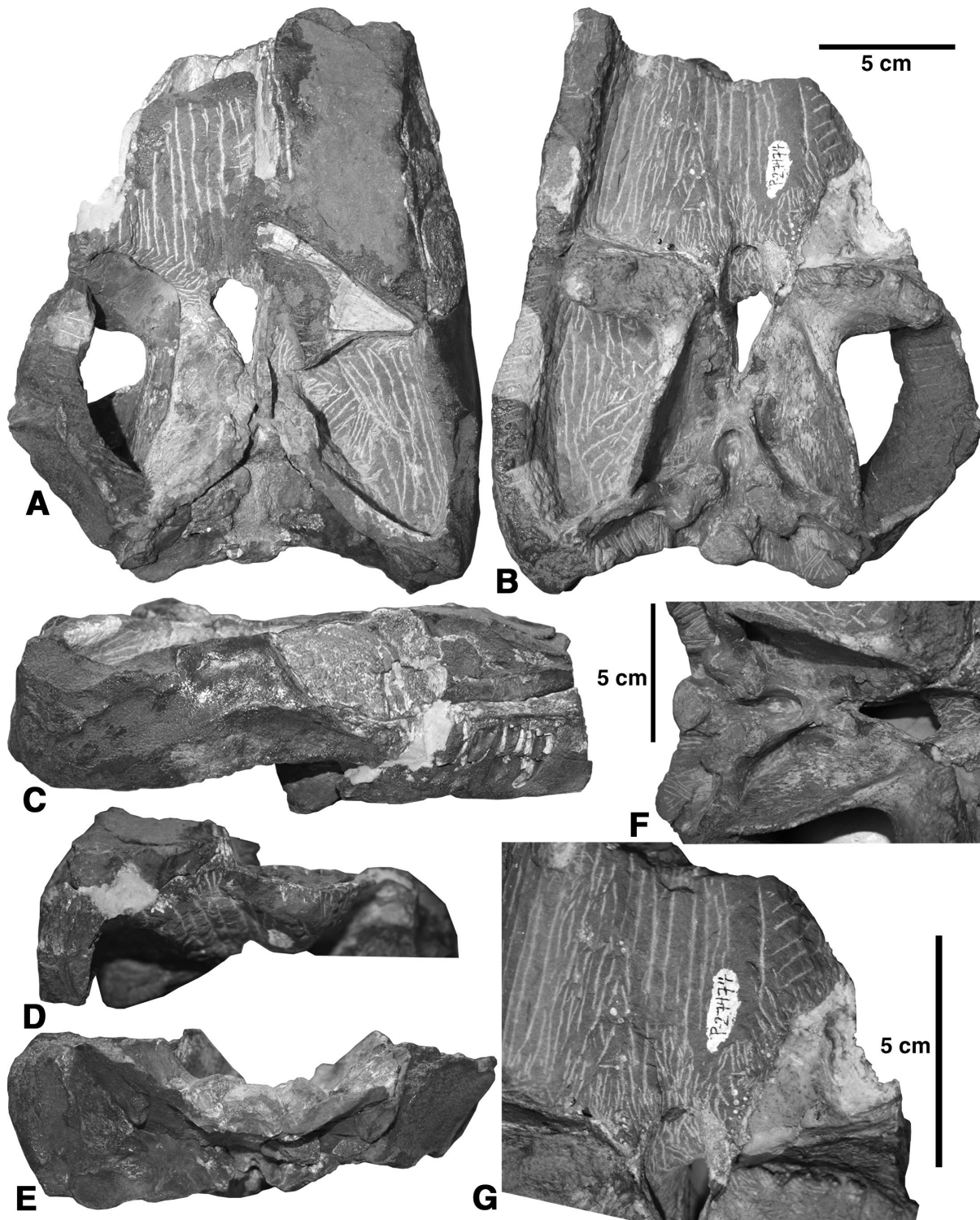


Fig. 10.—*Sphenacodon ferox*, NMMNH P-27474, incomplete skull, from NMMNH Locality 4035, in **A**, dorsal, **B**, palatal, **C**, right lateral, **D**, anterior and **E**, posterior views. **F**, closeup of braincase. **G**, closeup of left palatal denticle field. Scale bars: **A-E**, upper right; **F**, middle right; and **G**, lower right.

From UCMP V3740, the Johnson locality: NMMNH P-51879, P-51880, P-51881, neural spine segments. From NMMNH Locality 7060: NMMNH P-61669, numerous as-

sociated vertebrae, neural spines, ribs, and jaw fragments.

**Description.**—NMMNH P-27474 (Figs. 10–11) is an in-



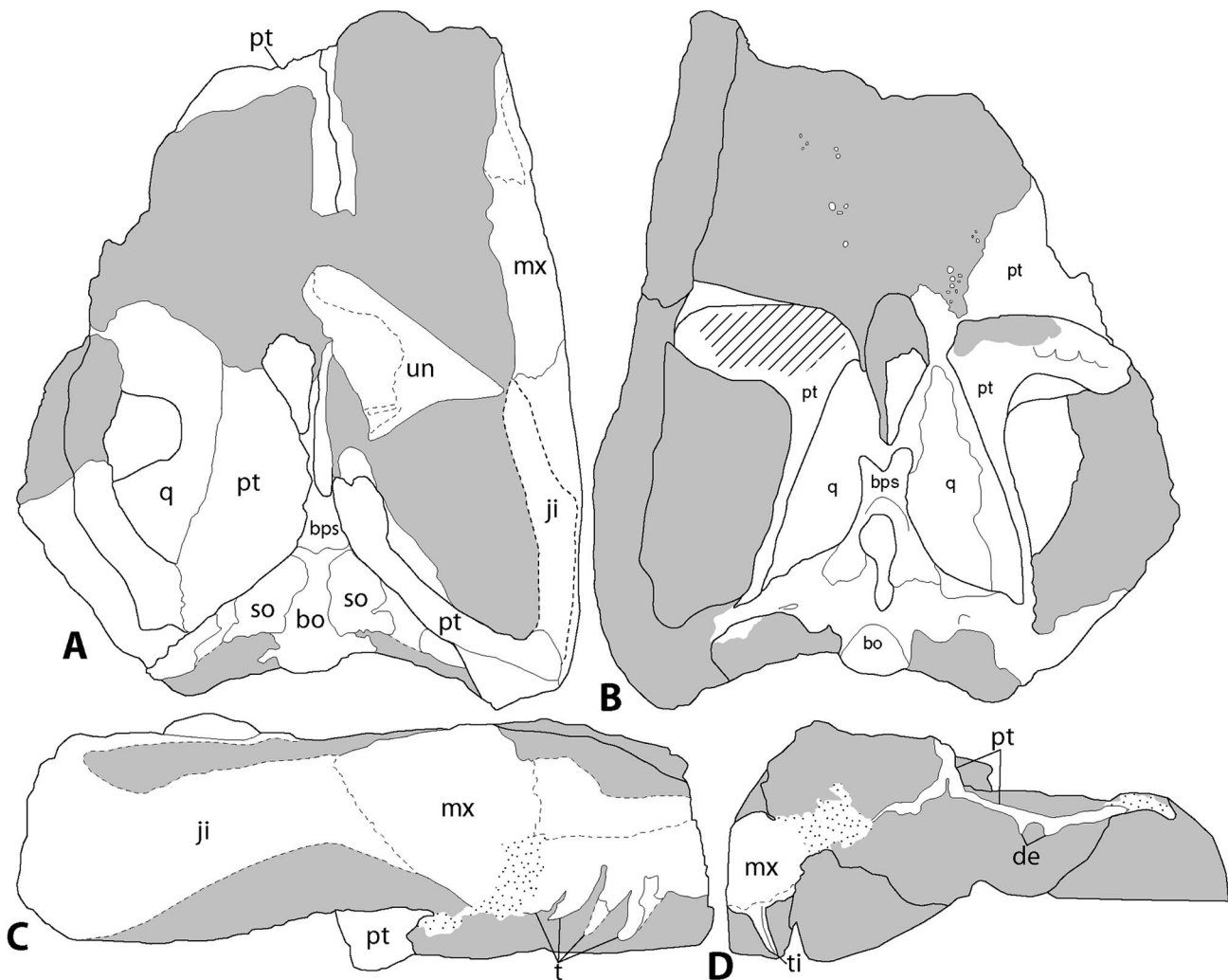


Fig. 11.—Interpretive drawing of *Sphenacodon ferox* skull, NMMNH P-27474, from NMMNH Locality 4035, in **A**, dorsal, **B**, palatal, **C**, right lateral, and **D**, anterior views. Broken bone surfaces are cross-hatched, matrix is gray, reconstructed areas are stippled, and bone impressions in matrix are outlined by dashes. **Abbreviations:** bo, basioccipital; bps, basiparasphenoid; de, denticles; ji, jugal impression; mx, maxilla; pt, pterygoid; q, quadrate; so, supraoccipital; t, teeth; ti, tooth impression; un, unknown bone fragment.

complete *Sphenacodon* skull encased in matrix, with some cranial elements being represented solely as impressions in the matrix. The right maxilla is preserved as a small patch of externally exfoliated bone and some matrix impressions in lateral view on the block's right side. Four teeth are preserved in articulation with the right maxilla in apical-basal cross-section. The maxilla-jugal suture cannot be determined, as the posterior maxilla and entire jugal are represented as matrix impressions.

Both pterygoids are the most completely represented elements of the skull. The palatal processes meet near the midline and are visible in both dorsal and anterior views. The left transverse flange is damaged, and no teeth are preserved, whereas the right transverse flange is incomplete, but preserves at least four teeth. The denticle fields on both pterygoids are difficult to discern given the encasing matrix,

but based on the right pterygoid the denticle field does not extend to the element's lateral margin. The quadrate processes are complete and fully visible in ventral view, with a slight color variation marking their sutural contact with the quadrates. Both quadrates are nearly complete and well exposed in both medial and lateral views.

The braincase is incomplete; however, most of the ventral elements can be discerned. Fragments of the supraoccipital may be preserved as linear outlines lateral to the basioccipital in occipital view. The dorsal margin of the basioccipital has been damaged, while much of the ventral aspect of this element is intact. The sutural surface with the basipterygoid is clearly discernible. The flange of the opisthotic contacting the parabasisphenoid is incomplete, but visible, with both of the fenestrae ovalis readily apparent. The parabasisphenoid is complete, but its sutural contact

with the quadrates is partially obscured by damage to the specimen. The basal tubera form triangular ridges that project posteriorly, and only the left carotid foramen is visible in this specimen.

An unidentified triangular element is positioned transversely in front of the temporal fenestra and is visible in dorsal view. This element likely represents a fragment of the anterior palate.

NMMNH P-27474 can be assigned to *Sphenacodon* based on the collection of *Sphenacodon* neural spines from the same locality (NMMNH Locality 4035). Further, the small overall size and pterygoid denticle fields that do not extend to the element's lateral margin identify this skull as *S. ferox*, following Spielmann et al. (2010).

**Discussion.**—The Jemez Springs fauna includes three sphenacodontids, *S. ferox*, *Sphenacodon ferocior* Romer, 1940, and *Dimetrodon occidentalis* Berman, 1977. This represents the only known co-occurrence of these three eupelycosaur taxa. *Sphenacodon* is characteristic of and restricted to the Coyotean land-vertebrate faunachron (lvf) (e.g., Lucas 2006), and is the common eupelycosaur in the Lower Permian of New Mexico, while *Dimetrodon* records are rare throughout the state (Cantrell et al. 2011). Neural spines characteristic of the medium-size sphenacodontid, *S. ferox*, are common throughout the fossil vertebrate sites of Cañon de San Diego. These records, though mostly fragmentary, demonstrate an abundance of *S. ferox* in the Jemez Springs vertebrate fossil assemblages comparable to that of the characteristic Coyotean assemblage from the upper part of the El Cobre Canyon Formation (Cutler Group) in the nearby Arroyo del Agua area (Berman 1993; Lucas et al. 2005b). Laterally compressed neural spines of small to moderate size that are diagnostic of *S. ferox* were recovered from all three stratigraphic intervals of the Jemez Abo Formation section. These occurrences, and the absence of *Seymouria* Broili, 1904, indicate the entire Jemez Springs vertebrate assemblage is of Coyotean age (see below and Lucas 2006).

In addition to isolated neural spines, *S. ferox* is recognized from an incomplete skull (NMMNH P-27474) (Figs. 10–11) and a group of associated vertebrae and neural spines (NMMNH P-61610) from NMMNH Locality 4035 in assemblage C. Together these specimens possibly represent a single individual. The skull, which consists primarily of bones of the palate, is assigned to *S. ferox* based on its associated neural spines, relatively small size and the morphology of the palatal ramus of the pterygoid on which the dental field does not extend to its lateral margin (see above).

*Sphenacodon ferocior* Romer, 1940

**Referred specimens.**—From Spanish Queen Mine vertebrate locality: MCZ 1489, holotype, skull and anterior vertebrae (Romer and Price 1940: figs. 4F, 23, 26, 36, 59); WM 11 (now at FMNH), fragmentary remains of a

disarticulated skeleton. From NMMNH Locality 4507: NMMNH P-32233, large neural spine; NMMNH P-32229, large proximal humerus.

**Discussion.**—Romer (1937) and Romer and Price (1940) described a large species of the genus *Sphenacodon*, *S. ferocior*, based on a well-preserved skull and anterior vertebrae from the Spanish Queen Mine vertebrate fossil locality. As stated above we believe this site to be within stratigraphic interval C, from which the partial skull of *S. ferox* (NMMNH P-27474) was also recovered. Although Romer and Price (1940) distinguished *S. ferocior* from *S. ferox* based mostly on size, a recent redescription of the skull of *S. ferox* demonstrated a total of 11 cranial characters by which these two species can also be distinguished (Spielmann et al. 2010).

Both species of *Sphenacodon* are also present in the faunal assemblage of the classic collecting locality of Arroyo del Agua. However, both Langston (1953b) and Romer (1960) argued that a biostratigraphic distinction can be made between the main vertebrate-fossil-producing horizon at Arroyo del Agua that yields *S. ferox*, and that of the stratigraphically higher Anderson quarry from which numerous cranial elements of *S. ferocior* were recovered. Lucas et al. (2005b) thus noted that the potential exists to subdivide the tetrapod localities at Arroyo del Agua into two biostratigraphic assemblages distinguished primarily by different species of *Sphenacodon*, *S. ferox* (lower quarries) and *S. ferocior* (two upper quarries known as Anderson and Cardillo). Langston (1953b) and Romer (1960) estimated a stratigraphic interval of 235 feet (71.63 meters) separate occurrences of the two *Sphenacodon* species in the Arroyo del Agua area. Thus, Romer (1960) suggested that a demonstrable trend in eupelycosaur evolution toward increase in size of stratigraphically younger species of a particular genus is applicable to the size difference between *S. ferox* and *S. ferocior*. However, the co-occurrence of *S. ferox* and *S. ferocior* in the same stratigraphic interval of the Abo Formation in the Jemez Springs area contradicts Romer's model of the species-level evolution of the genus *Sphenacodon*. Clearly, *S. ferox* and *S. ferocior* are coeval at some localities, not just temporally-successive species.

*Dimetrodon* Cope, 1878

*Dimetrodon occidentalis* Berman, 1977  
(Figs. 8G–O)

**Referred specimens.**—From CM Locality 1000: CM 26565, type, partial skeleton (Berman 1977, text-figs. 1-3). From CM Locality 4047: CM 86169, neural spine fragment. From NMMNH Locality 5366: NMMNH P-61632, 61633, 61634, neural spine segments (Figs. 8G–O); NMMNH P-61635, 20 neural spine fragments.

**Discussion.**—The first incontrovertible evidence that the

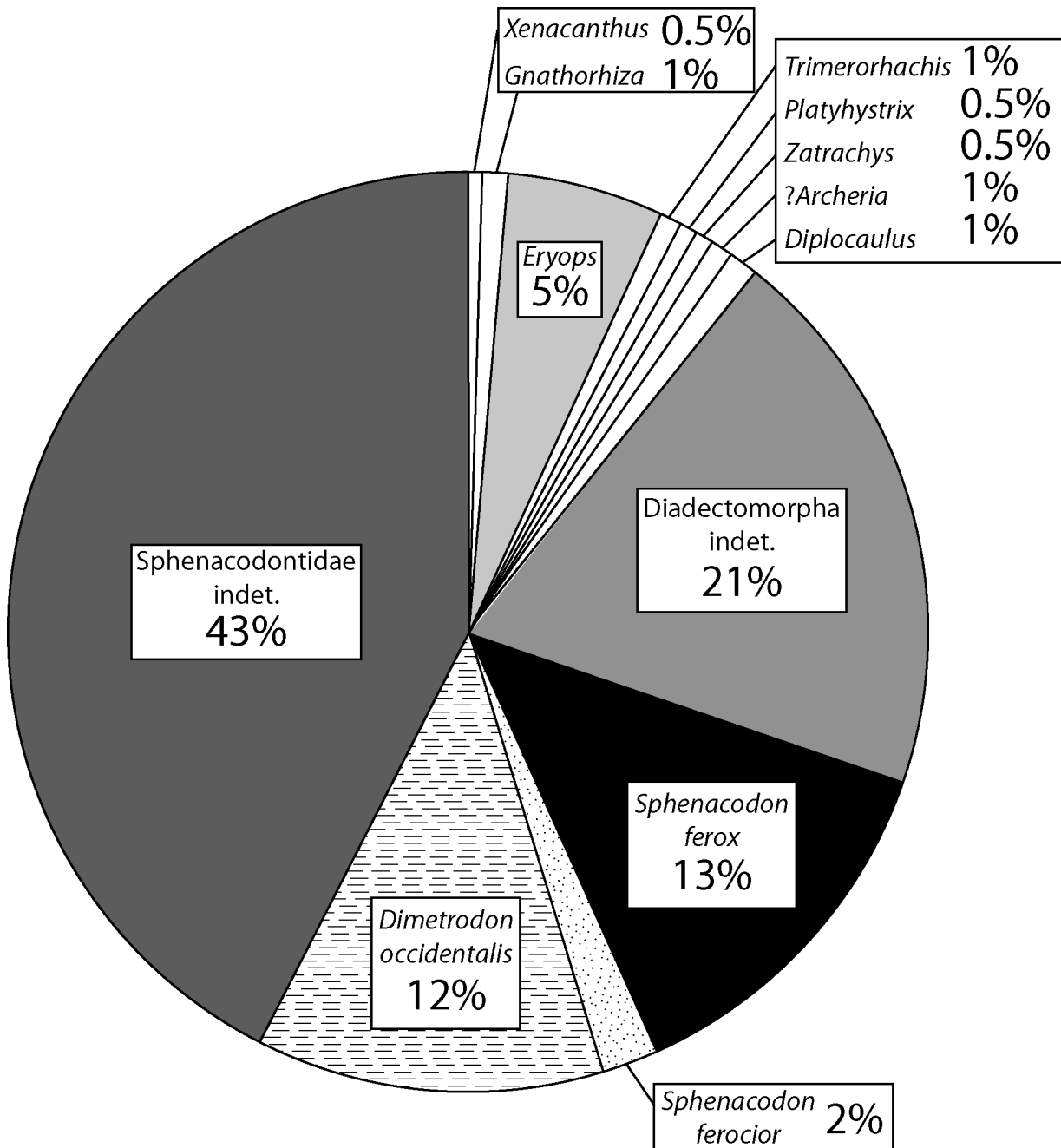


Fig. 12.—Pie diagram showing abundance of various vertebrate taxa, based on abundance of identifiable vertebrate fossils (see referred specimens), from the Abo Formation of the Jemez Springs area. N=205.

genus *Dimetrodon* is present in the Abo Formation of northern New Mexico, and not restricted to Lower Permian beds of north-central Texas and Oklahoma, was provided by Berman (1977). Description of *D. occidentalis* was based on a partial articulated sail and associated jaw elements collected from a site high in the Abo Formation (assemblage C) of the Jemez Springs area near the coeval Spanish Queen Mine vertebrate locality from which the type material of *S. ferocior*

was collected (Romer and Price 1940; Langston 1953b). Numerous isolated neural spine segments of *Dimetrodon* (Figs. 8G–O) with the characteristic figure-eight cross section are present at a second site (NMMNH L-5366) that is also within assemblage C. However, material diagnostic of *Dimetrodon* is absent in the stratigraphically lower assemblages A and B.

**Sphenacodontidae** indet. genus and species  
(Figs. 7A–B, 9J–M)

**Referred specimens.**—From CM Locality 1001: NMMNH P-61637, jaw fragment; NMMNH P-61638, centrum; NMMNH P-61639, numerous bone fragments; NMMNH P-61640. From CM Locality 4047: CM 86168, mandible; CM 86172, maxilla and ribs. From NMMNH Locality 4507: NMMNH P-32240, jaw fragment; NMMNH P-61688, maxilla fragment with teeth. From NMMNH Locality 5366: NMMNH P-61614, atlas centrum; NMMNH P-61615, atlas centrum; NMMNH P-61616, three associated cranial fragments; NMMNH P-61617, jaw fragment; NMMNH P-61618, tooth in jaw fragment; NMMNH P-61619, tooth; NMMNH P-61620, P-61621, tooth in matrix block; NMMNH P-61622, cervical centrum; NMMNH P-61623, lumbar centrum; NMMNH P-61624, P-61625, sacral vertebra; NMMNH P-61626, P-61627 rib fragment; NMMNH P-61628, distal tibia; NMMNH P-61629, proximal femur fragment. From NMMNH Locality 5381: NMMNH P-61646, articular fragment; NMMNH P-61647, quadrate fragment; NMMNH P-61648, P-61649, lateral flange of pterygoid; NMMNH P-61650, dentigerous pterygoid fragment; NMMNH P-61651, maxilla fragment with two teeth; NMMNH P-61652, six jaw fragments; NMMNH P-61653, dentigerous dentary fragments; NMMNH P-61654, three tooth fragments; NMMNH P-61655, vertebra; NMMNH P-61656, crushed vertebra; NMMNH P-61657, 10 vertebral fragments; NMMNH P-61658, pelvic girdle fragment; NMMNH P-61659, two metapodial fragments. From NMMNH Locality 7057: NMMNH P-61668, complete left tibia (Figs. 9J–M). From NMMNH Locality 7062: NMMNH P-61675, P-61676, vertebra; NMMNH P-61677, three caudal vertebrae; NMMNH P-61678, 11 vertebral fragments; NMMNH P-61679, proximal central of carpus; NMMNH P-61680, metatarsal I; NMMNH P-61681, seven metapodial fragments. From UCMP V3740, the Johnson locality: NMMNH P-51877, transverse flange of pterygoid; NMMNH P-51878, tooth in matrix; UCMP 195504, right femur (Figs. 7A–B); unnumbered UCMP specimens, incomplete dentary, quadrate, proximal and distal humeri, proximal and distal femora.

**Discussion.**—The fossil vertebrate localities of the Abo Formation in the Jemez Springs area yield numerous isolated, mostly fragmentary elements with features characteristic of the Sphenacodontidae (Figs. 7A–B, 9J–M). However, sphenacodontid cranial and postcranial morphology is remarkably conservative so that the generic distinction between *Sphenacodon* and *Dimetrodon* is based almost entirely on neural spine morphology. Nevertheless, the great number of indeterminate sphenacodontid elements recovered from nearly every fossil vertebrate site in the Jemez Springs area demonstrates the dominance of the Jemez Springs vertebrate assemblages by Sphenacodontidae.

PALEOECOLOGY

The vertebrate fossil assemblages from the Abo Formation in the Jemez Springs area (Fig. 12) are broadly similar to (and correlative to, see below) most of the vertebrate fossil assemblages found in strata of the El Cobre Canyon Formation of the Cutler Group in the Chama basin to the north, at Arroyo del Agua and in Cañon del Cobre (El Cobre Cañon) (Fig. 1). Thus, these Coyotean-age assemblages contain xenacanth sharks, lungfishes, temnospondyl and lepospondyl amphibians, anthracosaurs, diadectids, and (most diverse and abundant) eupelycosaur. However, the Jemez Springs assemblages, as currently known, are less diverse than the Arroyo del Agua assemblage.

The vertebrate taxa of the Jemez Springs vertebrate assemblages represent a mixed terrestrial-aquatic fauna. Key distinguishing features of this fauna include a diverse sphenacodontid component in which three different species occur in the same stratigraphic interval, and the relative abundance of diadectid material combined with sparse remains of semi-terrestrial or semi-aquatic vertebrates such as *Eryops* and *Ophiacodon*. With the exception of *Trimerorhachis*, specimens of obligatory aquatic amphibians and fish are rare.

The well-preserved, articulated condition of the holotype of *Trimerorhachis sandovalensis* from the Jemez Springs area is in direct contrast to the sparse, fragmentary remains of other obligatory aquatic amphibians of the Jemez Springs vertebrate fossil assemblages such as *Diplocaulus*, *Archeria*, and *Zatrachys*. The poor representation of this component of the fauna, coupled with the absence of rhipidistian fish, apparently represents a preservational bias against aquatic taxa. Or, it may indicate that there were not areas of permanent water bodies of sufficient size to support populations of these animals.

Jemez Springs is one of five *Diplocaulus* sites in Lower Permian red-bed sediments of mostly stream-channel deposition in the Abo and Sangre de Cristo formations of New Mexico. However, *Diplocaulus* fossils are absent from upper Virgilian and lower Wolfcampian tetrapod assemblages of New Mexico deposited in mixed marine-nonmarine strata in which fossils of paleoniscoid fish have been found (Red Tanks and Laborcita members of the Bursum Formation; Harris et al. 2004, 2005). Thus, the distribution of *Diplocaulus* fossils in New Mexico suggests a habitat preference for paleoenvironments subject to seasonal drought.

The rarity of fossils of the eupelycosaur *Ophiacodon* in the Jemez Springs vertebrate fossil assemblages contrasts with their abundance in other well-known fossil tetrapod assemblages near the Pennsylvanian-Permian boundary (e.g., Kissel and Lehman 2002; Lucas et al. 2005a, 2005b, 2010), as well as in the nearby characteristic Coyotean assemblage in the Arroyo del Agua area of Rio Arriba County (Lucas et al. 2005b; Lucas 2006) and a principal correlative in the Halgaito Formation of the Arizona-Utah borderland (Sumida et al. 1999; Lucas 2006). The paucity of *Ophiacodon* and *Eryops* remains in Abo Formation sediments of

the Jemez Springs area, coupled with the absence of *Edaphosaurus* Cope, 1882 (its characteristic neural spines, if present, would be easily recognized in the field), suggest an atypically small semi-aquatic or semi-terrestrial tetrapod faunal component in vertebrate assemblages B and C. The abundance of diadectid remains, coupled with the apparent absence of edaphosaurids, suggests a paleoflora in which terrestrial, high-fiber plants were dominant.

The plants from the Spanish Queen Mine locality are consistent with the general environmental interpretation of a warm climate with seasonal rainfall, indicating a substantial part of the year with evapotranspiration exceeding rainfall on a monthly basis. The paleoflora includes plants that have relatively broad leaves and probably moderate demands for soil moisture (higher than cactus or other arid land plants). These Abo plants had woody petioles and were likely adapted to shedding their leaves seasonally, similar to ocotillo or other such modern broad-leaved plants of arid environments.

The co-occurrence of the sphenacodontid genera *Dimetrodon* and *Sphenacodon* is rare, with only three other co-occurrences known, based mostly on isolated vertebrae and neural spines (Vaughn 1969; Sumida et al. 1999; Harris et al. 2004). Among species of the genus *Dimetrodon*, *D. occidentalis* ranks as one of the smallest, with an estimated weight of 41 kg (Berman 1977, 2003), whereas *S. ferocior* was as much as three times larger, weighing an estimated 129 kg (Romer and Price 1940). Clearly, unlike most large *Dimetrodon* species of the late Wolfcampian and Leonardian, *D. occidentalis* did not occupy the ecological role of dominant carnivore in this fauna. Instead, its diminutive size suggests predation on small aquatic amphibians and fish, leaving semi-aquatic vertebrates of moderate size, in addition to individuals of its own species, as potential prey of *S. ferocior*. However, with an estimated weight of 52 kg (Romer 1960), *S. ferox* was only slightly larger than *D. occidentalis*. Therefore, in light of their virtually indistinguishable skeletal morphology (with the exception of the dorsal sail), it is reasonable to conclude that *D. occidentalis* and *S. ferox* were highly competitive ecological equivalents (vicars).

#### BIOSTRATIGRAPHY AND AGE

Four lines of evidence can be brought to bear on the age of the Abo Formation in the Jemez Springs area: (1) regional lithostratigraphic correlation; (2) the age of the Guadalupe Box Formation, which stratigraphically underlies the Abo Formation; (3) fossil plant biostratigraphy; and (4) vertebrate biostratigraphy. Here, we review these data to conclude that the Abo Formation in the Jemez Springs area is very close in age to the base of the Permian (Fig. 13).

#### Regional Lithostratigraphy

A comparison of the lithofacies and mineralogical composition demonstrates that no significant differences exist

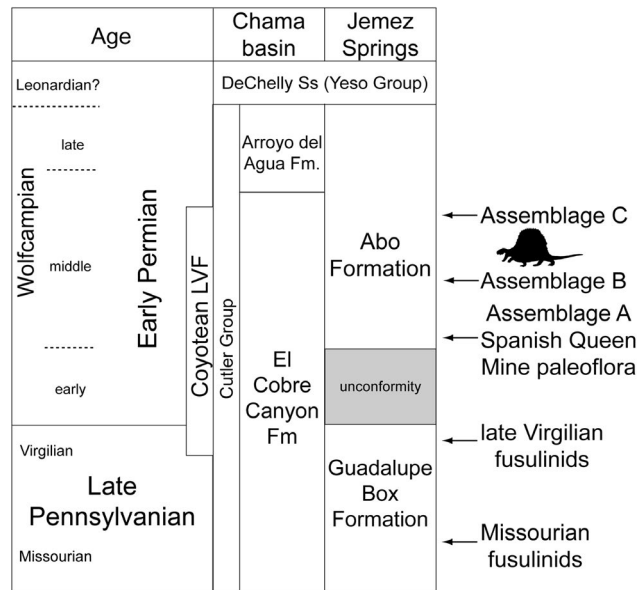


Fig. 13.—Summary of lithostratigraphy, biostratigraphy, age, and correlation of Abo Formation and adjacent strata in the Jemez Springs area.

between the red beds of the Cutler Group and the Abo Formation in northern New Mexico (Eberth and Miall 1991; Eberth and Berman 1993; Krainer and Lucas 2010). For this reason, it is impossible to draw a clearcut stratigraphic boundary between the Cutler Group and the Abo Formation in northern New Mexico. Indeed, in the northern Nacimiento Mountains, Wood and Northrop (1946) arbitrarily separated the Abo from the Cutler red beds along the border between Rio Arriba and Sandoval counties. Baars (1983) stated that the arkosic red beds of the Abo Formation are similar in physical aspect and age to the lower Cutler beds of the Defiance uplift and Monument Valley area of the Four Corners region. We therefore include the Abo Formation in the Cutler Group, as did Krainer and Lucas (2010).

At many places in central New Mexico, south of the Jemez Springs area, red beds of the Abo Formation disconformably overlie the Bursum Formation (e.g., Lucas and Krainer 2004; Krainer and Lucas 2009). Locally, the Abo Formation base is a conglomerate that erosively overlies the Bursum Formation. Limestone clasts in this conglomerate indicate that substantial parts of the Bursum Formation were eroded prior to deposition of the Abo red beds, probably due to the formation of deeply incised valleys (Krainer and Lucas 2009). This unconformity is also recognized at other locations and indicates a major tectonic pulse near the Virgilian/Wolfcampian boundary (Krainer and Lucas 2009; Lucas et al. 2009).

There is much evidence that the unconformity on top of the Bursum Formation resulted from a major tectonic pulse of the ancestral Rocky Mountain deformation, causing a significant rejuvenation of basement uplifts that resulted in increased siliciclastic influx and the deposition of

nonmarine red beds of the Abo Formation in central New Mexico. However, in the Chama basin this unconformity near the Virgilian/Wolfcampian boundary is not obvious within the Cutler Group in the upper part of the El Cobre Canyon Formation (Lucas and Krainer 2005a, 2005b). In the Jemez Springs area siliciclastic red beds of nonmarine origin at the base of the Abo Formation rest directly on marine strata at the top of the Guadalupe Box Formation. Our lithostratigraphic data (Fig. 4) suggest a substantial amount of stratigraphic relief (>60 m) in the Jemez Springs area. It thus seems likely that there is an unconformity at the base of the Abo Formation in the Jemez Springs area. Available data, however, do not allow a precise estimate of the temporal hiatus represented by the unconformity. It probably is a hiatus between middle Wolfcampian (age of base of Abo Formation regionally) and late Virgilian strata, but this cannot be demonstrated with certainty.

#### Age of the Guadalupe Box Formation

Henbest and Read (1944), Read and Wood (1947), DuChene (1973), Swenson (1996), Kues (1996, 2001), and Krainer et al. (2005) are among those who have reviewed previous studies of the lithostratigraphy and biostratigraphy of the Pennsylvanian marine strata in the Jemez Mountains. In the Jemez Springs area, the dominantly marine Pennsylvanian stratigraphic interval immediately beneath the Abo Formation belongs to the Guadalupe Box Formation, which can be divided into two members, an upper Jemez Springs Member (Sutherland and Harlow 1967) and a lower San Diego Canyon Member (Krainer et al. 2005).

The Jemez Springs Member, particularly in the upper part, contains abundant marine fossils, mostly well-preserved brachiopods, gastropods, bivalves, crinoids, and bryozoans, indicating a low-energy shallow marine environment with fine-grained siliciclastic influx (Sutherland and Harlow 1967; Kues 1996; Swenson 1996; Krainer et al. 2005). The limestone beds, which contain a diverse invertebrate fossil assemblage, were deposited during short periods of reduced siliciclastic influx in a shallow, open-marine setting. Muddy textures (mostly wackestone) indicate low energy conditions. A few limestone beds contain age-diagnostic fusulinids (Krainer et al. 2005).

The base of the Guadalupe Box Formation is thus dated by fusulinid biostratigraphy as latest Moscovian (= late Desmoinesian, DS4 zone of Wilde 1990) because of the presence of *Fusulina* aff. *F. acme* Dunbar et al., 1942, accompanied by *Climacammina* ex gr. *magna* Roth and Skinner, 1930, and indeterminate species of *Palaeotextularia* Schubert, 1921, and *Eugonophyllum* Konishi and Wray, 1961 (see Krainer et al. 2005 for documentation of these microfossils). The middle part of the Guadalupe Box Formation contains *Triticites* (*Schwageriniiformis*?) aff. *T. jemezensis* Needham, 1937. This level corresponds to the Missourian (= Kasimovian) MC1 or MC2 biozones of Wilde (1990) due to the primitive stage of evolution of

*Triticites* (comparable with the Tethyan genus or subgenus *Schwageriniiformis*). In the Jemez Springs section of Krainer et al. (2005) specimens of *Triticites* (*Triticites*) ex gr. *rhodesi* Needham, 1937, are numerous near the top of the Jemez Springs Member and indicate a late Virgilian age (= late Gzhelian; = VC3 biozone of Wilde 1990). This places a maximum age of late Virgilian on the base of the Abo Formation in the Jemez Springs area (Fig. 13).

#### Fossil Plant Biostratigraphy

The Spanish Queen Mine paleoflora is typical of Read and Mamay's (1964) Floral Zone 13, the Zone of *Callipteris* Brongniart, 1849, which they place at the base of the Permian. However, with the recently repositioned Pennsylvanian-Permian boundary to within the Wolfcampian, this zone straddles the Pennsylvanian-Permian boundary. Stratigraphically, the Spanish Queen Mine paleoflora is similar to that of the Lower Rotliegend of Germany (Kerp and Fichter 1985; Barthel 2009), particularly the lower portions of that interval, where a secure Pennsylvanian-Permian position is uncertain. Taxa of particular note in making this determination include *Neurodontopteris auriculata*, *Ernestiodendron filiciforme*, *Culmitzschia/Lobachia speciosa*, *Pecopteris bredovii* Germar, 1845, and *Gomphostrobus bifidus* (Geinitz) Potonié, 1891, all primarily Late Pennsylvanian and Early Permian in their occurrences. However, the Spanish Queen Mine paleoflora also contains elements, such as conifers, *Dichophyllum* Elias ex Andrews, 1941, and *Taeniopteris*, reported together as early as the Missourian from Midcontinent North America (Moore et al. 1936; Cridland and Morris 1963) and the Appalachians (McComas 1988). Other publications have shown that plants such as conifers may occur in the Middle Pennsylvanian of the American Illinois Basin (Plotnik et al. 2009; Falcon-Lang et al. 2009); conifer occurrences in the Middle Pennsylvanian are well established in Europe (e.g., Galtier et al. 1992, among many other reports). In all these instances, early appearances of plants such as those dominant at the Spanish Queen Mine locality, coincide with paleoenvironments indicative of seasonally dry climatic conditions and associated seasonal moisture stress.

At present there are too few occurrences of these seasonally dry paleofloras to allow the high precision needed for refined biostratigraphic interpretations. An example of the problems that can result from this is the study of Wagner and Lyons (1997), who incorrectly interpreted the 7-11 flora from the Missourian of Ohio described by McComas (1988) to be a latest Stephanian-equivalent (Gzhelian) rather than early Stephanian-equivalent (Kasimovian) age. This requires a gap of many millions of years to exist in the North American geological section, in contravention to all other means of correlation (Falcon-Lang et al. 2011). Similarly, the age of the non-marine Dunkard Group in the northern Appalachians has been difficult to resolve because of the intercalation of Permian-like, callipterid and conifer-

rich floras with Pennsylvanian-like wetland floras (Darrah 1975). Fortunately, in the case of the Spanish Queen Mine paleoflora, there are species that point clearly to a latest Pennsylvanian or earliest Permian age, such as *Alethopteris schneideri* Sterzel, 1881, *Callipteridium gigas* (Gutbier) Weiss 1870, *Neurodopteris auriculata*, *Rhachiphyllum schenkii*, and *Culmitzschia/Lebachia speciosa*, consistent with other lines of evidence for the age of these rocks.

### Vertebrate Biostratigraphy

In the Chama basin, particularly at Cañon del Cobre, the lower part of the Cutler Group (El Cobre Canyon Formation) yields plant and vertebrate fossils of both Late Pennsylvanian and Early Permian age (Lucas et al. 2010). At Arroyo del Agua only the upper part of the El Cobre Canyon Formation is exposed, and the vertebrate fossil assemblages are of Early Permian (middle Wolfcampian) age (Lucas 2006). Indeed, west of Arroyo del Agua, near Jaralosa and Gallina, marine limestones of the upper part of the Guadalupe Box Formation yield Virgilian fusulinids (Henbest and Read 1944), and these fusulinids are stratigraphically below the Coyotean-age vertebrate fossil assemblages at Arroyo del Agua.

In the Chama basin, the lowest occurrence of the eupelycosaur *Sphenacodon* marks the beginning of the Coyotean land-vertebrate faunachron, which began during the latest Pennsylvanian and encompasses much of Wolfcampian time (Lucas 2006). The vertebrate fossil assemblages from the Abo Formation in the Jemez Springs area clearly are of Coyotean age. This indicates correlation of the lower-middle Abo Formation at Jemez Springs with the upper part of the El Cobre Canyon Formation in the Chama basin (Fig. 13).

### Conclusions

The lower to middle part of the Abo Formation in the Jemez Springs area contains a paleoflora dominated by pteridosperms (including callipterids) and conifers, and eupelycosaur-dominated vertebrate fossil assemblages that also include a xenacanth chondrichthyan, a dipnoan, temnospondyl amphibians, an anthracosaur, a neotridian, and a diadectid. Marine strata of the Guadalupe Box Formation immediately beneath the Abo Formation contain late Virgilian fusulinids that place a maximum age on the Abo Formation fossil plants and vertebrates. The fossil plants do not indicate an exact age with respect to the Pennsylvanian-Permian boundary, but do indicate proximity to that boundary. The fossil vertebrates are readily assigned to the Coyotean land-vertebrate faunachron, of late Virgilian-Wolfcampian age. The vertebrate biostratigraphy thus permits correlation of the Jemez Springs fossil vertebrate assemblages with the Coyotean-age assemblages from the upper part of the El Cobre Canyon Formation in the Chama basin to the north. This correlation is consistent with the

lithologic similarity and similar stratigraphic position of the lower part of the Abo Formation in the Jemez Springs area and the upper part of the El Cobre Canyon Formation in the Chama basin. Thus, the lower-middle part of the Abo Formation and its fossil assemblages in the Jemez Springs area are best assigned a middle Wolfcampian age, close to the Pennsylvanian-Permian boundary (Fig. 13).

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## APPENDIX 1: Coordinates Of Measured Sections

Map coordinates of measured sections (section location: Fig. 2; stratigraphic sections: Fig. 4)

(UTM coordinates, datum NAD 27, all zone 13N).

**Spanish Queen Mine** — base at 345190E, 3955315N; top at 345611E, 3955122N.

**Neville** — base at 344672E, 3954765N; top at 344622E, 3954931N.

**Vista Linda** — base at 344473E, 3953530N; top at 344858E, 3953391N.

***Dimetrodon* Site (= Jemez River section of Krainer and Lucas 2010)** — base at 343754E, 3952554N; top at 344598E, 3952583N.

**Mesa de los Datiles** — base at 344855E, 3953389N; top at 342989E, 3949806N.

**Gilman B** — base at 343003E, 3949723N; top at 343954E, 3950169N.

**Gilman A** — base at 341134E, 3952490N; top at 341224E, 3952720N.

APPENDIX 2: Vertebrate Taxa By Locality In The Abo Formation  
In The Jemez Springs Area (*continued on the next page.*)

ASSEMBLAGE A

**UCMP Locality V3740 [Johnson locality] (= NMMNH L-6842)**

*Eryops* sp. (vertebrae, UCMP specimens; dermal bone, UCMP 195508; partial palate with teeth, UCMP 195509; premaxilla with two large teeth, UCMP 195510)  
**Embolomeri indet.** (embolomeric vertebra, UCMP 42158) (see Langston 1953a, 1953b)  
*Diplocaulus* sp. (vertebra, NMMNH P-51883; vertebra, NMMNH P-61686)  
**Diadectidae indet.** (jaw fragment in matrix, NMMNH P-51876)  
**Small diadectid** (specimens reported by Langston 1953b, right mandible, UCMP 195511)  
*Ophiacodon* sp. (vertebrae, UCMP 195505-195507)  
**Sphenacodontidae, genus indet.** (transverse flange of pterygoid, NMMNH P-51877; tooth in matrix, NMMNH P-51878; femur, UCMP 195504; proximal and distal femora, proximal and distal humeri, UCMP specimens)  
*Sphenacodon ferox* (neural spine segment, NMMNH P-51879; neural spine segment, NMMNH P-51880; 2 neural spine fragments, NMMNH P-51881)

**UCMP Locality V3855 (Spanish Queen Mine vertebrate locality)**

?*Archeria* (articulated vertebrae, associated ribs and unidentified fragments, UCMP 39179)  
**large diadectids** (see Langston 1953b)  
*Eryops grandis* (small, fragmentary skull, UCMP 39179)  
**Sphenacodontidae indet.** (see Langston, 1953b)  
*Sphenacodon ferocior* (skull and anterior vertebrae, holotype, MCZ 1489; fragmentary remains of a disarticulated skeleton, WM 11)

ASSEMBLAGE B

**NMMNH L-4507**

*Eryops* sp. (intercentrum, NMMNH P-32230)  
**Diadectidae indet.** (partial centrum, NMMNH P- 32234; zygapophyses, NMMNH P- 32235; neural spine, NMMNH P-61612; ungual phalanx, NMMNH P-32241; jaw fragment, NMMNH P-32243)  
**Sphenacodontidae, genus indet.** (vertebra with ribs, NMMNH P-32236; dentigerous maxilla fragment; dentigerous jaw element, NMMNH P-32240; proximal femur, NMMNH P-61687)  
*Sphenacodon ferox* (neural spine, NMMNH P- 61689)  
*Sphenacodon ferocior* (neural spine, NMMNH P- 32233; proximal humerus, NMMNH P- 32229)

**NMMNH L-5381**

?*Eryops* sp. (intercentrum, NMMNH P-61641)  
**Diadectidae indet.** (7 cranial fragments, NMMNH P 61642; sacral vertebra fragment, NMMNH P-61643; 4 zygapophyses, NMMNH P- 61644; 2 metapodial fragments, NMMNH P-61645)  
*Sphenacodon ferox* (vertebra, NMMNH P-61660; neural spine segments, NMMNH P- 61661 through P-61665; 8 neural spine fragments, NMMNH P-61666)

ASSEMBLAGE C

**CM Locality 999**

*Xenacanthus* (tooth, CM 38026)

**CM Locality 1000 (= NMMNH L-7056)**

?*Eryops* sp. (vertebral intercentrum and neural spine, CM 26567; jaw fragments, CM 86177)  
*Diplocaulus* sp. (vertebra, CM 38028),  
*Zatrachys serratus* (tabular, CM 41706),  
**Diadectidae indet.** (vertebra, CM 86173)  
*Sphenacodon* sp. (occiput, CM 26566)  
*Dimetrodon occidentalis* (partial skeleton, holotype, CM 26565)

**CM Locality 1001 (= NMMNH L-5380)**

?*Eryops* sp. (skull fragments, CM 86175)  
?*Trimerorhachis* sp. (partial skull w/ element of postcrania, CM 38027)  
**Diadectidae** (most of skeleton minus skull, CM 38041)  
**Sphenacodontidae, genus indet.** (jaw fragment, NMMNH P-61637; centrum, NMMNH P-61638; left premaxilla, CM 86176)  
*Dimetrodon occidentalis* (2 neural spine frags, NMMNH P-61640; vertebral and neural spine fragments, CM 86174)

**CM Locality 1002 (= NMMNH L-7055)**

*Trimerorhachis sandovalensis* (skull and partial, articulated skeleton, holotype, CM 38025)

**CM Locality 1003**

*Platyhystrix* sp. (neural spines, CM 38029)

APPENDIX 2: Vertebrate Taxa By Locality In The Abo Formation  
In The Jemez Springs Area (*continued from previous page.*)

ASSEMBLAGE C, continued

**CM Locality 4047**

*Sphenacodontid* indet. (mandible, CM 86168)

*Dimetrodon occidentalis* (neural spine fragment, CM 86169)

**CM Locality 4048**

*Eryops* sp. (neural spine, CM 86170)

**CM Locality 4049**

*Sphenacodontid* indet. (mandible, CM 86171; maxilla and ribs, CM 86172)

**CM Locality 4050**

*Diadectidae* indet. (partial postcranial skeleton, CM 86167)

**NMMNH L-4035**

*Diadectidae* indet. (12 associated vertebrae, NMMNH P- 61607; scapular blade, NMMNH P- 61608)

*Sphenacodon ferox* (partial skull, NMMNH P-27474; 11 associated vertebrae and 6 neural spines, NMMNH P-61610; associated bone fragments, NMMNH P-61611)

**NMMNH L-4508**

*Vertebrata* indet. (one indeterminate bone fragment, not collected)

**NMMNH L-5366**

*Temnospondyli* indet. (jaw frag, NMMNH P- 61613)

*Sphenacodontidae*, *genus* indet. (atlas centrum, NMMNH P-61614; atlas intercentrum, P-61615; 3 associated cranial fragments, P-61616; jaw fragment, P-61617; jaw fragment with tooth, P-61618; tooth, P-61619; tooth in matrix block, P-61620; cervical centrum, P-61622; lumbar centrum, P-61623; sacral vertebra, 61624; sacral vertebra, P-61625; rib fragment, P-61626; rib fragment, P-61627; distal tibia, P-61628; proximal femur, P-61629)

*Sphenacodon ferox* (neural spine segment, NMMNH P-61630; 8 neural spine fragments, NMMNH P-61631)

*Dimetrodon occidentalis*. (neural spine segment, NMMNH P- 61632; neural spine segment, NMMNH P-61633; neural spine segment, NMMNH P-61634; 20 unassociated neural spine frags, NMMNH P-61635)

**NMMNH L-7057**

*Sphenacodontidae*, *genus* indet. (complete tibia, NMMNH P-61668)

**NMMNH L-7060**

*Sphenacodon ferox* (assoc. vertebrae, neural spines and jaw frags of one individual, NMMNH P-61669)

**NMMNH L-7061**

*Tetrapoda* indet. (vertebra frag, NMMNH P-61670; bone frag, NMMNH P-61671)

NMMNH L-7062

?*Eryops* sp. (pleurocentrum, NMMNH P-61672)

*Diadectidae* indet. (zygapophyses, NMMNH P-61673; ungula phalanx, NMMNH P-61674)

**YPM lungfish locality**

*Gnathorhiza* (two tooth plates, YPM 8636-8637)