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DEFINITION AND CORRELATION OF THE LAMYAN: A NEW BIOCHRONOLOGICAL UNIT FOR THE NONMARINE LATE CARNIAN (LATE TRIASSIC)

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Abstract.—The Sonsela Member of the Petrified Forest Formation at Petrified Forest, Arizona and the Tres Lagunas Member of the Santa Rosa Formation in east-central New Mexico yield vertebrate fossil assemblages (faunas) that are intermediate in composition between the Adamanian and Revueltian lvfs in that they include co-occurrences of the phytosaurs *Rutiodon* and *Pseudopalatus* and the unique taxon *Typothorax antiquum*. These faunas define an upper subdivision of Adamanian time that we refer to as the Lamyan sub-faunachron. The earlier Adamanian is distinguished as the St. Johnsian sub-faunachron. This refinement demonstrates the utility of defining biochronologic units in that it spurs detailed examination of biostratigraphy and lithostratigraphy. The Lamyan provides evidence that there is no major tetrapod extinction within the Late Triassic, specifically at the end of the Carnian.

INTRODUCTION

The most complete sequence of Late Triassic nonmarine tetrapod fossil assemblages (faunas) is in the Chinle Group of western North America (Lucas, 1997). These faunas have formed the basis of a biochronological scheme that has global utility (Lucas and Hunt, 1993; Lucas, 1997, 1998, 1999). Thus, Lucas and Hunt (1993) defined four land-vertebrate faunachrons (lvfs) to encompass Late Triassic time based on the faunas of the Chinle Group. Subsequently, Lucas and others (Lucas et al., 1997; Lucas, 1998; Hunt, 2001) further refined this biochronology, which was principally based on the stratigraphic ranges of genera of phytosaurs and aetosaurs.

Recent work has refined the stratigraphic ranges of known tetrapod taxa and has recognized new records of taxa in strata of Adamanian age. These new data are principally from the Petrified Forest National Park (Heckert and Lucas, 2002; Hunt et al., 2002; Woody, 2003; Woody and Parker, 2004) in Arizona and the extensive exposures of the Chinle Group in east-central New Mexico (Hunt and Lucas, 1995b, 2005; Lucas et al., 2002). The purpose of this paper is to review some of these data as they relate to the late Carnian-Norian succession of tetrapod fossil assemblages in New Mexico and Arizona and to distinguish and define new biochronological intervals that further refine the existing biochronological scheme.

LATE TRIASSIC BIOCHRONOLOGY BASED ON PHYTOSAURS AND AETOSAURS

All vertebrate biochronologies of the Late Triassic have been primarily based on phytosaurs. Camp (1930), in his classic monograph on phytosaurs, recognized a lower interval of the Chinle Group characterized by various species of *Machaeroprosopus* (e. g. *M., adamanensis*, *M. lithodendorum*, *M. zunii*), which are now referred to *Rutiodon* (*Leptosuchus* of some authors e.g., Long and Murry, 1995), and an upper Chinle Group interval characterized by the species *M. tenuis*, *M. andersoni* and *M. validus,* which are now referred to *Pseudopalatus* (e.g., Ballew, 1989; Hunt, 1994; Long and Murry, 1995). These and subsequent authors (e. g., Long and Ballew, 1985; Ballew, 1989; Lucas and Hunt, 1993; Long and Murry, 1995; Lucas, 1998) recognized this fundamental division, together with other tetrapod taxa (including phytosaurs) defining older and younger portions of the Chinle.

Aetosaurs, which were originally considered to be a subset of phytosaurs, began to have biochronological utility with the work of Gregory (e. g., 1953) and later Long and Ballew (1985), who clarified issues of alpha taxonomy. Thus, Lucas and Hunt (1993) recognized four land-vertebrate faunachrons (LVFs) based primarily on the temporal distribution of the genera of phytosaurs and aetosaurs, which are in ascending order of age: Otischalkian, Adamanian, Revueltian and Apachean. The Adamanian (late Carnian) and Revueltian (Norian) are of concern here. The Adamanian is based on index taxa that include the phytosaur *Rutiodon* and the aetosaurs *Desmatosuchus haplocerus* and *Stagonolepis*, and the Revueltian includes the phytosaur *Pseudopalatus* and the aetosaur *Typothorax*.

It is important to note that this biochronology has held up remarkably well, and in some cases has been improved, in spite of extensive work on the systematics and stratigraphic distribution of the key index taxa, especially the aetosaurs (e.g., Lucas and Heckert, 1996; Heckert and Lucas, 1998b, 2000). Lucas et al. (2002a) distinguished a new species of *Typothorax, T. antiquum,* and demonstrated that this taxon is restricted to the later Adamanian, whereas the type species, *T. coccinarum,* is an index taxon of the Revueltian. Similarly, Zeigler et al. (2002a) identified a new species of *Desmatosuchus*, *D. chamaensis*, which is restricted to strata of Revueltian age.

EAST-CENTRAL NEW MEXICO

Lithostratigraphy of the Chinle Group

Rich (1921) first published the name Santa Rosa Sandstone in reference to a sandstone-dominated package at the base of the Triassic sequence in east-central New Mexico, and Darton (1922, p. 183) formally named it (Fig. 1). Following Gorman and Robeck (1946), several workers subdivided the Santa Rosa Formation. Lucas and Hunt (1987) removed the basal unit as the Anton Chico Member of the Moenkopi Formation and formalized a subdivision of the remaining portion of the Santa Rosa

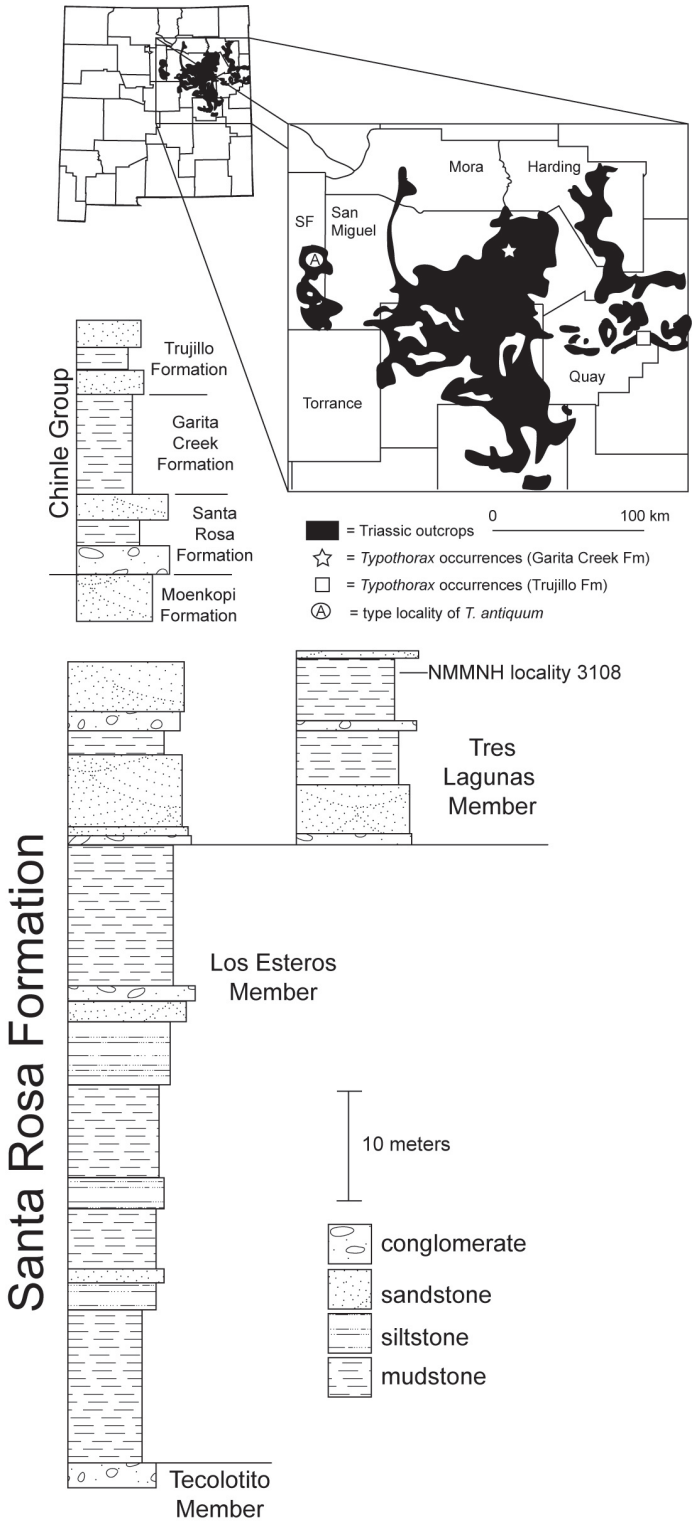


FIGURE 1. Lithostratigraphy of the Santa Rosa Formation and Chinle Group in east-central New Mexico. NMMNH locality 3108 is the type locality of *Typothorax antiquum* and yielded the partial phytosaur skull (NMMNH P-25745) identified here as *Pseudopalatus* sp. (Fig. 4).

Formation into members, in ascending order: Tecolitito (up to 34 m of sandstone and conglomerate), Los Esteros (up to 44 m of dominantly mudstone and subordinate sandstone and conglomerate), and Tres Lagunas (up to 46 m of dominantly sandstone with subsidiary conglomerate and mudstone) (Fig. 1). The Tres Lagunas Member of the Santa Rosa Formation is usually a cliff-forming sandstone unit throughout most of its outcrop belt, but in Santa Fe County it consists of two sandstones with a medial mudstone interval (Fig. 1).

Overlying the Santa Rosa Formation in east-central New Mexico is a sequence of stratigraphic units with a complex history of nomenclature (Lucas et al., 1985; Lucas and Hunt, 1989) that are now assigned to the Chinle Group of Lucas (1993). These units are (in ascending order) the Garita Creek, Trujillo, Bull Canyon and Redonda formations (Lucas and Hunt, 1989; Lucas et al., 2001). The Garita Creek Formation was first distinguished as the "lower shale member" of the Chinle Formation by Kelley (1972), and it was subsequently formalized by Lucas and Hunt (1989). The Garita Creek is up to 76 m of mudstone with lesser amounts of sandstone and conglomerate.

The Trujillo Formation is as much as 68 m-thick and is a dominantly sandstone unit that represents a medial, ledge-forming unit of the Chinle Group in east-central New Mexico. It was first recognized in New Mexico by Darton (1928) and was named the Cuervo Member of the Chinle Formation (Kelley, 1972). Subsequently, Lucas and Hunt (1989) assigned these strata to the Trujillo Formation of Gould (1907). The Trujillo in eastern New Mexico is up to 68 m of mainly micaeous sandstone with minor beds of conglomerate and mudstone.

Lucas and Hunt (1989) named the Bull Canyon Formation for strata previously referred to the "upper shale member of the Chinle Formation" by Kelley (1972). The Bull Canyon Formation is up to 110 m of mostly mudstone, with lesser amounts of sandstone and minor beds of siltstone and conglomerate (Lucas et al., 2001).

The Redonda Formation of Dobrovolny et al. (1946) is the youngest Triassic stratigraphic unit in eastern New Mexico. The Redonda is up to 92 m of laterally continuous beds of sandstone, siltstone and mudstone of dominantly lacustrine origin (Hester and Lucas, 2001).

Tetrapod Biostratigraphy

The Santa Rosa Formation in east-central New Mexico yields scant vertebrate fossils except in Santa Fe County. The lowest Tecolotito Member has only produced abraded bone fragments (including material identifiable as large metoposaurs and phytosaurs) and petrified wood. The medial Los Esteros Member has yielded a diverse Adamanian fauna that includes the phytosaurs *Rutiodon* and *Angistorhinus* and the aetosaurs *Desmatosuchus haplocerus* and *Stagonolepis wellesi* (Hunt and Lucas, 1988, 1995b; Hunt et al., 1993). The uppermost Tecolotito Member has a fauna that includes the phytosaur *Pseudopalatus* and the aetosaur *Typothorax antiquum* (Lucas et al., 2002; Hunt and Lucas, 2005).

The Garita Creek Formation yields a sparse tetrapod assemblage that includes the aetosaurs *Desmatosuchus haplocerus* and *Typothorax antiquum* (Hunt et al., 1989; Lucas et al., 2002). The Garita Creek Formation is also host to the famous Lamy amphibian quarry, where dozens of individuals of the metoposaurid amphibian *Buettneria* are preserved (Romer, 1939; Colbert and Imbrie, 1956; Hunt, 1993; Zeigler et al., 2002c). The Trujillo Formation contains a very small fauna from eastern Quay County that includes a pseudopalatine-grade phytosaur and the aetosaur *Typothorax coccinarum* (Hunt, 1991, 2001; Lucas et al., 2002).

The Bull Canyon Formation yields the type fauna of the Revueltian lvf that includes the phytosaur *Pseudopalatus* spp. and the aetosaurs *Typothorax coccinarum*, *Desmatosuchus chamaensis*, *Aetosaurus* sp. and *Paratypothorax* sp. (Hunt, 2001; Zeigler et al., 2002a). The Redonda Formation yields the type fauna of the Apachean lvf, including the phytosaur *Redondasuchus* and the aetosaur *Redondasaurus* (Hunt and Lucas, 1991, 1993; Lucas et al., 2001; Heckert et al., 2001).

PETRIFIED FOREST NATIONAL PARK, ARIZONA

Lithostratigraphy of the Chinle Group

The Chinle Group is represented in Petrified Forest National Park in Apache and Navajo counties, Arizona by the following units (in ascending stratigraphic order): Bluewater Creek Formation, Blue Mesa, Sonsela and Painted Desert members of the Petrified Forest Formation and the Owl Rock Formation (Lucas, 1993, 1994, 1995; Heckert and Lucas, 2002).

The stratigraphically lowest Chinle strata in the Park were historically considered to pertain to the lower portion of the Blue Mesa Member of the Petrified Forest Formation (= lower Petrified Forest Formation; e.g., Billingsley, 1985a,b). Heckert and Lucas (1998a, 2002) have demonstrated that these beds actually represent the Bluewater Creek Formation. This unit consists of sandstone, bentonitic mudstone and siliceous, color-mottled strata (Heckert and Lucas, 2002).

The Blue Mesa Member of the Petrified Forest Formation (= lower Petrified Forest Formation of earlier authors: e. g., Stewart et al., 1972) of Lucas (1993) is 77 m thick at the Park. It consists of purple and white mudstones interbedded with sandstone beds of varying thickness and persistence (Lucas, 1993; Heckert and Lucas, 2002).

The Sonsela Member of the Petrified Forest Formation (Fig. 2) is widely exposed in northeastern Arizona and northwestern New Mexico (Lucas, 1993). The Sonsela is predominantly composed of sandstone and conglomerate and separates the mudstone-dominated Blue Mesa Member from the overlying, mudstone-dominated Painted Desert Member.

There has been some confusion historically as to which sandstone bodies within the Petrified Forest National Park pertain to the Sonsela. At its type section, the Sonsela consists of a tripartite sandstone-mudstone-sandstone division (Akers et al., 1958), with the medial mudstone portion strongly resembling the Blue Mesa Member in color and lithology. Heckert and Lucas (2002) formalized a nomenclature within the Park that also recognizes a tripartite Sonsela (Fig. 2). Thus, the Sonsela in the Park consists of a lower Rainbow Forest Bed (predominantly sandstone and conglomerate), a medial Jim Camp Wash Bed (interbedded mudstone and sandstone) and an upper Agate Bridge Bed (dominantly sandstone) (Fig. 2).

The Painted Desert Member of the Petrified Forest Formation was previously referred to as the upper Petrified Forest Formation (e. g., Long and Ballew, 1985). At its type section in the Park, the Painted Desert Member consists of 147 m of mudstone with

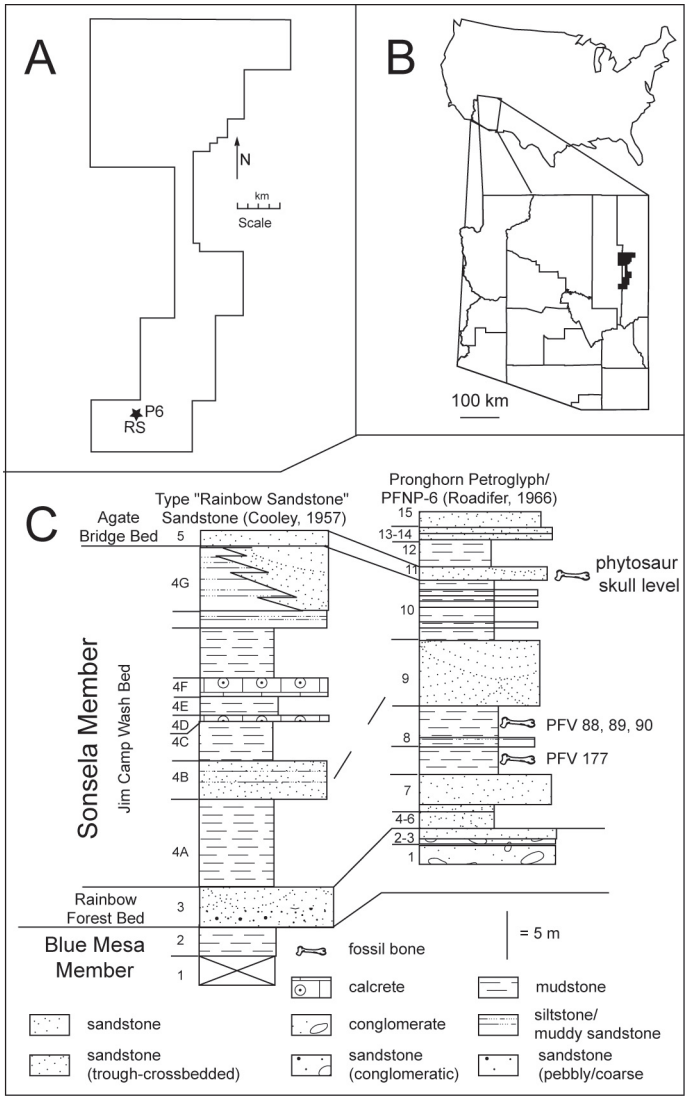


FIGURE 2. Location maps (A-B) and stratigraphic section (C) of the Sonsela Member of the Petrified Forest Formation at Petrified Forest National Park, Arizona (after Heckert and Lucas, 2002; Hunt et al., 2002). On A, RS marks the location of Cooley's (1957) Rainbow Forest measured section and P6 Roadifer's (1966) PFNP-6 section with additions from Heckert and Lucas (2002). Star marks the location of phytosaur skull in the Agate Bridge Bed of the Sonsela Sandstone (Fig. 3). The localities on the measured section correspond to the following: 90 = UCMP 84242, 89 = UCMP 84224 Bowman locality, 88 = UCMP V84220 Bat Cave, 87 = UCMP 84221 Jim Camp 1, 177 = UCMP V82232 Giant Logs.

minor sandstone, tuffaceous sandstone and conglomerate (Lucas, 1993; Heckert and Lucas, 2002). Several sandstone beds within this unit are laterally extensive and have been named (Heckert and Lucas, 2002).

Biostratigraphy

The limited outcrops of the Bluewater Creek Formation are unfossiliferous at Petrified Forest National Park. The Blue Mesa Member has been extensively collected over 80 years and it yields the type fauna of the Adamanian (late Carnian) lvf (Lucas, 1993, 1998; Lucas and Hunt, 1993; Hunt and Lucas, 1995a). This fauna includes the phytosaur *Rutiodon* spp. (= *Leptosuchus*), the aetosaurs *Desmatosuchus* and *Stagonolepis* and the dicynodont *Placerias*, among other, less biostratigraphically useful taxa.

The sandstone beds of the Sonsela Member contain few identifiable fossils. However, the Agate Bridge Bed includes the skull of a *Pseudopalatus*-grade phytosaur (Hunt et al., 2002) (Figs. 2-3). The Jim Camp Wash Bed contains a number of fossil localities (Hunt et al., 2002, fig. 1) that yield fragmentary aetosaur osteoderms. Long and Murry (1995) referred this material to the aetosaur *Typothorax coccinarum*. Hunt et al. (2002) noted field identifications of *Typothorax* sp. for stagonolepidid specimens from this stratigraphic interval. We believe that all these specimens pertain to *Typothorax antiquum*, which was not described until 2002 (Lucas et al., 2002). We have also seen fragmentary osteoderms in the Jim Camp Wash Bed that are only identifiable as *Typothorax* sp. We consider PEFO 26694 from the Rainbow Forest Bed to be specifically indeterminate and to represent *Typothorax* sp. (*Typothorax coccinarum* of Parker and Irmis, 2005, fig. 5E).

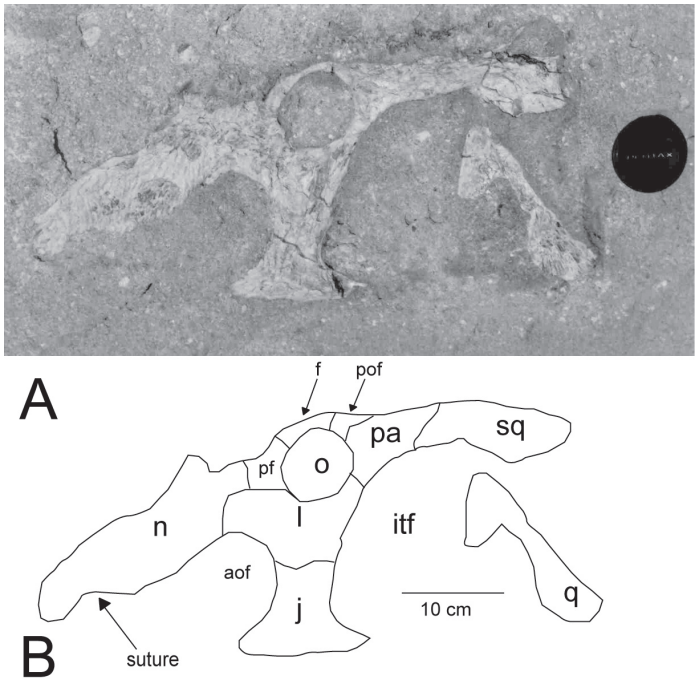


FIGURE 3. Phytosaur skull in Agate Bridge Bed of the Sonsela Member of the Petrified Forest Formation at Petrified Forest National Park, Arizona (Hunt et al., 2002). **A,** Skull fragment of pseudopalatine in field. **B,** Interpretative drawing of A. Abbreviations are: aof, antorbital fenestra, f, frontal, itf, inferior temporal fenestra, j, jugal, l, lachrymal, n, nasal, o, orbit, pf, prefrontal, pof, postfrontal, pa, parietal, q, quadrate, sq, squamosal.

The Jim Camp Wash Bed also includes *Rutiodon* (=*Leptosuchus*), *Pseudopalatus*, *Stagonolepis*, *Paratypothorax* and *Desmatosuchus* (Woody, 2003; Woody and Parker, 2004; Parker and Irmis, 2005). The Sonsela is an acme zone for *Paratypothorax* in the Chinle of the Petrified Forest National Park (Woody, 2003).

The Painted Desert Member of the Petrified Forest Formation yields a typical Revueltian (early-middle Norian) fauna (e.g., Lucas, 1993; Lucas and Hunt, 1993; Hunt and Lucas, 1995a; Lucas and Heckert, 1996). This fauna includes the phytosaur *Pseudopalatus* spp. and the aetosaur *Typothorax coccinarum*. The Owl Rock Formation is unfossiliferous in the park.

PSEUDOPALATUS IN THE SANTA ROSA FORMATION

Two partial phytosaur skulls from the Tres Lagunas Member of the Santa Rosa Formation in Santa Fe County represent pseudopalatines (Hunt and Lucas, 2005). These skulls have biochronological significance because the Santa Rosa Formation had previously only yielded specimens of the characteristic Adamanian phytosaur *Rutiodon*. Hunt and Lucas (1995b) tentatively identified these two specimens as "*Belodon*-grade" phytosaurs.

NMMNH P-25745 is a partial phytosaur skull from NMMNH locality 3108 (type locality of *Typothorax antiquum*) (Fig. 4) represented by the region posterior to the mid-point of the orbits. The specimen is approximately 300 mm wide and long and 90 mm high. It is not completely prepared and is largely covered by a thin concretionary layer, so that sutures are discernable in only some areas, particularly the skull deck. The skull is slightly flattened dorsoventrally. The anterior margin slopes anteriorly, so that the lateral temporal fenestrae are preserved on both sides. They are narrow and elongate dorso-posteriorly to anteroventrally. The supratemporal fenestrae are slit-like in dorsal view. The postorbital squamosal bar is relatively wide (400 mm at midpoint of supratmporal fenestra). The posterior squamosal process is extremely elongate; in lateral view it extends 105 mm posterior to the quadatojugal. This process has the shape of a rounded acute triangle in lateral view and has a bulbous tip. NMMNH P-25745 can be assigned to *Pseudopalatus* on the basis of possessing the following characteristics: a moderately wide postorbital-squamosal bar, posteriorly elongate squamosal process that lacks large pendant process, supratemporal fenestrae that are short and narrow in dorsal view with narrow anterior margins; and a parietal-supraoccipital complex that has an inverted U-shape (Ballew, 1989; Hunt, 1994; Zeigler et al., 2002b).

NMMNH P-25744 is a second skull fragment that represents the majority of a skull from the mid-rostrum to the anterior margin of the supratemporal fenestrae. It is less well preserved than NMMNH P-25745. The external nares are at the level of the skull deck. The anterior end of the supratemporal fenestra is only preserved on the right side, and it is narrow. The combination of external nares at the level of the frontals and narrow, slit-like

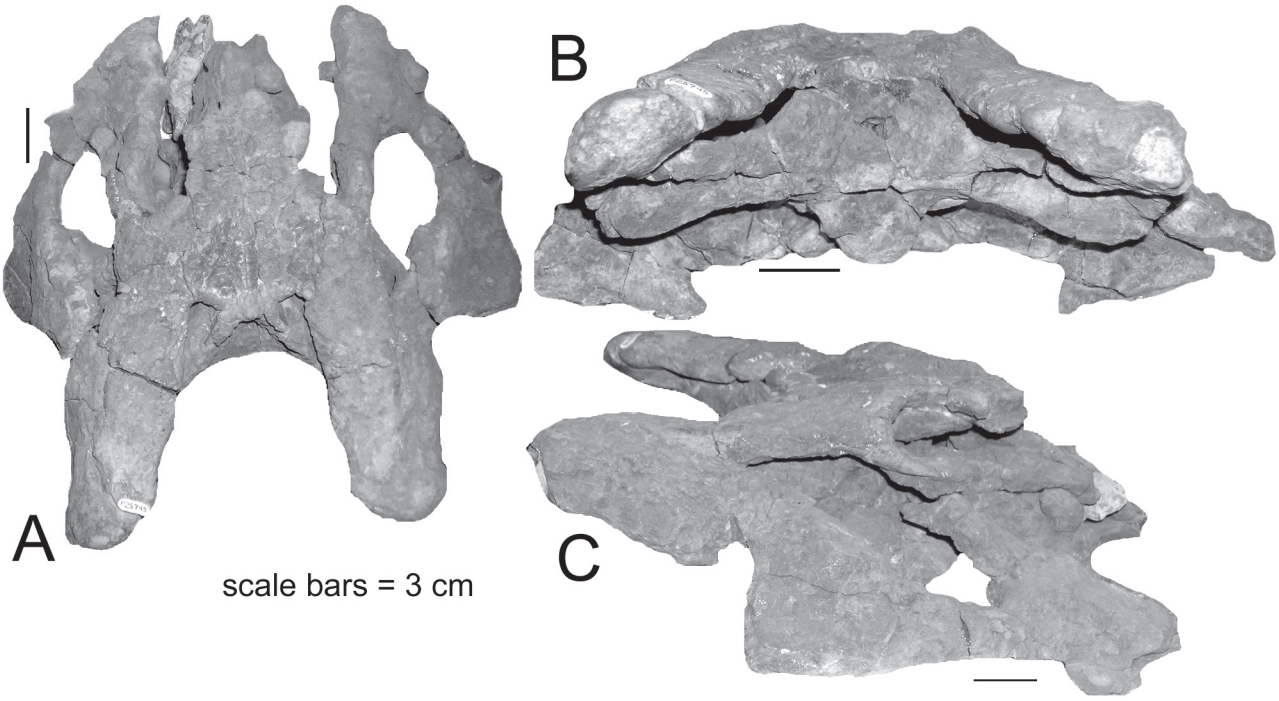


FIGURE 4. Partial skull of *Pseudopalatus* sp. (NMMNH P-25745) from NMMNH locality 3108, in the Tres Lagunas Member of the Santa Rosa Formation in Santa Fe County, New Mexico, in dorsal (A), posterior (B) and lateral (C) views.

supratemporal fenestrae might suggest an assignment to *Nicrosaurus*, but we are hesitant to make this identification based on such a poorly preserved specimen. However, we can conclude that this specimen is likely a *Pseudopalatus*-grade phytosaur.

BIOCHRONOLOGY

Data that necessitate a refinement of Late Triassic tetrapod biochronology include new information about lithostratigraphy and biostratigraphy. It is important to note that a major intent of a formalized biochronology is to spur a greater refinement of biostratigraphy, which has been achieved in this case.

At Lamy, recent work has recognized a significant mudstone interval within the Tres Lagunas of the Santa Rosa Formation that yields a fauna that contains the phytosaur *Pseudopalatus* and the aetosaurs *Typothorax antiquum* and *Stagonolepis* (Lucas et al., 2002; Hunt and Lucas, 2005b). Prior to 2002, both *Pseudopalatus* and *Typothorax* were thought to be restricted to the Revueltian lvf and to not co-occur with the Adamanian index taxon *Stagonolepis*.

Heckert and Lucas (2002) recognized that the Sonsela Member of the Petrified Forest Formation at Petrified Forest National Park comprises not a single sandstone bed, but also consists of a medial mudstone interval and a lower sandstone interval. The medial Jim Camp Wash Bed contains a mixture of tetrapod faunal elements previously considered restricted to the Adamanian lvf (*Buettneria, Trilophosaurus*, *Stagonolepis*, *Rutiodon* [=*Leptosuchus*], *Placerias*) and to the Revueltian lvf (*Pseudopalatus*) (Woody, 2003; Woody and Parker, 2004; Parker and Irmis, 2005). In addition, *Typothorax* sp. is also present in this stratigraphic interval (Woody, 2003; Woody and Parker, 2004; Parker and Irmis, 2005).

Clearly, the tetrapod fossil assemblages of the Tres Lagunas and Jim Camp Wash Bed indicate that there is a "transitional" fauna between the Adamanian and Revueltian lvfs (Woody and Parker, 2004). We term this interval the Lamyan. Should the Lamyan be a new lvf or a sub-unit of the Adamanian or Revueltian? We feel that this time interval does not merit the naming of a new lvf because the common elements of its fauna are not restricted to this time interval. We also consider that it should represent a subdivision of the Adamanian because the dominant elements of the fauna are typical of the Adamanian (*Rutiodon, Desmatosuchus haplocerus, Stagonolepis, Placerias*). The subdivision of the Adamanian into two sub-faunachrons is analogous to that proposed by Hunt (2001) for the Revueltian, in that a long-ranging fauna of common large terrestrial tetrapods can be subdivided by reference to less common and smaller faunal elements.

Adamanian Land-Vertebrate Faunachron

Lucas and Hunt (1993) defined the Adamanian LVF and it was subsequently redefined by Lucas et al. (1997) and Lucas (1998). Lucas and Hunt (1993) based the Adamanian LVF on the vertebrate fauna of the Blue Mesa Member of the Petrified Forest at Petrified Forest National Park. Lucas (1998) termed this the *Rutiodon* Assemblage Zone. It has long been clear that the typically Otischalkian phytosaurs *Paleorhinus* and *Angistorhinus* occur in the early Adamanian (Hunt et al., 1993; Lucas et al., 1997), so that there was a possibility of subdividing the Adamanian.

Lamyan land vertebrate sub-faunachron

Definition

The Lamyan is here characterized as the time period equivalent to the vertebrate fossil assemblage of the Tres Lagunas Member of the Santa Rosa Formation in Santa Fe County, New Mexico (Fig. 5). The Lamyan is named for the village of Lamy, which is close to the principal collecting area. The beginning of Lamyan time is defined as the FAD of *Typothorax antiquum*, which approximately equates to the FAD of *Pseudopalatus*. The end of the Lamyan is the beginning of the Revueltian, which is defined by the FAD of the aetosaur *Typothorax coccinarum* (Lucas et al., 2002).

First Appearance

Tetrapod first appearances in the Lamyan include *Pseudopalatus, Typothorax antiquum* and *Paratypothorax*.

Last Appearance

Tetrapod last appearances in the Lamyan include *Trilophosaurus jacobsi, Buettneria, Rutiodon, Stagonolepis, Desmatosuchus haplocerus, Poposaurus* and *Placerias.*

Index fossils

The only common tetrapod taxon restricted to the Lamyan is *Typothorax antiquum* Lucas et al. (2002a). This time is also the acme of *Paratypothorax* (Hunt and Lucas, 1992; Woody, 2003).

Type assemblage

The type fauna of the Lamyan is the assemblage of vertebrate fossils found in the Tres Lagunas Member of the Santa Rosa Formation near Lamy, New Mexico, which includes *Pseudopalatus*, *Desmatosuchus haplocerus*, *Rutiodon* and *Typothorax antiquum* (Hunt and Lucas, 1988, 1995b, 2005; Lucas et al., 2002).

Principal correlatives

The principal correlative of the type Lamyan assemblage is the vertebrate fauna from the lower part of the Sonsela Member (Rainbow Forest and Jim Camp Wash beds) of the Petrified Forest Formation at Petrified Forest National Park. The tetrapod fauna of the Garita Creek Formation of east-central New Mexico is also of Lamyan age.

Age

The Adamanian lvf is considered late Carnian in age on the basis of palynostratigraphy, sequence stratigraphy and magnetostratigraphy (Lucas, 1998). The Revueltian lvf is of Norian age based on the occurrence of *Aetosaurus* in Norian marine strata and on palynostratigraphy, sequence stratigraphy and magnetostratigraphy (Lucas, 1998).

The Lamyan interval is within the "Blue Mesa Member" magnetostratigraphic section of Steiner and Lucas (2000), which indicates that it is late Carnian age. Woody (2003) reported that the Sonsela may have yielded both late Carnian and Norian pollen. Sequence stratigraphic relationships suggest that the Sonsela is close to the Carnian-Norian boundary (Lucas, 1998). Thus, we consider it most likely on the basis of magnetostratigraphy, pollen and sequence stratigraphy that the Lamyan is of late, if not latest Carnian age.

Comments

This time interval is apparently not widely represented by fossil faunas in the Chinle Group. It appears that Lamyan time is either represented by the unconformity below the medial sandstone complex of the Chinle (Trujillo-Sonsela-Moss Back-Poleo) or within the lower portion of these sandstones, which are nearly devoid of identifiable fossils. The upper Trujillo in east-central New Mexico yields a small fauna that includes the Revueltian index taxon *Typothorax coccinarum* (Hunt, 1991, 2001; Lucas et al., 2001, 2002), indicating that at least the upper Trujillo in this area is of post-Lamyan age.

Hunt (2001) suggested that the interval of time represented by this portion of Trujillo deposition might be termed "?Rainbowforestan" and considered it part of the earliest Revueltian (R0 of his usage). However, the term "Rainbowforestan" is of doubtful validity and has not been utilized by other workers. Heckert and Lucas (2002) coined the term Rainbow Forest Bed for a stratigraphic unit that is Lamyan in age. We feel that the term "Rainbowforestan" is best abandoned at this time. If there is a discrete "Rainbowforestan" time interval then it is basal Revueltian in age and should receive a new name.

There is potential to subdivide the Lamyan in the future. The older Lamyan contains the dicynodont *Placerias*, the poposaurid *Poposaurus* and the ?sphenosuchian *Parrishea,* which are absent from the younger portion (Fig. 5).

St. Johnsian land vertebrate sub-faunachron

Definition

The St. Johnsian (Fig. 5) is here characterized as the time period equivalent to the vertebrate fossil assemblage of the *Placerias* quarry in the Bluewater Creek Formation in Apache County, Arizona. The St. Johnsian is named for the village of St. Johns, which is close to the principal collecting area. The beginning of St. Johnsian time is defined by the FAD of *Rutiodon* (*Leptosuchus* of some authors), which approximately equates to the FAD of *Desmatosuchus, Stagonolepis, and Placerias*. The end of the St. Johnsian is the beginning of the Lamyan, which is defined by the FAD of the aetosaur *Typothorax antiquum*.

First Appearance

Tetrapod first appearances in the St. Johnsian include *Rutiodon, Desmatosuchus haplocerus, Paratypothorax, Stagonolepis, Par-*

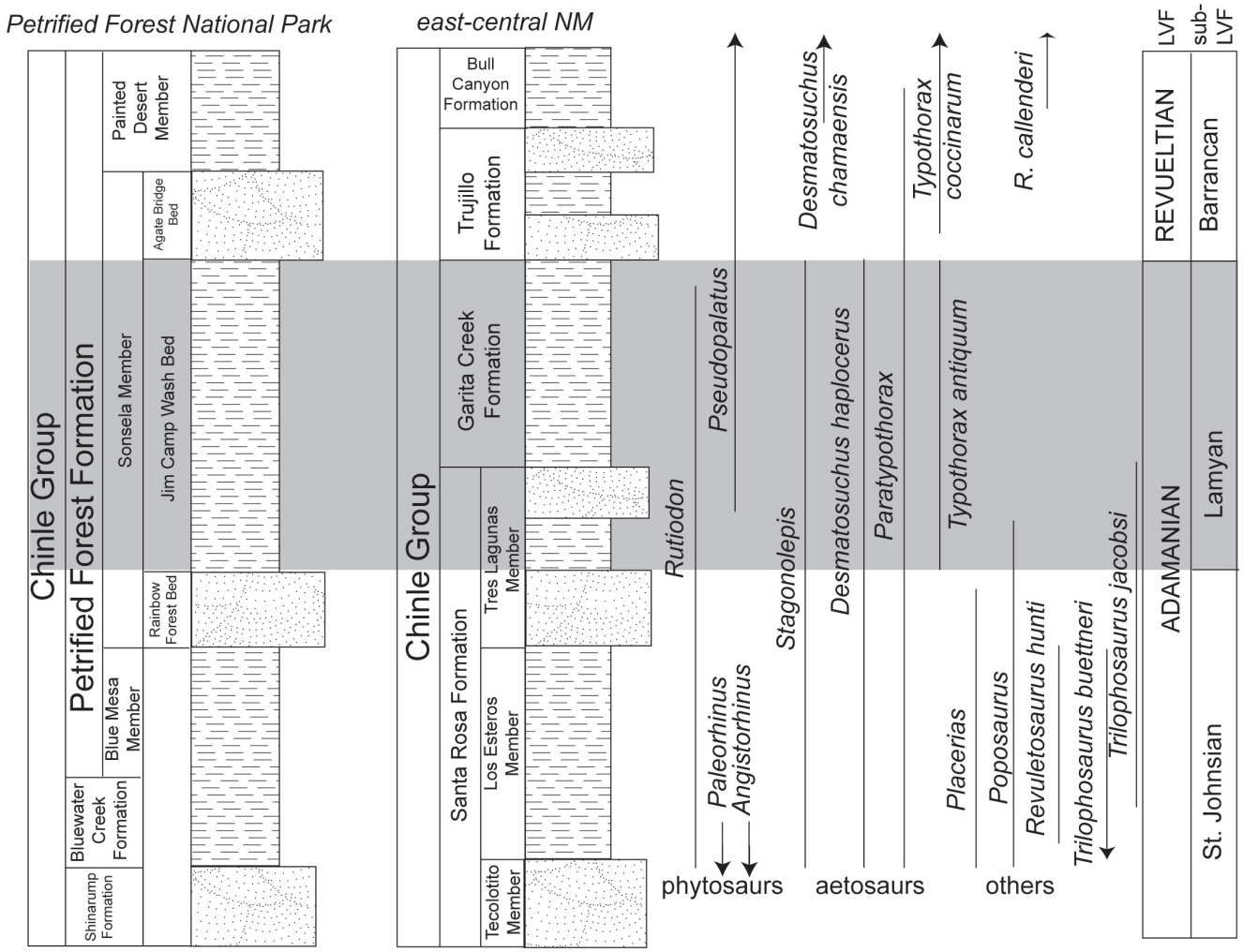


FIGURE 5. The lithostratigraphy and biostratigraphy of the Late Triassic Adamanian and Revueltian lvfs, and their subdivisions, in east-central New Mexico and Petrified Forest National Park, Arizona. The Lamyan interval is shaded.

rishia, Postosuchus, Hesperosuchus, "Revueltosaurus" hunti, *Crosbysaurus* and *Tecovasaurus*.

Last Appearance

Tetrapod last appearances in the St. Johnsian include *Paleorhinus*, *Angistorhinus*, and *Trilophosaurus buettneri*.

Index fossils

The St. Johnsian is principally recognized by the co-occurrence of the phytosaurs *Paleorhinus, Angistorhinus* and *Rutiodon* (and an absence of *Pseudopalatus*) and a co-occurrence of the aetosaurs *Desmatosuchus haplocerus* and *Stagonolepis* (and an absence of *Typothorax antiquum*). Relatively rare index taxa include the putative ornithischians *Revueltosaurus hunti*, *Crosbysaurus* and *Tecovasaurus* (Heckert, 2002, 2004).

Type assemblage

The type fauna of the St. Johnsian is the assemblage of vertebrate fossils found in the *Placerias* quarry of northeastern Arizona, which yields a diverse macro- and micro-vertebrate fauna (Lucas et al., 1997)

Principal correlatives

The principal correlatives of the St. Johnsian are the vertebrate faunas of the Blue Mesa Member of the Petrified Forest Formation in northeastern Arizona, the Tres Lagunas Member of the Santa Rosa Formation in east-central New Mexico and the Tecovas Formation of West Texas.

Age

The St. Johnsian interval of the Adamanian lvf is considered late Carnian in age on the basis of palynostratigraphy, sequence stratigraphy and magnetostratigraphy (Lucas et al., 1997; Lucas, 1998).

Comment

This time interval is widely represented by fossil faunas in the Chinle Group. It is clear that there is potential to subdivide the St.

Johnsian, as there is an older time interval that includes *Paleorhinus* and *Angistorhinus* and a younger one that does not (Hunt et al., 1993; Lucas et al., 1997) (Fig. 5).

Revueltian land-vertebrate faunachron

Redefinition

Lucas and Hunt (1993) named the Revuletian LVF, and Lucas (1998) subsequently refined the definition. Lucas (1998) termed this the *Pseudopalatus* Assemblage Zone. Hunt (2001) provided an exhaustive summary of the vertebrate fauna of the type Revueltian and proposed a possible further subdivision. The Revueltian is redefined here to begin with the FAD of the aetosaur *Typothorax coccinarum* (Lucas et al., 2002). The "*Pseudopalatus* Assemblage Zone" now equates to both Lamyan and Revueltian time.

Index fossils

The tetrapod taxa that are restricted to Revueltian time are widespread and/or common, including *Typothorax coccinarum*, *Aetosaurus*, *Desmatosuchus chamaensis* and *Revueltosaurus callenderi*.

Type assemblage

The type assemblage of the Revueltian is that of the Bull Canyon Formation in east-central New Mexico (Lucas and Hunt, 1993; Lucas, 1998; Hunt, 2001).

Principal correlatives

In the American Southwest, principal correlatives include the Painted Desert Member of the Petrified Forest Formation in Arizona, New Mexico, and Utah, and the Bull Canyon Formation in West Texas (Hunt, 2001). For correlatives outside of the American Southwest, see Lucas (1998).

Comment

The genera *Typothorax* and *Pseudopalatus* are no longer index taxa of the Revueltian, although the species *T. coccinarum* is restricted to this LVF.

THE LAMYAN AND THE MYTH OF AN END-CARNIAN MASS EXTINCTION

Olson (1952) defined a chronofauna, with its principal characteristic being a community that changed little in basic structure over a long period of time. The terrestrial tetrapod fauna of the Late Triassic of western North America well fits this definition (Hunt and Lucas, 2004). The Chinle Group of western North America extends from Texas in the south to Idaho in the north and preserves four superposed, biochronologically-distinct assemblages of Otischalkian (late Carnian), Adamanian (late Carnian), Revueltian (early-middle Norian) and Apachean (late Norian/Rhaetian?) age. These faunas range in age from about 225 to 200 Ma and thus encompass the majority of Late Triassic time.

Each of the four faunachrons has yielded extensive tetrapod assemblages from rocks that crop out of an area of more than 2.3 million square km. Each successive fauna has a similar trophic/guild structure. The most numerous carnivorous tetrapods are phytosaurs, which are represented by three morphs in each fauna that probably are two sexual dimorphs of one gracile species, and a second robust species (Hunt, 1989; Zeigler et al., 2002b). Each fauna also includes a large "rauisuchian" and the enigmatic *Shuvosaurus/Chatterjeea*. Theropod dinosaurs, including herrerasaurs and ceratosaurs, occur in all faunas, but they are rare except at one locality of Apachean age. Metoposaurid amphibians occur in all four faunas. The most numerous herbivores in each fauna are aetosaurs, represented by at least two genera, including one large form. Herbivorous dinosaurs, including ornithischians and prosauropods, are present but rare in all faunas.

There are genus- and species-level turnovers between many of the faunas, but the basic community structure remains constant in Chinle Group faunas over a period of about 20 million years. (Minor elements of the Chinle faunas indicate biochronologically significant trends such as the extinction of dicynodonts and rhynchosaurs and the early diversification of dinosaurs).

This is persuasive evidence that there is no major tetrapod extinction during the Late Triassic, specifically at the end of the Carnian, contrary to Benton (1986a, b, 1991, 1993). Marked faunal change across the Carnian/Norian boundary and within the Norian in other areas (notably Germany and South America) includes the loss of semiaquatic forms such as phytosaurs, proterochampsids and temnospondyls and an apparently explosive radiation of dinosaurs. The "Rosetta Stone" of Western North America indicates that these turnovers do not represent global event(s). The recognition of the Lamyan is important in this regard because it shows a "transitional" fauna between that of the late Carnian Adamanian lvf and the Norian Revueltian lvf.

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