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STRATIGRAPHY AND PALEONTOLOGY OF THE LOWER CHINLE GROUP (ADAMANIAN: LATEST CARNIAN) IN THE VICINITY OF ST. JOHNS, ARIZONA

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Abstract.—Topographically low exposures of Upper Triassic Chinle Group strata near St. Johns, Arizona, overlie the Middle Triassic Moenkopi Formation and can be assigned to four formation-rank units. These are, in ascending order, the Zuni Mountains (= "mottled strata"), Shinarump, Bluewater Creek (= "Mesa Redondo"), and Petrified Forest formations. Petrified Forest Formation strata in the vicinity of St. Johns pertain to three members, the basal Blue Mesa, medial Sonsela, and upper Painted Desert members. There are two principal unconformities in this section, the Tr-3 unconformity at the base of the Chinle and the Tr-4 unconformity at the top of the Blue Mesa Member. The Sonsela Member of the Petrified Forest Member disconformably overlies the Blue Mesa Member throughout this region. However, although the Sonsela consists of basal extrabasinal conglomerates overlain by coarse-grained sandstones, it does not always form a persistent bench or ledge, and often must be identified by lithology alone, not merely by topographic expression. In the northern and easternmost Blue Hills northeast of St. Johns, the Painted Desert Member of the Petrified Forest Formation crops out as badlands of reddish-brown, bentonitic mudstone.

Numerous important vertebrate fossils are known from the St. Johns area. The *Placerias* quarry south and west of St. Johns, arguably the richest Late Triassic tetrapod quarry in the world, is very low in the Bluewater Creek Formation, only a few meters above the top of the Zuni Mountains Formation. The presence of the aetosaur *Stagonolepis* and the phytosaur *Rutiodon* at the *Placerias* quarry establish an Adamanian age for this fauna. Vertebrate fossils found in the Blue Hills northeast of St. Johns are stratigraphically high in the Bluewater Creek Formation and very low in the Blue Mesa Member of the Petrified Forest Formation. Fossil vertebrate collections from the Blue Hills include the type specimen of the phytosaur *Rutiodon* (=*Machaeroprosopus*) *zunii* and an incomplete skeleton of the aetosaur *Stagonolepis wellesi*. These index fossils of the Adamanian land-vertebrate faunachron indicate an Adamanian age for the fossil assemblages of the Blue Hills. Furthermore, the National Museum of Natural History (Smithsonian) fossil vertebrate collection includes two *Rutiodon* skulls from the vicinity of St. Johns, further supporting the Adamanian age of lower Chinle Group strata in this area.

INTRODUCTION

The St. Johns area in east-central Arizona and western New Mexico contains the easternmost outcrops of the Upper Triassic Chinle Group in the drainage basin of the Little Colorado River (Fig. 1). This area of relatively subdued topography is often mantled by covered intervals, but some of the outcrops here are developed as extensive badlands, and contain several important fossil localities, including the world-famous *Placerias* quarry. Therefore, understanding the stratigraphy of the St. Johns area is critical to developing and testing biostratigraphic and biochronologic hypotheses about the Late Triassic.

Vertebrate paleontologists have long known of the fossiliferous Triassic strata around St. Johns, and various parties working for the University of California Museum of Paleontology (UCMP) and United States National Museum (Smithsonian—USNM) have made significant collections in this area (Long and Murry, 1995). More recently, we have also initiated a collecting program in the vicinity of St. Johns, principally by exploiting localities brought to our attention by NMMNH research associate, Stan Krzyzanowski.

Here, we briefly detail the history of past stratigraphic work in the St Johns area, list our stratigraphic observations, describe the faunas from the vicinity of St. Johns, and place them in a biostratigraphic and biochronologic framework. Throughout this paper NMMNH = New Mexico Museum of Natural History, Albuquerque; PFNP = Petrified Forest National Park, Arizona; UCMP = University of California Museum of Paleontology, Berkeley; USNM = United States National Museum (Smithsonian), Washington, D.C.

HISTORY OF STUDY

Dutton (1885) first studied low badlands of Triassic rock surrounding St. Johns, Arizona. Charles Camp was alerted to the presence of fossil bones from outcrops southwest of town in the 1920s when passing through St. Johns (Long and Murry, 1995), and the site he excavated soon became known as the "*Placerias* quarry," after the minimum of 39 individual dicynodonts preserved there (Camp and Welles, 1956; Long et al., 1989; Long and Murry, 1995; Fiorillo et al., 2000). Parties under the direction of Camp also excavated phytosaurs, including the type specimen of "*Machaeropro-*

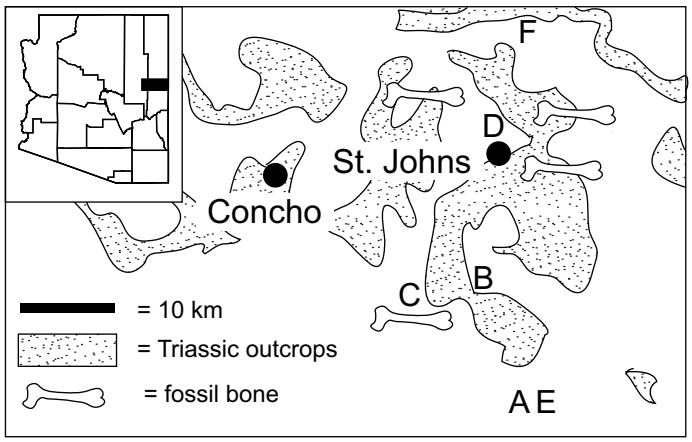

FIGURE 1. Map of the St. Johns area showing Triassic outcrops (shaded), fossil localities (bones) and locations of measured sections in Figure 2 (letters). Outcrop pattern after Stewart et al. (1972a).

sopus" [=*Rutiodon*] *zunii* and other reptiles from localities in the badlands of the Blue Hills northeast of St. Johns (Camp, 1930).

Also during the 1920s, 1930s, and 1940s, the United States National Museum collected fossil vertebrates in eastern Arizona. In particular, G.E. Hazen collected two phytosaur skulls from the vicinity of St. Johns in the 1940s. One of these specimens came from near Picket House Draw and was collected in September, 1946. The other specimen has less precise locality information, but was collected in the vicinity of St. Johns in 1948. These specimens were mentioned by Long and Murry (1995) and reviewed by Lucas and Heckert (2000).

Camp and Welles (1956) focused primarily on the abundant fossils of *Placerias* from the *Placerias* quarry area and made few stratigraphic observations. They did note, however, the general lack of outcrop in the vicinity of the *Placerias* quarry, concluding that the presence of *Rutiodon* (=*Machaeroprosopus*) indicated that the beds are low in the Chinle (Camp and Welles, 1956, p. 258-9). Likewise, Camp considered the *Rutiodon* skull in the Blue Hills to have come from the lower Petrified Forest Member of the Chinle Formation (Camp, 1930; Camp and Welles, 1956).

Cooley (1957, 1958) studied Chinle Group stratigraphy in the St. Johns area. He measured the type section of his Mesa Redondo Member of the Chinle Formation approximately 25 km west-northwest of St. Johns (Cooley, 1958). This unit is homotaxial with, but significantly more sandstone-dominated than, his "lower red member," which Lucas and Hayden (1989) subsequently named the Bluewater Creek Formation. Stewart et al. (1972a) utilized Cooley's stratigraphic terminology in the St. Johns area, where they measured four sections, three of which are pertinent to discussion of the lower Chinle Group (Figs. 1-2). They also recognized the Bluewater Creek Formation as their "lower red member" of the Chinle in the Blue Hills.

Akers (1964) continued to map the area of the *Placerias* quarry as within the lower Petrified Forest Member, a conclusion supported by Jacobs and Murry (1980, p. 56): "[The *Placerias* quarry is] low in the Petrified Forest Member, low in the Chinle." Tannenbaum (1984) and Kaye and Padian (1994) described numerous microvertebrate fossils from the *Placerias* quarry, expanding the database begun by Jacobs and Murry in 1980, but made no contribution to the understanding of the geology or stratigraphy of the area. Lucas et al. (1992) noted that the relatively low stratigraphic position of the *Placerias* quarry indicated that a small ceratosaur (holotype of *Camposaurus arizonensis* of Hunt et al., 1998) from the quarry is one of the oldest known dinosaurs. Comments on the taphonomy of the *Placerias* quarry by Fiorillo and Padian (1993) made no additional insight into the stratigraphic position of the quarry, instead furthering the accepted belief in its position within the Petrified Forest Member.

Lucas (1993) raised the Chinle to group status, thereby raising all former members to formation status. Lucas and Heckert (1996), Heckert and Lucas (1997), Lucas et al. (1997), and this report all demonstrate that the *Placerias* quarry is stratigraphically much lower than previously believed, and is at the base of the Bluewater Creek Formation. Fiorillo et al. (2000) published a detailed study of the taphonomy of the site. Stratigraphically, they merely enumerated the stratigraphic assertions of previous authors, including Camp and Welles (1956), Cooley (1957), Stewart et al. (1972), and Lucas et al. (1997), without reaching a conclusion.

Dubiel et al. (1993) considered stratigraphically low Chinle outcrops near St. Johns, particularly in the Blue Hills, to pertain to the Monitor Butte Member of the Chinle Formation. Following the work of Green (1956), they also noted that many of the beds of sandstone there appear to demonstrate syndepositional slumping. Lucas and Hunt (1993a) refuted their arguments, and placed these strata in the Bluewater Creek Formation of Lucas and Hayden (1989) and considered the tilted beds part of the regional pattern of Laramide deformation. Dubiel et al. (1993) did not address the stratigraphic position of the *Placerias* quarry.

STRATIGRAPHY OF THE ST. JOHNS AREA

Lower Chinle Group units cropping out at or near St. Johns, Arizona, are assigned to the (in ascending order): Zuni Mountains (= "mottled strata"), Shinarump, Bluewater Creek (=Mesa Redondo), and Petrified Forest formations. The Petrified Forest Formation consists of the Blue Mesa, Sonsela, and Painted Desert members (Fig. 2).

The Zuni Mountains Formation disconformably overlies sediments of the Moenkopi Formation and is disconformably overlain by the Shinarump Formation in places. Locally, the Shinarump Formation is absent, and the Bluewater Creek Formation disconformably overlies the Zuni Mountains Formation. Shinarump Formation strata in the St. Johns area are as much as 10 m of trough-crossbedded conglomeratic sandstones and extrabasinal conglomerates. The Bluewater Creek Formation consists of as much as 50 m of stacked mudstones and sandstones and dominates the low badlands exposures of the Blue Hills near St. Johns and is the dominant unit above either the Shinarump or the Zuni Mountains formations. A persistent, ripple-laminated, bench-forming sandstone high in the Bluewater Creek Formation is the southwesternmost known outcrop of the McGaffey Member, a unit first identified in New Mexico by Anderson and Lucas (1993).

We use the term Bluewater Creek Formation to replace the more problematic Mesa Redondo Formation. As originally described by Cooley in his thesis (1957) and subsequent papers (1958, 1959), the Mesa Redondo Formation is considerably thinner (<40 m) and dominated by sandstones, but is otherwise homotaxial with the Bluewater Creek Formation or, possibly, part of the Shinarump and/or Zuni Mountains formations. Indeed, we have re-measured the type section of the Mesa Redondo Formation described by Cooley (1958) (Fig. 2). In doing so we discovered that: (1) the lower part includes strata, among them extrabasinal conglomerates, better assigned to the Shinarump Formation; (2) typical Mesa Redondo Formation strata are generally similar to strata assigned by us to the Bluewater Creek Formation elsewhere, and (3) the type section lacks a top—uppermost exposed "Mesa Redondo" strata are a stripped surface, with the nearest exposures of stratigraphically equivalent and younger rocks several kilometers to the north. We also note here that, with the exception of Stewart et al. (1972) and our own work (e.g., Heckert, 1997; Heckert and Lucas, 1997, 2001), almost no worker has ever used the term Mesa Redondo to describe a Triassic stratigraphic unit in this area. Fur-

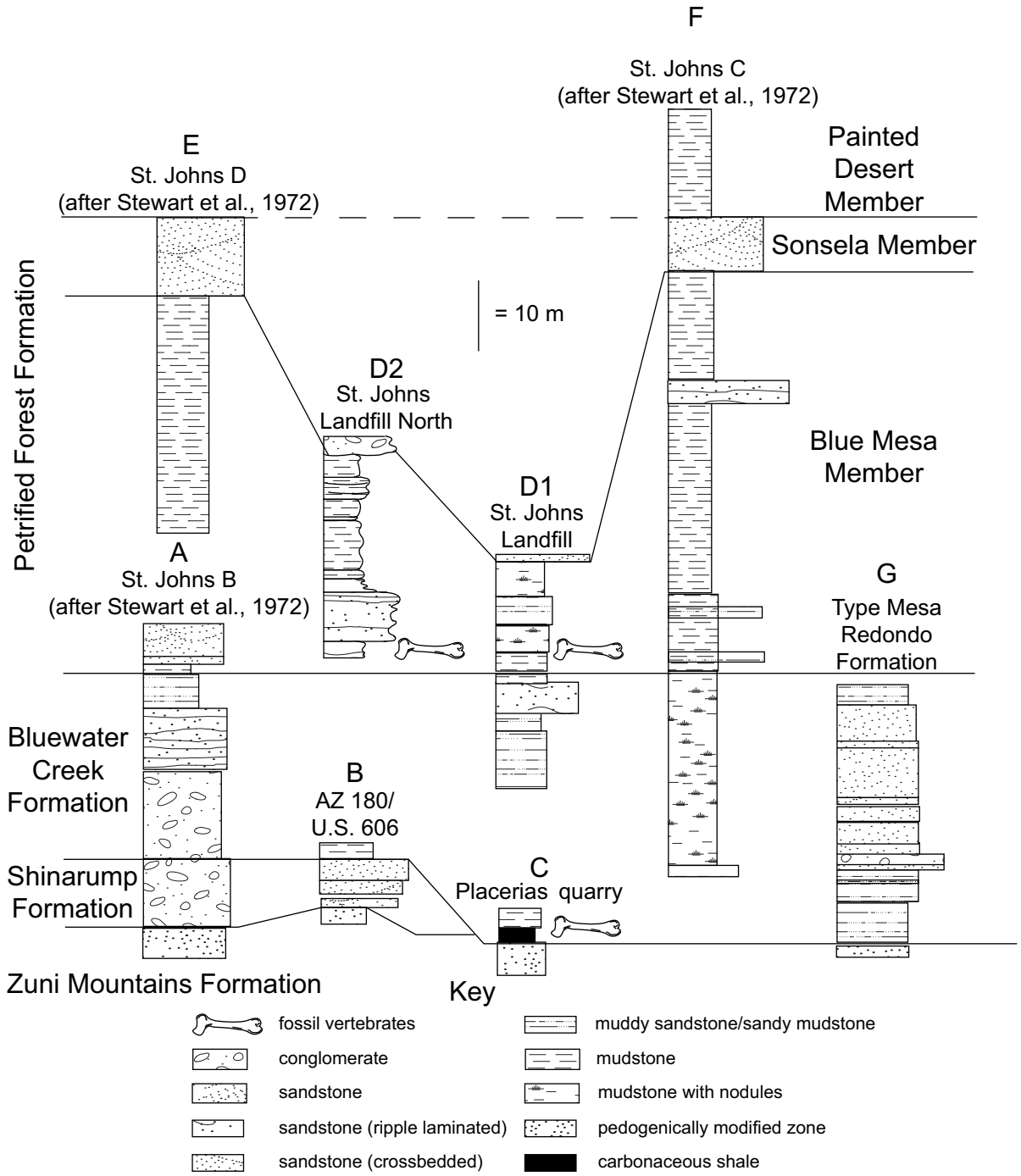

FIGURE 2. Correlated measured sections in the vicinity of St. Johns, Arizona. Locations of sections shown in Figure 1. For detailed descriptions of measured sections see Stewart et al. (1972) and Heckert (1997).

thermore, the topographic feature Mesa Redondo is a grammatical error, and should have been identified as Mesa Redonda. In contrast, the original type section of the Bluewater Creek Formation (Lucas and Hayden, 1989; see also Heckert and Lucas, 2002b) is well exposed and complete, with unambiguous upper and lower contacts. In light of all these factors, we abandon the term "Mesa Redondo" for Chinle strata and replace it with Bluewater Creek Formation, except where, as we noted, basal "Mesa Redondo" strata are better assigned to the Shinarump Formation.

In the St. Johns area, the Blue Mesa Member conformably overlies the Bluewater Creek Formation and maintains a thickness significantly thinner (<30 m) than at the Petrified Forest National Park (Lucas, 1993; Heckert and Lucas, 2002a). This is probably due to erosion associated with development of the Tr-4 unconformity (Heckert and Lucas, 1996).

Bentonitic mudstones and sandstones of the Blue Mesa Member represent floodplain and channel depositional environments, respectively. The Sonsela Member of the Petrified Forest

Formation disconformably overlies the Blue Mesa Member north of St. Johns. The Sonsela Member in the Blue Hills yields petrified trunks of the conifer *Araucarioxylon*, although these are not as common as those from the same unit at Petrified Forest National Park (Heckert and Lucas, 1998). Although the entire lower Chinle Group section is not preserved intact at a single locality anywhere in the region due to low topographic relief and structural complexities, the total sedimentary succession from the base of the Chinle to the top of the Sonsela is generally less than 100 m thick (Fig. 2).

One key aspect of our recent work is recognition of the Sonsela Member in the Blue Hills. Extensive stratigraphic work both here and in the vicinity of the Petrified Forest National Park reveals that there is no pinch-out of the Sonsela anywhere in eastern Arizona (Heckert and Lucas, 2002a). What does happen is that, locally, the Sonsela thins to <1 m of coarse sandstone over an extrabasinal conglomerate lag. In many places, this lithologic change is not expressed in the weathering profile, so there is no prominent bench or ledge where the Sonsela crops out. However, careful stratigraphic work shows that Sonsela lithologies are always present in Chinle sections, typically between reddish purple mudrocks of the overlying Painted Desert Member and bluish purple mudrocks of the underlying Blue Mesa Member. Indeed, this subtle color change is useful in identifying the Sonsela interval at a distance.

VERTEBRATE PALEONTOLOGY

Diverse vertebrate fossil assemblages are known from both the *Placerias*/Downs' quarries (Camp and Welles, 1956; Jacobs and Murry, 1980; Tannenbaum, 1984; Kaye and Padian, 1994; Long and Murry, 1995) and several localities in the Blue Hills (Camp, 1930; Long and Murry, 1995). The named vertebrate fossils described by various authors are summarized in Table 1. Phytosaur taxonomy used here follows Ballew (1989), Hunt (1994), and Hungerbühler (2002), rather than Long and Murry (1995). Long and Murry (1995) and Lucas and Heckert (2000) also briefly summarized other collections from this area, made principally by parties working for the USNM, and we augment those summaries with illustrations (Fig. 3). Polycn et al. (2002) recently described several vertebrate faunas from the vicinity of Stinking Springs Mountain, northwest of St. Johns and approximately halfway between St. Johns and the Petrified Forest National Park to the northwest. These faunas support the lithostratigraphic and biostratigraphic conclusions we advance here.

This region is paleontologically important for several reasons. The *Placerias* quarry represents the largest accumulation of dicynodonts in the Upper Triassic. Its fauna, combined with that of the Downs' quarry, is also one of the most diverse macrovertebrate assemblages known in the Upper Triassic, and the addition of the microvertebrates reported by Tannenbaum (1984) and Kaye and Padian (1994) ranks the combined *Placerias*-Downs' quarries as one of the most diverse assemblages of Triassic vertebrates known. In addition to the common forms, some fragmentary vertebrate taxa found at the *Placerias* quarry are dinosaurs (Lucas et al., 1992; Hunt and Lucas, 1994; Kaye and Padian, 1994; Long and Murry, 1995; Hunt et al., 1998), which, by the biostratigraphy and biochronology utilized here, must be some of the oldest known dinosaurs (Lucas et al., 1992).

Northeast of St. Johns, the Blue Hills Chinle outcrops also yield a diverse tetrapod assemblage from the uppermost Bluewater Creek Formation and the lowermost Blue Mesa Member of the Petrified Forest Formation (Fig. 2; Table 1). The macrovertebrate assemblage includes numerous *Rutiodon*-grade phytosaurs, including the type of *Rutiodon* (= *Machaeroprosopus*) *zunii* (Camp), the aetosaurs *Stagonolepis* (= *Calyptosuchus*) *wellesi* (Long and Ballew) and *Desmatosuchus haplocerus* (=*Acaenasuchus geoffreyi*) (Cope), the metoposaurid amphibians *Buettneria perfecta* Case and *Apachesaurus gregorii* Hunt, the "pseudosuchian" *Parrishea mccreai* Long and Murry, the poposaurid *Poposaurus gracilis* Mehl, and indeterminate ornithischian dinosaurs as well as the dipnoan *Arganodus* sp. (Long and Murry, 1995; Heckert, 2001). More recently we reported an assemblage of small vertebrates, including at least one and probably two theropod dinosaurs (Heckert et al., 1999; Heckert, 2001). Thus, while this assemblage is stratigraphically higher than the *Placerias* quarry, it also includes the Adamanian index taxa *Rutiodon* and *Stagonolepis*, indicating that Adamanian time lasted throughout the deposition of at least 50 m of strata locally (Fig. 2).

Other Upper Triassic tetrapod fossils from the vicinity of St. Johns include several collections now in the Smithsonian (USNM). Long and Murry (1995) listed a sparse fauna of *Buettneria perfecta* and *Rutiodon* (= *Leptosuchus*) from Picket House Draw, approximately 5 km east of St. Johns. Lucas and Heckert (2000) identified a phytosaur skull (USNM 17098) as *Rutiodon* sp. and indicated that the Bluewater Creek Formation was the likely horizon of collection, 15 m above the Chinle-Moenkopi contact. This specimen, USNM 17098, is a large skull of *Rutiodon* (= *Leptosuchus* of Long and Murry, 1995) (Fig. 3).

Long and Murry (1995, p. 213) listed the dipnoan *Arganodus* sp., the metoposaurid amphibian *Buettneria perfecta*, the aetosaur *Stagonolepis wellesi* and *Rutiodon*-grade phytosaurs from "Big Hollow Wash N" approximately 5 km northwest of St. Johns. Lucas and Heckert (2000) identified the phytosaur material from this locality (USNM 183131) as *Rutiodon* and indicated that it was presumably collected from the Bluewater Creek Formation.

Importantly, the *Rutiodon* skulls are not from classic collecting localities such as the *Placerias* quarry, the Blue Hills, or within the PFNP. This suggests that additional work in east-central Arizona may yield additional significant Upper Triassic tetrapod records.

TETRAPOD BIOCHRONOLOGY

Lucas and Hunt (1993b, see also Lucas, 1998) established a four-fold vertebrate biostratigraphic subdivision of the Chinle Group (Fig. 4). According to this scheme, the lower two divisions, the Otischalkian (early late Carnian) and Adamanian (latest Carnian) land-vertebrate faunachrons (lvf) divide fossil-bearing lower Chinle Group strata into a biostratigraphic succession of two faunas. In gross terms, the phytosaurs *Paleorhinus* and *Angistorhinus* and the aetosaur *Longosuchus* typify the Otischalkian, whereas the phytosaur *Rutiodon* and the aetosaur

Table 1: Tetrapod Faunal List of the Lower Chinle Group in the Vicinity of St. Johns, Arizona.

Taxa	*Placerias*-Downs' quarries	Blue Hills
Amphibia:	*Buettneria perfecta*	*Buettneria perfecta*
	Apachesaurus gregorii	*Apachesaurus gregorii*
	numerous undescribed microvertebrate forms	
Primitive Reptiles:	*Trilophosaurus* sp.	
	Tanytrachelos sp.	
	Chinleogomphius jacobsi	
	Numerous undescribed microvertebrate forms	
Dicynodonts:	*Placerias hesternus*.	*Placerias* sp.
Phytosaurs	*Paleorhinus* sp.	*Rutiodon* spp.
	Rutiodon spp	
Aetosaurs:	*Desmatosuchus haplocerus* (includes *Acaenasuchus*)	*Desmatosuchus haplocerus* (includes *Acaenasuchus*)
	Stagonolepis wellesi	*Stagonolepis wellesi*
Rauisuchians	*Postosuchus* sp.	*Postosuchus* sp.
	Chatterjeea elegans	Aff. *Saurosuchus*
Poposaurids	*Poposaurus gracilis*	*Parrishea* sp.
Dinosauria:	*Tecovasaurus murryi*	Indeterminate ornithischian
	herrerasaurid theropod	
	ceratosaurian theropod	Derived theropod(s)
Trace fossils (vertebrate):	abundant coprolites	coprolites

Stagonolepis serve as index taxa of the Adamanian. The faunas of the St. Johns area are particularly interesting because taxa known from both the Otischalkian and the Adamanian lvfs co-occur at the *Placerias*-Downs' quarries in the Bluewater Creek Formation. No tetrapod fossils have been reported from either the Shinarump or the "Mesa Redondo" formations, so all biostratigraphy in the area relies on the vertebrate records of the Bluewater Creek Formation and the Blue Mesa Member, including the fauna of the *Placerias*-Downs' quarries. Biochronologically useful fossils known from the *Placerias* quarry include the phytosaurs *Paleorhinus* and *Rutiodon* and the aetosaurs *Stagonolepis* and *Desmatosuchus* (Long and Murry, 1995; Lucas et al., 1997).

Biochronologically useful fossils reported from the Bluewater Creek Formation in the Blue Hills include numerous specimens of the phytosaur *Rutiodon* and the aetosaur *Stagonolepis* (Camp, 1930; Long and Murry, 1995). Almost all of these fossils indicate an Adamanian (latest Carnian) age. The presence of *Paleorhinus*, elsewhere known only from strata of Otischalkian (late Carnian) age (Hunt and Lucas, 1991), is the sole exception (Fig. 4).

Lucas (1998) defined the beginnings of eight Triassic land-vertebrate faunachrons based on the first appearance datum (FAD) of tetrapod index taxa. He thus defined the beginning of the Otischalkian by the first appearance of *Paleorhinus* and the beginning of the Adamanian by the first appearance of *Rutiodon*. Thus, the presence of *Rutiodon*, by definition, indicates an Adamanian age for the *Placerias* quarry, and we consider the *Paleorhinus* specimen a holdover from the Otischalkian (Lucas et al., 1997).

Numerous lines of evidence support the Adamanian age of the *Placerias* quarry. Long and Murry (1995) recognized literally hundreds of elements, principally osteoderms (= scutes), of the aetosaur *Stagonolepis* in the UCMP collections from the *Placerias*/Downs' quarries. *Stagonolepis* is an index taxon of the Adamanian lvf (Lucas and Hunt, 1993b; Lucas et al. 1997; Lucas, 1998). Similarly, Long and Murry (1995) note that remains of *Desmatosuchus* also number in the hundreds. Furthermore, we consider *Acaenasuchus* to be a junior subjective synonym of *Desmatosuchus*, as the former appears to represent a juvenile of the latter, and is in fact only known from deposits of Adamanian age that also produce fossils of *Desmatosuchus* (Lucas et al., 1997; Heckert and Lucas, 2002c). This further increases the observed number of specimens of *Desmatosuchus* known from this locality by as many as 30 additional osteoderms found at the two quarries (Long and Murry, 1995). Interestingly, aetosaur and phytosaur osteoderms were routinely discarded during the initial excavation of the *Placerias*-Downs' quarries (Camp and Welles, 1956, p. 259), so the aetosaurs are not as heavily represented as they might have been without this collecting bias.

The biostratigraphic argument for an Adamanian age involves more than the presence of abundant *Stagonolepis* and *Desmatosuchus*. The Adamanian phytosaur *Rutiodon* (= *Leptosuchus* of Long and Murry, 1995) also occurs in the *Placerias/*Downs' quarries as several squamosals representing at least three individ-

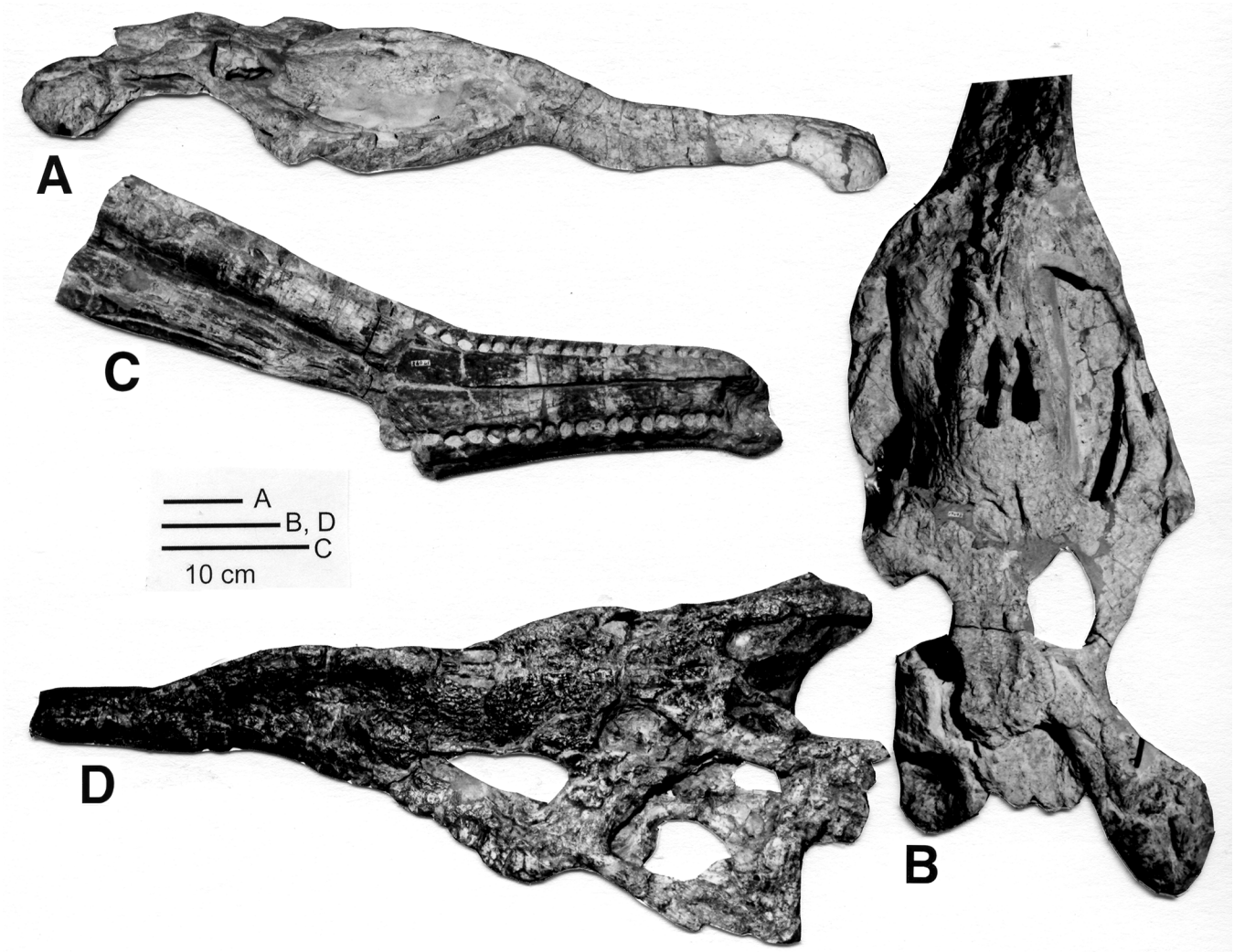

FIGURE 3. Phytosaur skulls and jaw fragment from the Chinle Group in east-central Arizona. A-C. *Rutiodon* sp., USNM 17098, collected 5 km east of St. Johns near Picket House Draw by G. E. Hazen, September 1946, in the Bluewater Creek Formation, 15 m above the Chinle Group base, right lateral view of skull (A), dorsal view of skull (B) and dorsal view of incomplete lower jaw (C). D. USNM 15841, *Rutiodon* sp. for comparison, oblique view of skull collected 6.4 km southwest of Adamana, at Point of Bluff, in the Blue Mesa Member of the Petrified Forest Formation, by George Pearce in 1937.

uals (Long and Murry, 1995). In contrast, *Paleorhinus* is known from the same quarries by only a partial skull of a subadult phytosaur, consisting of the external nares and a portion of the snout, the exact affinities of which have been debated (Lucas and Hunt, 1993b; Padian, 1994; Long and Murry, 1995; Lucas et al. 1997).

These facts, when corroborated with the low stratigraphic position of the *Placerias*/Downs' quarry complex, suggest that the sediments of these quarries were deposited very early in Adamanian time. This was after the first appearance of *Stagonolepis* and *Rutiodon*, with abundant *Desmatosuchus*, all hallmarks of the Adamanian. The occurrence of comparatively rare *Paleorhinus* indicates holdover of that taxon into the earliest Adamanian.

The fauna of the Blue Hills, while perhaps 30-40 m higher in the section, is essentially identical to that of the *Placerias*-Downs' quarries. In particular, there are numerous specimens of both *Rutiodon* and *Stagonolepis* in the Blue Hills, all from either high in the Bluewater Creek Formation or low in the Blue Mesa Member. This provides a minimum local stratigraphic thickness of approximately 30-40 m for Adamanian faunas.

Correlation of these strata to the type Adamanian fauna in the Petrified Forest National Park, which is high in the Blue Mesa Member (Lucas, 1993; Lucas and Hunt, 1993b; Lucas et al., 1997), adds as much as 50 m more stratigraphic section without any significant changes in the tetrapod fauna. This in turn suggests that Adamanian "time" is equivalent to approximately 100 m of lower Chinle Group strata in east-central Arizona.

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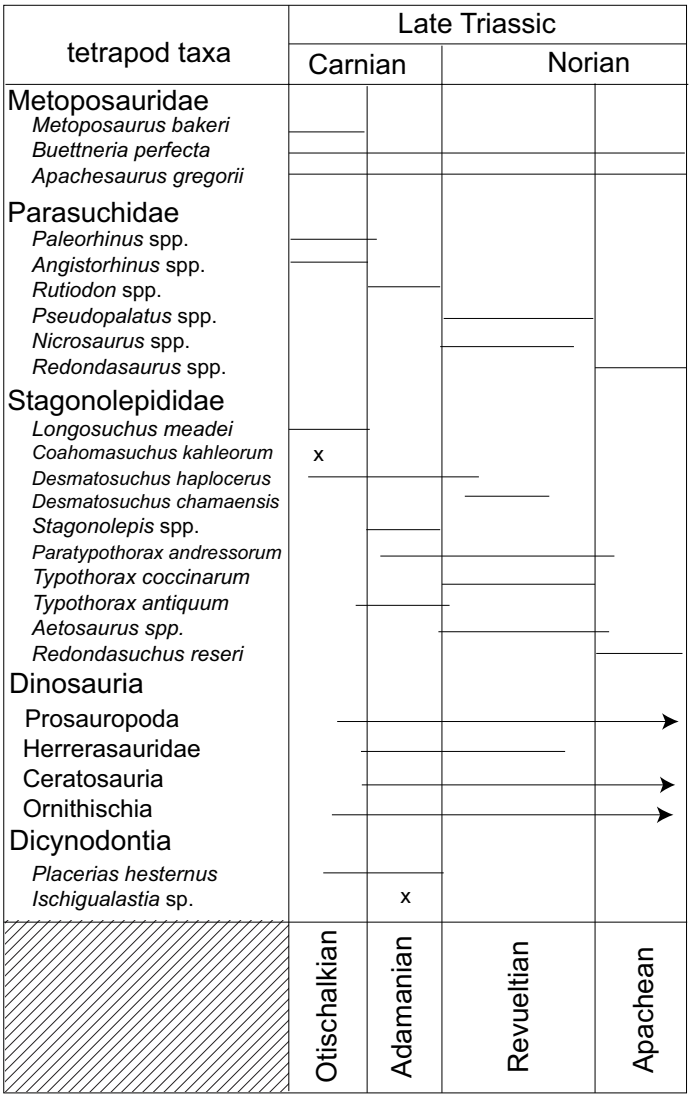

FIGURE 4. Basic biostratigraphic hypothesis of Lucas and Hunt (1993b), with some modification to reflect new taxonomic and stratigraphic information, principally that of Hunt (1994), Long and Murry (1995), and Lucas et al. (1997).

Paleontology. S. Harris and C. Whittle helped measure stratigraphic sections. Adrian Hunt, Kate Zeigler, and an anonymous reviewer read earlier drafts of this manuscript.

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