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# THE STRATIGRAPHIC DISTRIBUTION OF MAJOR FOSSIL LOCALITIES IN PETRIFIED FOREST NATIONAL PARK, ARIZONA

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**ABSTRACT –** Precise field relocation and documentation of fossil localities in Petrified Forest National Park allows for better resolution of the stratigraphic ranges of taxa thought to have biochronological significance. Palynomorph data suggests that the Sonsela Member of the Chinle Formation is Latest Carnian-Early Norian in age and that the boundary between the Carnian and Norian Stages lies in the lower-middle portion of the member. There is no evidence for a significant unconformity at this boundary and whereas the Sonsela Member fauna appears to be transitional, there appears to be an abrupt change in the flora in this section.

**Keywords: Triassic, Petrified Forest, Chinle Formation, Biostratigraphy, fossil localities**

## INTRODUCTION

ON DECEMBER 3rd, 1853 the geologist Jules Marcou noted "fossil trees imbedded in a layer of hard, thick bedded, gray, pink, and whitish-gray sandstone exposed along Lithodendron Creek" (Marcou, 1855). This is the first direct reference to a specific fossil with an accompanying lithologic description from the Petrified Forest National Park (PEFO) area that can be assigned to a specific stratigraphic interval. It is nearly certain that Marcou was describing the Black Forest bed (Ash, 1992) of the Petrified Forest Member of the Upper Triassic Chinle Formation, a prominent petrified wood bearing layer within the Lithodendron Wash drainage in what is now the northern or Painted Desert portion of Petrified Forest National Park (Fig. 1).

The Chinle Formation in the PEFO region has a thickness of approximately 300 meters (Creber and Ash, 2004) and is currently divided into five units from oldest to youngest: an unnamed basal unit, the Blue Mesa, Sonsela, Petrified Forest, and Owl Rock Members (Fig. 2; Woody, 2003; this volume). The basal unit is exposed only in the Tepees area of the park (Fig. 2) consisting mainly of reddish, silty sandstone, underlying the Blue Mesa Member, has been assigned to the Moenkopi Formation by Dubiel et al. (1999), but probably represents the Mesa Redondo Member (Cooley, 1958) of the Chinle Formation (Parker and Irmis, 2005).

The Triassic faunas of the PEFO area have been discussed in great detail (e.g., Colbert, 1985; Long and Ballew, 1985; Long and Padian, 1986; Murry and Long, 1989; Good, 1998), and more recently by Long and Murry (1995), Irmis (2005), and Parker (2005b). Likewise, the fossil floras have also received much attention (e.g., Daugherty, 1941; Ash, 1972; Ash, 1989; Ash, 2005b) including recent discussions regarding reconstructions of various trees (Ash and Creber, 2000; Creber and Ash, 2004) and arthropod-plant interactions (Ash 1997, 1999, 2000, 2001). Despite this extensive body of work, past attempts at constructing a biochronology of the park, especially with vertebrate taxa, have been plagued by inconsistencies between various workers with taxonomy of relevant taxa (e.g., Camp, 1930; Long and Ballew, 1985; Lucas and Hunt, 1993; Long and Murry, 1995) and stratigraphic correlations (e.g., Heckert and Lucas, 1998; Dubiel et al., 1999). Furthermore, studies focusing on palynomorphs or magnetostratigraphy have either been part of larger studies on the Chinle Formation (e. g., Litwin et al., 1991) or have focused only on a single stratigraphic unit (e. g., Fischer and Dunay, 1984; Pocock and Vasanthy, 1988; Steiner and Lucas, 2000) thus providing limited detailed information for correlating various strata within the park.

Recently, as part of a comprehensive paleontological inventory, a database of all known paleontological localities has been compiled (Parker, 2002). At this time, over 500 localities have been recorded with at least a third of these being relocated and documented using GPS technology and photography (Parker and Clements, 2004). This paper contains a description of the faunas and floras of some of the more biostratigraphically important localities from the park and places them in the revised stratigraphy advocated by Heckert and Lucas (2002) and Woody (2003; this volume).

*Abbreviations*.—AMNH, American Museum of Natural History, New York; PEFO, Petrified Forest National Park, Arizona; PFV, Petrified Forest National Park fossil vertebrate locality; PFP, Petrified Forest National Park fossil plant locality; UCMP, University of California Museum of Paleontology.

## PREVIOUS BIOSTRATIGRAPHIC WORK

Like Marcou, Ward (1905) also noted the distinct lithology that differentiates the Black Forest Bed from the rest of the Chinle beds, including it in his Leroux Member of the Shinarump Formation. There is some discrepancy regarding the name of this unit because Ward (1905: p. 20) mentions the name Lithodendron Member for the unit that

contains the Black Forest Bed petrified logs, yet places the Black Forest Bed in the overlying Leroux Member in his geological column on page 45 ("sandstone ledge with black logs; local"). Nonetheless, this figure represents the first published geologic section for the Chinle Formation and is easily interpreted because Ward's (1905) Shinarump Formation is essentially the equivalent of Gregory's (1917) Chinle Formation, with the top of the modern Sonsela Member forming the top of the Lithodendron Member and the Black Forest bed being situated medially in the Leroux Member, a unit that also includes the modern Owl Rock Member.

Working mainly in Gregory's (1917) divisions C and D of the Chinle Formation (later named the Petrified Forest and Mesa Redondo members [in part], respectively), Camp (1930) proposed biozones for the Chinle based on numerous vertebrate fossils of phytosaurs. This work was continued by Camp and Welles (1956) and later reestablished by Long and Ballew (1985) who also noted the potential biostratigraphic use of aetosaurs in addition to phytosaurs. On the basis of this past work, Lucas (1993) proposed four "land vertebrate faunachrons" (lvf) for Late Triassic terrestrial strata for the southwestern United States, which were formalized by Lucas and Hunt (1993). In ascending order, these consist of an Otischalkian lvf of middle to late Carnian in age and characterized by the phytosaurs "*Paleorhinus*" and *Anghistorhinus* (=*Rutiodon,* see Hungerbühler, 2001), and the aetosaur *Longosuchus*; the Adamanian lvf of latest Carnian age and characterized by the phytosaur *Leptosuchus* (*Rutiodon* of Lucas and Hunt, 1993 and Lucas, 1998) and the aetosaur *Stagonolepis wellesi* (*Calyptosuchus* of Long and Ballew, 1985); the Revueltian lvf of early to middle Norian age and characterized by the phytosaur *Pseudopalatus* and the aetosaur *Typothorax coccinarum*; and the Apachean lvf of Rhaetian age and characterized by the phytosaur *Redondasaurus* and the aetosaur *Redondasuchus*. Lucas and Hunt (1993) and Lucas (1998) established the type fauna of the Adamanian lvf as the Blue Mesa Member fauna of the PEFO area. Lucas (1998) incorporated this regional Late Triassic biostratigraphy into a global Triassic vertebrate biostratigraphy. Recently, these faunachrons have come under close scrutiny and many authors have suggested they are in need of revision because of taxonomic changes and recognized overlaps between some of the index taxa (Lehman and Chatterjee, 2005; Parker and Irmis, 2005; Hunt and Lucas, 2005; Langer, 2005; Rayfield et al., 2005).

Langer (2005) and Rayfield et al. (2005) stressed that many of the current correlations using the lvfs of Lucas (1998) were made on the basis of specimens with dubious taxonomic status. Both authors demonstrated that the Otischalkian and Adamanian lvfs possess similar reference faunas; however, Langer (2005) subsumed the Otischalkian into his upper Ischigualastian lvf throughout Pangaea based on the presence of "*Paleorhinus*" and the lack of *Leptosuchus*. Rayfield et al. (2005) used a GIS based approach to test the validity of the lvfs for the Late Triassic proposed by Lucas and Hunt (1993) and concluded that there was little support for the use of proposed vertebrate index taxa, mainly due to taxonomic instability and discouraged the use of "grade-level" associations of taxa.

In response to the discovery of a pseudopalatine phytosaur from strata believed to be Adamanian in age (Hunt and Lucas, 2005), Hunt et al. (2005) revised the division of the Adamanian into to sub-lvfs, the St. Johnsian and the Lamyan, differentiated mainly by the presence or absence of the aetosaur *Typothorax antiquum*. Heckert (this volume) recognizes the Lamyan as a valid sub-lvf, but considers it to be a lower portion of the Revueltian rather than the upper division of the Adamanian. Nonetheless, the validity of the Lamyan rests on the taxonomic validity of *T. antiquum* (see discussion below).

Ash (1976, 1980) proposed three floral zones for the Chinle Formation based on plant megafossils. The oldest biostratigraphic unit, the *Eoginkgoites* zone, is late Carnian in age and in Arizona is restricted to the Shinarump Member. Above this is the *Dinophyton* zone, which is latest Carnian in age and includes the Mesa Redondo and Blue Mesa Members as well as the lower and middle portions of the Sonsela Member. The youngest zone, the *Sanmiguela* zone, is Norian in age and occurs in the Owl Rock Member (Ash, 1987). Recently, Ash (2005a) noted the presence of *Dinophyton* cf. *spinosus* from the Shinarump Member near Cameron, Arizona; however, he also discussed the possibility that these specimens may represent a new species because they lack the spine-like trichomes that are characteristic of *D. spinosus*. Rayfield et al. (2005) argued that the *Eoginkoites* and *Dinophyton* zones contain the same macroflora and should be combined; however, Ash (2005), on the basis of new work, has demonstrated that the floras in the two zones are quite distinct.

Litwin et al. (1991) divided the Chinle Formation into three zones based on fossil palynomorphs. In Arizona, the Shinarump, Mesa Redondo and Blue Mesa Members as well as the basal beds (Rainbow Forest beds and lowermost Jim Camp Wash beds) of the Sonsela Member occur within Zone II. The upper Sonsela (middle and uppermost Jim Camp Wash beds and the Flattops One bed), Petrified Forest and Owl Rock Members occur within Zone III. Zones II and III are equivalent to the New Oxford-Lockatong and lower Passaic-Heidlersburg palynofloral zones of the Newark Supergroup, respectively (Litwin et al., 1991). Zone II is believed to be Late Carnian in age whereas Zone III is considered Norian in age (Litwin et al., 1991).

## LITHOSTRATIGRAPHY

Gregory (1917) named the Chinle Formation for Upper Triassic strata in the Chinle Valley of northeastern Arizona. Initially, Gregory divided the Chinle into four parts, to which later workers have applied formal names (Stewart et al., 1972a).

### Mesa Redondo Member

Cooley (1958) provided the name Mesa Redondo Member for a reddish, predominantly sandstone unit in the Little Colorado River Valley of Arizona that intertongues with the underlying Shinarump Member as well as the overlying 'lower red' and Blue Mesa Members. Whereas Cooley argued that the Mesa Redondo was distinct from the lower red member, Heckert and Lucas (2003) and Heckert et al. (2005) have argued that they represent the same unit. Lucas and Hayden (1989) applied the formal name Bluewater Creek Member to the 'lower red member' in New Mexico and use of this name has since been extended into eastern Arizona (e.g., Heckert and Lucas, 1997). However, if the Mesa Redondo and Bluewater Creek are synonymous units, the former name has priority (*contra* Heckert and Lucas, 2003).

Heckert and Lucas (1998) assigned reddish strata 20 meters below the Newspaper Sandstone bed in the Tepees area of the park to the Mesa Redondo (Bluewater Creek of their usage) Member, whereas Dubiel et al. (1999) assigned these rocks to the 'mottled strata' that overlies the Moenkopi Formation throughout parts of northeastern Arizona (Stewart et al., 1972b). The basis for the argument of Dubiel et al. (1999) was that a coarse-grained sandstone unit overlying the reddish unit in the park represents the Shinarump Member. Therrien et al. (1999) also considered this sandstone to represent the Shinarump; however, recent field investigations of this unit by the author demonstrate that these 'Shinarump' beds pinch out laterally into bluish beds of the Blue Mesa Member, suggesting that they instead represent a distinct facies in that unit. Furthermore, better exposures of the unit that Dubiel et al. (1999) assigned to the 'mottled strata' are present outside of the park to the west. This unit is stratigraphically above Shinarump Member exposures in and around the city of Holbrook, and are therefore part of the Chinle Formation (pers. obs.). Thus, Heckert and Lucas (1998) were probably correct in assigning this unit to the Mesa Redondo Member, although a direct correlation to the type section of the Mesa Redondo Member is impossible.

### Blue Mesa Member

Lucas (1993) named strata in Petrified Forest National Park that underlie the basal sandstone of the Sonsela Member the Blue Mesa Member . The Blue Mesa Member is characterized by its lighter coloration and its weathering profile, forming low rounded badlands (Woody, 2003). The Blue Mesa member represents the lower portion of what was previously known as the lower Petrified Forest Member (Akers et al., 1958). It is important to note that Lucas' (1993) Blue Mesa Member is part of his Petrified Forest Formation and his original description and type section includes much of what is now included within the Sonsela Member. Therefore, Woody (2003; this volume) redefined this unit to reflect this change.

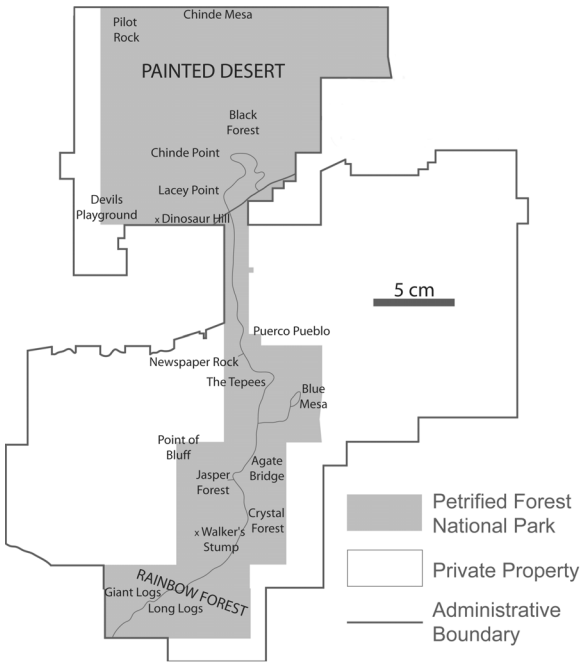


Figure *1*. Map of Petrified Forest National Park showing major geographical areas discussed in the text.

Recent authors have assigned portions of the Blue Mesa Member (in addition to the Newspaper Rock bed) to the Monitor Butte (e. g., Demko et al. 1998) and Mesa Redondo Members (Dubiel et al., 1999) but did not justify these assignments in detail. Therefore, retention of these strata in the Blue Mesa Member as advocated by Heckert and Lucas (2002) and Woody (this volume) is preferred for this study pending further investigation.

*Newspaper Rock bed*.—The Newspaper Rock bed is a prominent local marker horizon within the Blue Mesa Member (Fig. 1). The Newspaper Rock bed mainly outcrops in the Tepees/Blue Mesa portions of the park and extends eastwards past the 2004 park boundary, and is also present southwest of the Tepees at the base of Point of Bluff (Fig. 1). This unit consists of interfingering fine-grained ripple-laminated sandstone, greenish-gray mudstones ("leaf shale beds" of Stagner, 1941), and reddish pedogenic siltstones (Fig. 3; Dubiel et al., 1999). Dubiel et al. (1999) interpreted these facies as representing incised valley fills in the Chinle depositional system. Note that I consider the Newspaper Rock bed to constitute all of these interfingering facies following Dubiel et al. (1999), whereas Billingsley (1985) and Heckert and Lucas (2002) restricted the unit to only the sandstone facies. However, I disagree with Dubiel et al. (1999) that this unit is assignable to the

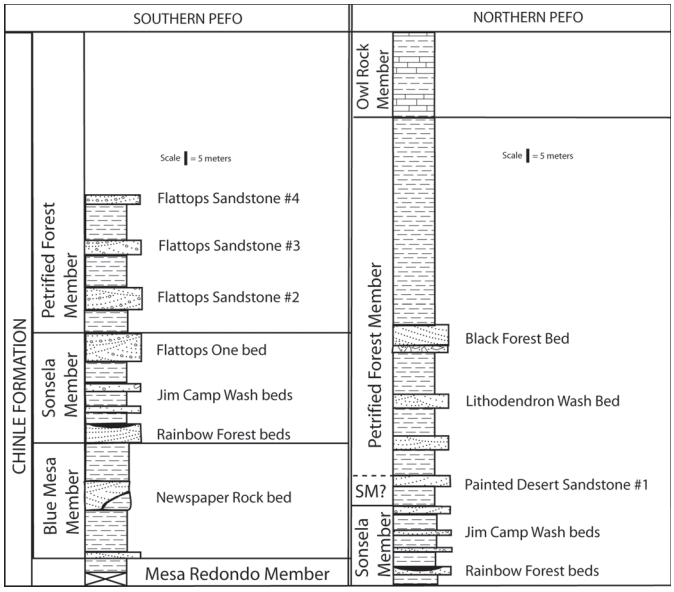


Figure *2*. Generalized stratigraphic columns for the Chinle Formation of Petrified Forest National Park showing the relations of beds and members in the southern and northern portions of the park. These columns are not intended to demonstrate correlations between beds, but do display true thicknesses of the units. Adapted from Murry (1990), Lucas (1993), and Heckert and Lucas (2002).

Monitor Butte Member, and instead consider it part of the Blue Mesa Member (Heckert and Lucas, 2002; Woody, 2003, this volume).

**Sonsela Member**

Lucas (1993) originally raised the Sonsela Sandstone bed to member status, but did not modify its stratigraphic definition. Heckert and Lucas (2002) revised and expanded the Sonsela Member to include the medial sandy interval of the Chinle Formation that has a maximum thickness of 40 meters in the park and consists of a basal sandstone unit, a medial siltstone and sandstone unit, and an upper sandstone (the traditional Sonsela Sandstone bed). Woody (2003; this volume) independently came to the same conclusion, revised the identifying lithologic criteria, provided an alternative correlation throughout park strata, and described informal nomenclature for the Sonsela Member that is preferred for this study. The upper sandstone (Flattops One bed) includes the "Sonsela Sandstone bed" of Akers et al. (1958) and the Flattops Sandstone #1 of Billingsley (1985). The lower sandstone unit (Rainbow Forest beds) consists of the Rainbow Forest bed of Billingsley (1985) and the "Camps Butte" sandstone of Murry (1990). In the past, the medial portion has been assigned to both the upper portion of the 'lower Petrified Forest Member' and the lower portion of the 'upper Petrified Forest Member' (Billingsley, 1985; Murry, 1990; Long and Murry, 1995). Woody (2003; this volume) provided a detailed facies analysis of the Sonsela Member.

The Sonsela Member is also widely exposed in the Devils Playground area of the park where the 'Brown Sandstone' of Billingsley (1985) may represents the upper sandstone unit; however, direct correlations to beds in the southern portion of the park are not presently possible.

**Petrified Forest Member**

Woody (2003; this volume) restricted the Petrified Forest Member to its upper portion of which had been previously known as the 'upper Petrified Forest Member' (Billingsley 1985). This includes all strata between the top of the Sonsela Member and the base of the Owl Rock Member. In Petrified Forest National Park, the Petrified Forest Member can be distinguished mainly by its predominantly reddish color.

*Black Forest Bed*.—The thin distinctive white and pink unit containing black petrified logs that Marcou and Ward recognized in the vicinity of Lithodendron Wash was noted many years later by Cooley (1959) and Roadifer (1967) both of whom referred to it as a tuff bed. It was called the Black Forest Tuff by Billingsley (1985) and the Black Forest Sandstone Bed on the unpublished geologic map of the park by Billingsley, et al. (1985). Ash (1992) formally named and described the unit the Black Forest Bed (Fig. 2). The Black Forest Bed has a maximum thickness of 12.6 meters and is located approximately 130 meters above the top of the Sonsela Member and approximately 110 meters below the Owl Rock Member (Ash, 1992). The Black Forest Bed consists of a basal nodular conglomerate and an upper white to pink tuffaceous sandstone. Riggs et al. (2003) published a radiometric date for this unit, using detrital zircons, of 213±1.7 ma, which is early Norian in age (Gradstein et al., 2005).

**Owl Rock Member**

Limited exposures of this unit occur within Petrified Forest National Park. The most prominent exposure, on Chinde Mesa (Fig. 2), has a thickness of 80 meters (Ash, 1992). No vertebrate or plant fossils have been collected from Owl Rock exposures in the park although elsewhere in Arizona the Owl Rock is highly fossiliferous (Kirby, 1991).

## BIOSTRATIGRAPHY

**Mesa Redondo Member**

No fossils have been found to date in the Mesa Redondo Member of PEFO, mainly because of the limited outcrop exposure. However, a wealth of vertebrate material has been collected from Mesa Redondo (=Bluewater Creek) exposures near St. Johns, Arizona, most notably from the *Placerias* quarry (Long and Murry, 1995). Significant fossils from this locality include the metoposaurid *Buettneria perfecta*, the aetosaurs *Stagonolepis wellesi* and *Desmatosuchus haplocerus*, the phytosaur *Leptosuchus*


Figure *3*. Photograph of the Newspaper Rock bed from the Tepees are showing relationship of the three distinct facies that make up the unit.

*adamanensis*, the 'poposaur' *Poposaurus gracilis*, and the dicynodont *Placerias hesternus*.

**Blue Mesa Member**

No fossils, plant or animal, have been recovered from strata in PEFO that are below the level of the Newspaper Rock bed. The basal portion of the sandstone facies of the Newspaper Rock bed contains preserved woody material, but whole logs are extremely rare throughout the unit. Trace fossils are common. The only possible vertebrate fossils known from the "leaf shale" facies of the Newspaper Rock bed are some small possibly shark egg cases described elsewhere in this volume by Axsmith. Invertebrate fossils from the "leaf shale" facies include crayfish, conchostracans, and insects (Miller and Ash, 1988). Blue Mesa Member strata above the Newspaper Rock bed are extremely fossiliferous containing numerous vertebrate, invertebrate, and locally abundant petrified logs and in situ stumps (Fig. 4).

PFP 001 - This locality was discovered in the early 1930s by workers building the main park road and is the main locality (UCMP P3901-1) of Daugherty (1941). It is located in the greenish mudstone facies of the Newspaper Rock bed, the "leaf shales" of Stagner (1941). This site is important not only for the diversity and abundance of plant fossils, but also because of the preservational quality; many of the species are known from complete leaves and the epidermis and cuticle are preserved on many of them. This is the type locality for numerous plant fossils including the fern-like foliage *Cladophlebis yazzia* Ash (1973) and *Sphenopteris arizonica* Daugherty emend. Ash (1999), the ferns *Clathropteris walkeri* Daugherty emend. Ash (1970a), *Phlebopteris smithii* Daugherty (1941), *Wingatea plumosa* (Daugherty) Ash (1970a); the possible ginkgoalean *Baiera arizonica* Daugherty (1941), the seeds *Samaropsis puerca* Daugherty (1941), and *Carpolithus chinleana* Daugherty (1941). Biostratigraphically significant fossils include the fern *Todites fragilis* Daugherty emend. Ash (1970a), the fern-like foliage *Marcouia neuropteroides* (Daugherty) Ash, and *Cladophlebis daughertyi* Ash (1970a), as well as the bennettitalean *Zamites powellii* all of which characterize the *Dinophyton* floral zone of Ash (1980). The enigmatic plant fossil *Dinophyton spinosus* also occurs at this site.

PFP 002 - This locality is a short distance west of PFP 001 and was reported by Daugherty (1941). It occurs in the same unit as the previous locality and contains a similar flora and includes many specimens of the horsetail *Equisetites bradyi* Daugherty, 1941. This is the type locality of the conifer *Podozamites arizonicus* Daugherty (1941). Palynomorphs have also been collected from this site, including *Equisitosporites*

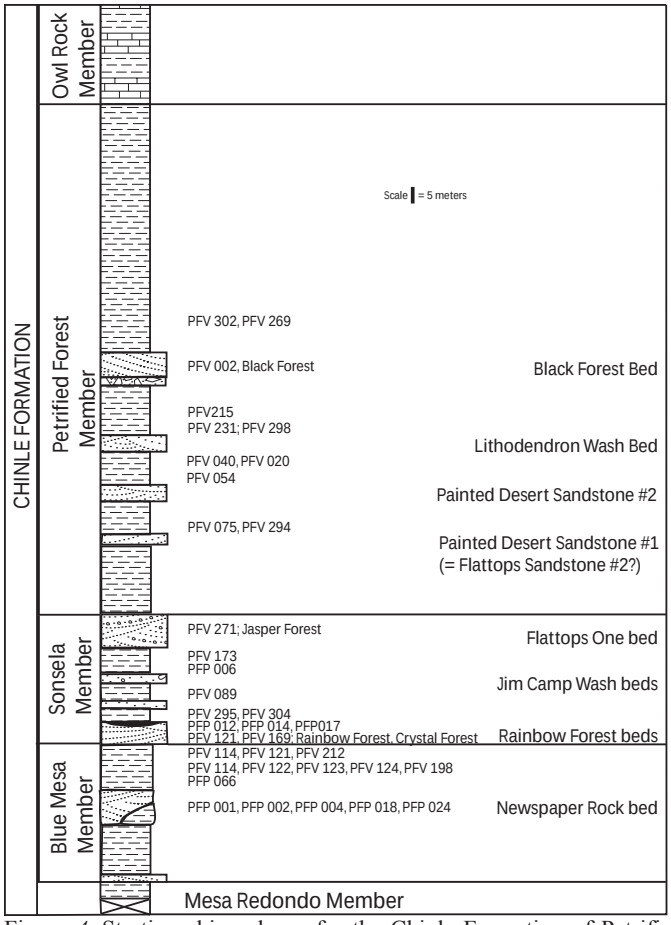


Figure 4. Stratigraphic column for the Chinle Formation of Petrified Forest National Park showing the locations of prominent fossil localities. Adapted from Lucas (1993).

*chinleanus* Daugherty (1941), which is characteristic of palynomorph zone II of Litwin et al. (1991) and suggests a Carnian age for this flora.

PFP 004 – This locality is a short distance east of locality PFP 001 and contains a large flora that includes most of the species recognized at that locality together with several other noteworthy fossils including the bennettitalean pollen-bearing structure *Androcycas santuccii* Watson and Ash (this volume), the pollen bearing organ *Creberanthus bealeii* Axsmith and Ash, this volume), the large horsetail cone *Equicalostrobus chinleana* (Daugherty) Grauvogel-Stamm and Ash, 1999, the unusual pollen bearing organ *Pramelreuthia yazzi* Ash and Litwin, 1994. The locality also contains carapaces of chonchostracans, beetle elytra, crayfish, and possible shark egg cases (Miller and Ash, 1988; Axsmith, this volume).

PFP 017 - This locality is southeast of Billings Gap on top of an elongate bluff capped by a thick cross-bedded sandstone unit. Past workers (Billingsley et al., 1985; Long and Murry, 1995) have considered this sandstone to represent the traditional Sonsela Sandstone bed (=Flattops One bed of Woody, this volume); however, recent investigations by the author suggest that this horizon represents the Rainbow Forest beds. This site is significant because it provided the "Sonsela Sandstone Bed" palynomorph sample (R4341) of Litwin et al. (1991). This site contains the palynomorph taxa *Plicatisaccus badius*, *Camerosporites secatus*, and *Cycadopites stonei*, which are representative of palynomorph zone II and considered by Litwin et al. (1991) to indicate a Carnian age for this flora.

PFP 018 - This site is north of a large archaeological site known as Puerco Pueblo and is also in the greenish mudstone facies of the Newspaper Rock bed. This locality contains the leaf *Marcouia neuropteroides* and shoots of *Dinophyton spinosus*, which are characteristic of the *Dinophyton* zone of Ash (1980). It also contains many of the other species found at locality PFP 001 as well as *Araucarites rudicula* Axsmith and Ash, this volume, *Podozamites* n. sp., and *Ginkgoites* n. sp. In addition it contains specimens of the seed fern leaf *Sphenopteris arizonica* Daugherty emend. Ash, 1999 that show evidence of having been attacked by insects (Ash, 1999).

PFP 022 - This locality is in a narrow dry wash about 600 meters west of PFP 001 and is at the same horizon as the previously discussed localities. It was discovered by the wife of the Chief Ranger in 1985 when she observed freshly exposed fossil leaves in a block that had fallen from the wall of the wash. The cycad leaf, *Aricycas paulae* Ash, 1991, which came from this locality was named after her (Paula Andress). Other significant taxa from this locality include *Cladophlebis daughertyi* and *Zamites powellii*.

PFP 066 - Blue Mesa Stump Field. This site is located several meters above the Newspaper Rock bed and is just below a greenish mudstone horizon that contains many of the vertebrate localities of the Blue Forest area (e.g., PFV 122). The lithology of PFP 066 is a bluish pedogenic mudstone that is common in the Blue Forest area and often contains in-situ stumps, most likely of *Araucarioxylon arizonicum* (Ash and Creber, 1992). Jones and Ash (this volume) document a stump from this locality that appears to have been charred by fire.

PFV 114 - Blue Forest General Area. Many of Charles Camp's 1921 and 1923 collections fall under this locality number (UCMP V7038). Most of the fossils consist of phytosaur and metoposaur material, including good skull material of *Buettneria perfecta* and *Leptosuchus adamanensis*. An isolated tooth (UCMP 175149) represents the only occurrence of the pseudosuchian *Revueltosaurus hunti* from Petrified Forest National Park.

PFV 121 (in part) - Phytosaur Basin E. This locality was collected by Charles Camp in 1921 and consists of beds from both the Blue Mesa and lower Sonsela Members. Camp collected a skull (UCMP 27007) and partial skeleton (UCMP 27008) of *Leptosuchus adamanensis* from the Blue Mesa Member beds (Camp, 1930).

Hunt (1998) reported the collection of a partial aetosaur skeleton from the Blue Mesa Member in the same

horizon as UCMP 27007. This specimen has never been formally described, but Hunt (1998) refers it to *Typothorax antiquum*, a taxon described by Lucas et al. (2002) from the Santa Rosa Formation of New Mexico. This specimen (PEFO uncat) is only a few meters stratigraphically below the base of the Sonsela Member and represents the lowest occurrence of *Typothorax* in the park.

*Typothorax antiquum* was described by Lucas et al. (2002) for a partial skeleton from the Santa Rosa Formation of New Mexico. According to these authors, *T. antiquum* can be differentiated from *T. coccinarum* on the basis of: 1) paramedian plates with a lower width to length ratio (~2-3:1); 2) pitting of the paramedian plates that is less dense and with larger pits; and 3) a more robust ilium. However, examination of the type material shows that many of the dorsal paramedian plates of *T. antiquum* (e.g., Lucas et al. 2002:figs. 3d, f) actually have width to length ratios higher than 3:1 and even more than 4:1 in some plates. Lower ratio plates assigned to the dorsal region (Lucas et al., 2002:figs. a, e, g) have the crescentic shape, faint ornamentation, and slightly medially offset boss that is characteristic of cervical plates (Martz, 2002). The plates considered to be cervical paramedians by Lucas et al. (2002: figs. a-c) are actually caudal paramedians and a lateral plate (Martz, 2002). Moreover, the density and coarseness of the ornament pitting varies highly among specimens of *Typothorax coccinarum* (pers. obs.). Finally, robustness of the ilium is also a highly variable character and could be equally attributed to individual variation, ontogeny, or sexual dimorphism rather than taxonomic variation (see PFV 231 discussion below), given that few complete *T. coccinarum* ilia are known. Therefore, *T. antiquum* is considered here to be a junior synonym of *T. coccinarum*.

PFV 122 – Dying Grounds. This site is stratigraphically several meters lower than PFV 121 in an extremely fossiliferous greenish mudstone horizon that contains numerous fossil localities. The Dying Grounds is significant for its microvertebrate fauna (Murry, 1989; Heckert, 2004). Recently, the author recognized a proximal end of a femur (PEFO 34347) that had been collected from this locality in the 1990s. This specimen is important because it represents a dinosauriform similar to *Silesaurus* (Dzik, 2003) and *Eucoelophysis* (Nesbitt et al, submitted), and represents the earliest unambiguous occurrence of a *Silesaurus*-like dinosauriform in North America (Parker et al., this volume).

PFV 123 – Annie's Canyon. Charles Camp collected the holotype specimen of *Machaeroprosopus* (=*Leptosuchus*) *adamanensis* (UCMP 26699) (Camp, 1930) from this locality in 1921. It is at the same stratigraphic horizon as Crocodile Hill (PFV 124) and the Dying Ground (PFV 122), stratigraphically high in the Blue Mesa Member.

PFV 124 – Crocodile Hill. Charles Camp excavated this quarry in 1923 and recovered numerous specimens, including many metoposaurs and phytosaurs. Murry (1989) described the microvertebrates from this locality, and Philip Vancleave probably also collected the type specimen of the enigmatic archosauromorph *Vancleavea campi* from here (Long and Murry, 1995). Important specimens include numerous skull and pectoral elements referable to *Buettneria perfecta* and at least two skulls of *Leptosuchus adamanensis* (UCMP 27070).

PFV 198 – Blue Mesa N. Long and Ballew (1985) documented *Dematosuchus haplocerus* from only six localities within PEFO, commenting on the rarity of this taxon. Subsequent examination of the material from these localities by the author determined that none of the material was actually referable to *Desmatosuchus*. Nonetheless, in recent years *Desmatosuchus haplocerus* material has been recovered from three sites in the park. PFV 198 is located north of Blue Mesa and is situated approximately 8 meters above the red pedogenic facies of the Newspaper Rock bed. Plate fragments from this locality (PEFO 31177) are referable to *D. haplocerus* (Parker and Irmis, 2005). This locality is in the same horizon as PFV 122 and represents the lowest stratigraphic occurrence of *Desmatosuchus* in the park.

PFV 212 –Dinosaur Ridge N. This locality is located in the uppermost portion of the Blue Mesa Member, just a few meters below the Sonsela Member and is within Charles Camp's "Phytosaur Basin" locality (PFV 121). Hunt et al. (1996) documented theropod material from this locality; however, it has never been described. This site contains one of the few occurrences of *Desmatosuchus haplocerus* from the park (PEFO 26668) (Parker and Irmis, 2005) and represents the highest stratigraphic occurrence of that taxon. *Stagonolepis wellesi* is also present at this locality.

**Sonsela Member**

The recently expanded Sonsela Member (Heckert and Lucas, 2002; Woody, 2003) encompasses strata in the park previously assigned to both the upper and lower Petrified Forest Members (Billingsley, 1985). Many of these strata are fossiliferous and contain numerous biostratigraphically important localities.

*Rainbow Forest beds*.—PFV 121 (in part). Phytosaur Basin E – Charles Camp collected an interclavicle (UCMP 27009) of *Buettneria perfecta* from the whitish sandstone that represents the base of the Sonsela Member (Camp Butte sandstone = Rainbow Forest beds) in the Blue Forest area. Parker and Irmis (2005) figured a partial plate of *Typothorax* (PEFO 26694) from the same unit, assigning it to *Typothorax coccinarum* based on the dorsoventral flexion of the plate and the coarse pitting. Hunt et al. (2005) consider this plate to be indeterminate to species. Under either interpretation, this plate represents the second lowest occurrence of *Typothorax* from

the park. Although, *Typothorax* plates occur widely throughout the Sonsela Member (Long and Murry, 1995), many are too fragmentary to assign to a specific species *contra* Hunt et al. (2005), who assign all *Typothorax* specimens from the Sonsela to *T. antiquum* without providing any discussion supporting these referrals. Nonetheless, as discussed previously, *T. antiquum* cannot be adequately differentiated from material of *T. coccinarum* and therefore all known *Typothorax* material is assigned to the latter taxon.

PFV 169 – Battleship NW. Two distinct lithologies of the Rainbow Forest beds are found at this locality, a cross-bedded, weakly lithified sandstone and a laterally equivalent sandy mudstone. Significant fossils from these facies include a partial skeleton of *Stagonolepis wellesi* (PEFO 31217), paramedian plate fragments of *Paratypothorax* sp. (UCMP 126960), and a left squamosal (PEFO 23333) and partial skull (PEFO 34034) of *Leptosuchus adamanensis*. This locality represents the lower stratigraphic occurrence of *Paratypothorax*.

Rainbow Forest – Thousands of colorful logs characterize the area known as the Rainbow Forest, all of which are currently considered to represent *Araucarioxylon arizonicum.* These logs mainly derive from the Rainbow Forest beds; however, to the northeast, along old Highway 180, many logs of *Araucarioxylon* can also be seen weathering from the Jim Camp Wash beds.

*Jim Camp Wash beds*.—Crystal Forest – This site also contains a large petrified wood accumulation mostly referable to *Araucarioxylon arizonicum* (however, see Savidge and Ash, this volume). The logs occur at various levels in both the Rainbow Forest bed and the Jim Camp Wash beds.

PFV 295 – Jablonsky Site. This site is located in a grayish mudstone that is a few meters about the Rainbow Forest beds near Mountain Lion Mesa. Significant fossils from this site include the skull of a new species of *Pseudopalatus* (Parker and Irmis, this volume) and paramedian plates of *Typothorax coccinarum*. This site represents the lowest unequivocal stratigraphic occurrence of both taxa.

PFV 304 – Milkshake Quarry. This site is located in the southern portion of the park and is situated approximately five meters above the Rainbow Forest bed and approximately 10 meters below the siliceous layer described by Creber and Ash (1992) and Woody (2003, this volume). In 2004, a relatively complete carapace of *Stagonolepis* sp. was collected from this site. Potential apomorphies of the osteoderms suggest that this may represent a new species (Parker and Irmis, 2005); however, the specimen is still being prepared. This is the highest occurrence of *Stagonolepis* in the park.

PVF 089 – Bowman Locality. This locality is also in the southern end of the park and is situated approximately 6 meters above PFV 304. Significant taxa from this locality include *Buettneria perfecta*, *Typothorax coccinarum.*, *Paratypothorax* sp., *Pseudopalatus pristinus*, and an indeterminate saurischian dinosaur.

PFP 006 – Walker's Stump. In January, 1936, park naturalist Myrl Walker partially excavated a 'standing' stump of *Araucarioxylon* from the Flattops area of the park (Walker, 1936). Preliminary investigations in 1935 and a second partial excavation in 1936 recovered cycad and conifer leaves, scales, and seeds (Walker, 1936). Walker (1936) felt that the close association of a trunk in place and conifer leaves strongly suggested that the leaves and stem (trunk) belonged to the same tree. Daugherty (1941) assigned the cycad leaves to *Otozamites* (=*Zamites*) *powellii* and the conifer leaves to *Pagiophyllum newberryii*, which Ash (1970c) later assigned to a new species, *Pagiophyllum simpsonii*. Many years later this stump was reinvestigated by S. R. Ash and it was noted that the stump is inclined at an angle of about 17 degrees from the vertical in contrast with other in situ stumps in the park, most of which are nearly vertical (S. R. Ash, pers. commun., 2006). According to Ash (pers. commun., 2006) this may indicate that the stump was rafted to its present location and pushed over slightly by the current of water when the root caught on the bottom of the stream. After the eruption of Mt. St. Helens several stumps were observed in similar positions in the flood damaged areas including one that was deposited upright on a section of paved highway (S. R. Ash, pers. commun., 2006). Nonetheless, the discovery of this stump set people to thinking about the possibility of there being other standing stumps and eventually such stumps were recognized in both the Blue and Black forests.

PFV 173 – Crystal Forest Buttes. This site is located east of Crystal Forest and 12 meters below the Flattops One bed. Significant fossils from this locality include a partial carapace of *Paratypothorax* sp. (PEFO 3004) (Hunt and Lucas, 1992) and two squamosals of *Leptosuchus* sp. (UCMP 126998; UCMP 139554). This locality represents the highest occurrence of *Leptosuchus* in the park, exclusive of the Devils Playground area (see discussion below).

PFV 268 - Clambodia. This locality is situated in Rainbow Forest approximately 40 meters below the Flattops One bed. Significant taxa include *Paratypothorax* sp. and *Typothorax coccinarum*.

*Flattops One bed*.—Jasper Forest – Numerous specimens of the conifer *Araucarioxylon arizonicum* are encased in the Flattops One bed. These logs weather in sections and subsequently slide and tumble into the valley below, which is commonly known as the Jasper Forest.

PFV 271 – This locality in the southern end of the park is just above the Rainbow Forest residential area. In the 1990s, park staff discovered a phytosaur skull in a fallen sandstone block just below and originally from the Flattops One bed. Hunt et al. (2002) disagreed on the taxonomic assignment of the specimen and described this skull alternatively as either *Nicrosaurus* sp. or *Pseudopalatus* sp. This specimen (PEFO 31205) has subsequently been collected and partially prepared, demonstrating that it

represents a specimen of *Pseudopalatus* sp. (Parker, 2005b). Note that Parker (2005b:44) erroneously lists this specimen as PEFO 31218. This specimen is the only vertebrate body fossil known from the Flattops One bed.

**Petrified Forest Member**

Woody (this volume) restricted the Petrified Forest Member in PEFO to strata originally referred to as the upper portion of the Petrified Forest Member (Billingsley, 1985). Laterally persistent sandstone beds are common in this unit and have been used as marker beds (e.g., Billingsley, 1985; Long and Murry, 1995). Sandstone beds in the southern end of the park are informally known as the Flattops sandstones, whereas those in the northern end of the park are informally called the Painted Desert sandstones (Billingsley,1985). Direct correlation of these beds between the northern and southern ends of the park is extremely difficult; however it appears that Painted Desert Sandstone #1 and Flattops Sandstone #2 are roughly equal (pers. obs.). Alternatively, Therrien and Fastovsky (2000) correlated the Painted Desert Sandstone #1 with the Flattops Sandstone #3, approximately 25-30 meters of vertical difference from my interpretation.

A volcaniclastic unit that represents the highest mappable sandstone bed of the Petrified Forest Member in the north end of the park was named the Black Forest Bed by Ash (1992). Riggs et al. (2003) determined a radiometric date of 213±1.7 ma for this bed using detrital zircons. The Black Forest Bed contains a large concentration of logs that are assigned to *Araucarioxylon arizonicum* Knowlton, 1888, *Schilderia adamanica* Daugherty, 1934, *Woodworthia arizonica* Jeffrey, 1910. Vertebrates from the Black Forest Bed include pseudopalatine phytosaurs and *Typothorax coccinarum*. The presence of *Paratypothorax* (Long and Murry, 1995) from this horizon is based on an undiagnostic fragment.

PFV 075 – Karen's Point. This locality is in the Flattops area of the park and situated just above Flattops Sandstone #2. Significant taxa from this site include the aetosaurs *Typothorax coccinarum* and "*Desmatosuchus*" *chamaensis* (Parker and Irmis, 2005). "*D.*" *chamaensis* is otherwise only known from New Mexico in the Petrified Forest Member of the Chama Basin and the Bull Canyon Formation of Quay County (Zeigler et al., 2002). Parker (2003, in press) determined that "*D.*" *chamaensis* does not represent a valid species of *Desmatosuchus* and is instead referable to a new genus closely related to *Paratypothorax*.

PFV 070 – Flattops NW. This locality is also in the Flattops area of the park and is located at the top of Flattops Sandstone #2. Significant specimens from this site include well-preserved paramedian plates of *Typothorax coccinarum*.

PFV 294 – Delaney Tank NE. This locality is just west of Point of Bluff and is situated stratigraphically just above the Flattops Sandstone #2. In 1962, the MNA collected a partial lateral plate (MNA V697) of *Desmatosuchus* from this locality that Long and Ballew (1985) interpreted as a cervical lateral plate of *D. haplocerus*. Parker (2005a) determined that it was instead from the dorsal lateral region and represented the only known Arizona occurrence of *Desmatosuchus smalli*. *Typothorax coccinarum* also occurs at this locality.

PFV 040 – Dinosaur Hill. The fauna of the Dinosaur Hill locality has been extensively discussed by Padian (1986, 1990), Murry and Long (1989), Parrish (1991), Long and Murry (1995); Hunt et al. (1998), and Heckert (2004). Significant taxa from this locality include *Coelophysis* sp., *Hesperosuchus agilis*, *Apachesaurus gregorii*, *Pseudopalatus* sp., *Typothorax coccinarum*, and *Revueltosaurus callenderi*.

PFV034 – Billingsley Hill. This site is located approximately 450 meters due north of and is 6 meters stratigraphically lower than PFV 040. This locality contains *Pseudopalatus* sp., *Typothorax coccinarum*, and *Apachesaurus gregorii*. More importantly, this site is the type locality for *Kraterokheirodon colberti*, an enigmatic tetrapod known only from this locality and from a second locality near St. Johns, Arizona that is situated either low in the Blue Mesa Member or high in the Mesa Redondo (=Bluewater Creek) Member (Irmis and Parker, 2005).

PFV 020 – Dinosaur Hollow. This locality is roughly at the same stratigraphic horizon as PFV 040, but 6 kilometers to the northeast. This is the type locality of the basal saurischian *Chindesaurus bryansmalli* (Long and Murry, 1995). Long and Murry (1995) and unpublished field notes from Long also document a partial skeleton of *Shuvosaurus* (=*Chatterjeea*) from this locality, although this specimen is lost. Other taxa occurring at this locality include *Typothorax coccinarum* and *Apachesaurus gregorii*.

PFV 215 – Zuni Well Mound. This site is stratigraphically 18 meters above PFV 040, 1.8 km to the northeast, and is located just slightly above the Lithodendron Wash bed of Heckert and Lucas (2002) (=Painted Desert Sandstone #3 of Billingsley, 1985). Significant fossils from this locality include a centrum of a large metoposaurid, material of *Apachesaurus gregorii*, and teeth of *Revueltosaurus callenderi*. Also recovered from this site was a partial skeleton of the diapsid *Vancleavea* sp. (Parker and Irmis, 2005) and purported theropod material (Hunt and Wright, 1999).

PFV 231 – The Giving Site. Stratigraphically this site is approximately 6 meters above PFV 040 and PFV 020, and 12 m below PFV 215. The fauna at this locality is quite diverse and represents only the second occurrence of both *Coelophysis* sp. and *Chindesaurus bryansmalli* (Parker and Irmis, 2005). Other taxa include indeterminate pseudopalatine phytosaurs, adult and juvenile specimens of *Typothorax*, *Vancleavea* sp., *Shuvosaurus* sp.,

*Postosuchus*, *Revueltosaurus callenderi*, and an indeterminate crocodylomorph. The *Typothorax* material is of special interest because the juvenile material (*Typothorax coccinarum*) is the first juvenile aetosaur material from the Chinle Formation that can be unambiguously referred to a previously known taxon. This material is referable to *Typothorax coccinarum* because of the pitted ornamentation, high width/length ratio, and pronounced dorsoventral flexion of the paramedian armor (Martz, 2002; Lucas et al, 2002). An almost complete sacrum with associated armor and vertebrae of an adult specimen of *Typothorax* (PEFO 33967) displays similarities with *Typothorax antiquum* (e.g., broader neck of the robust ilium, flat paramedian plates with a low width-length ratio, and coarser pitting of the plate ornamentation). This would represent the highest stratigraphic occurrence of this taxon and suggest that its stratigraphic range overlaps with *T. coccinarum*. Nevertheless, because *Typothorax antiquum* cannot be adequately diagnosed and differentiated from *T. coccinarum*, this specimen is interpreted here as representing a specimen of *T. coccinarum* and the low-width length ratio of the plates is attributable to their position in the carapace (i.e. pelvic or anterior caudal).

PFV 298 – *Revueltosaurus* Quarry. This locality is at roughly the same horizon as PFV 231. The quarry is dominated by the remains of the pseudosuchian *Revueltosaurus callenderi*, including collected material from a minimum of a dozen individuals (Parker et al., 2005). Vertebrae and other elements of a single specimen of *Shuvosaurus* sp. were also collected from this locality.

PFV 002 – Black Forest. This is a widespread area covering several kilometers of exposures of the Black Forest Bed (Ash, 1992). This reworked volcaniclastic unit is highly fossiliferous. A large petrified wood deposit known as the Black Forest contains the trees *Araucarioxylon arizonicum*, *Shilderia adamanica*, and *Woodworthia arizonica*. To date, *Shilderia* and *Woodworthia* have only been found in the Black Forest Bed (Creber and Ash, 2004). This is the highest documented occurrence of plant fossils in the park. Fossil vertebrates are also common and include *Typothorax coccinarum* and *Pseudopalatus* sp. Long and Murry (1995) listed *Paratypothorax* sp. as being present in the Black Forest Bed; however, this assignment is based on an undiagnostic specimen.

PFV 269 – Judy's Luck. This locality is stratigraphically about 12 meters above the Black Forest bed and with PFV 302 represents the highest documented occurrence of vertebrates in the park. The fauna includes indeterminate archosaurs including phytosaurs and aetosaurs, as well as the temnospondyl *Apachesaurus gregorii*.

PFV 302 – Rabbit Foot Hills. This locality is at the same stratigraphic horizon as PFV 269. It represents the highest documented occurrence of *Typothorax coccinarum* in the park.

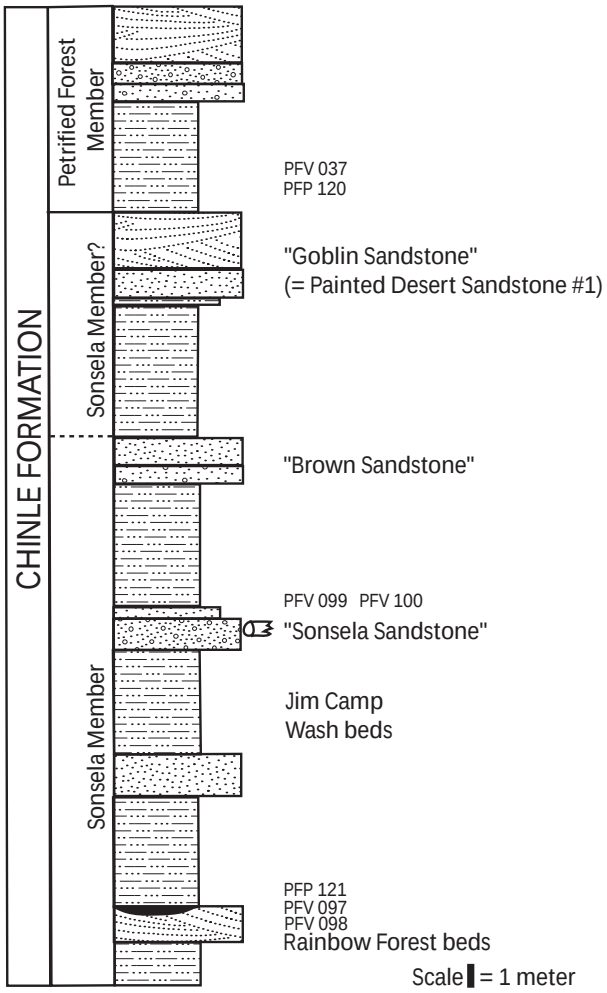


Figure 5. Stratigraphic column for the Chinle Formation in the Devils Playground area of Petrified Forest National Park, showing the locations of prominent fossil localities. Adapted from Murry (1990).

## DEVILS PLAYGROUND AREA

Because of a discontinuity of the outcrop sections and local geologic structure it is difficult to directly correlate strata between the southern and northern portions of the park (Billingsley, 1985). This is especially true for the "Devils Playground" area, which is located north of Interstate 40 on the western park boundary. The main exposures in the Devils Playground area are lower stratigraphically than the rest of the northern portion of the park . Most of the exposures possess a lithology that is characteristic of the Sonsela Member, but bed correlations are tentative because there are many more sandstone bodies than observed in the southern portion of the park. For example, Billingsley (1985) named a prominent ledge-forming sandstone in the area the Brown Sandstone and assigned it to a stratigraphic position equivalent to the Newspaper Rock bed. Subsequently, Murry (1990) correlated a wood bearing sandstone unit in the area to the Flattops One bed (traditional Sonsela Sandstone bed). Recent investigation by the author suggests that the Brown Sandstone may actually be equivalent to the Flattops One bed (but see Raucci et al., this volume) and

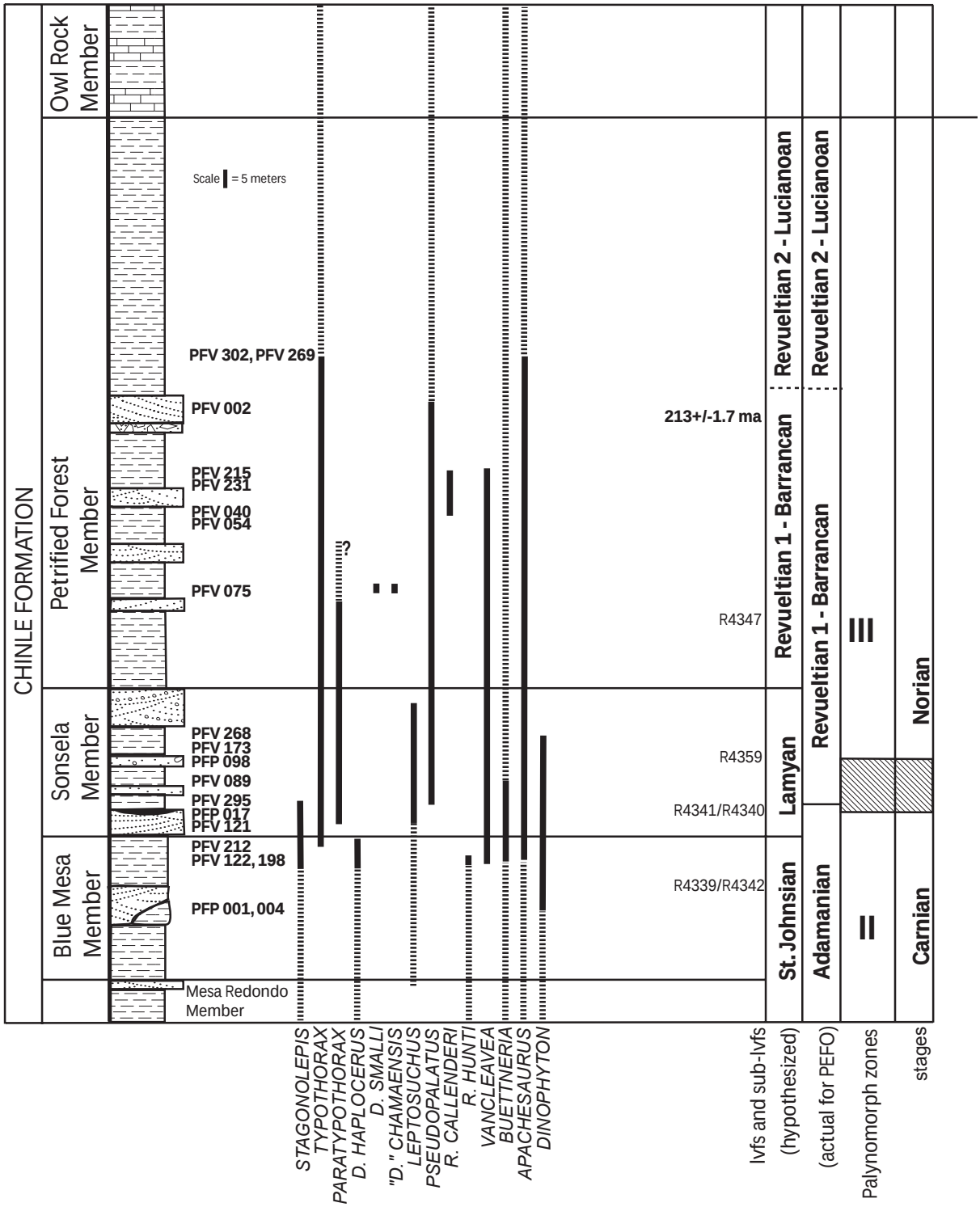


Figure *6* Stratigraphic ranges of taxa from the Chinle Formation of Petrified Forest National Park and Arizona. Solid lines indicate ranges between unambiguous occurrences. Dashed lines with question marks indicate possible range extensions. Dashed lines without question marks indicate range extensions from occurrences at other localities in Arizona. Palynomorph ranges and sample numbers (with R prefix) are from Litwin et al. (1991); hypothetical land vertebrate faunachron ranges are from Hunt et al. (2005); the U/Pb radiometric date for the Black Forest Bed is from Riggs et al. (2003).

that the bed considered by Murry (1990) to represent the "Sonsela Sandstone bed" is in the Jim Camp Wash beds. Most of the outcrop in the lower part of the section clearly represents this unit (Jim Camp Wash beds), a correlation that is supported by the paleontology. Therefore, I tentatively correlate the Brown Sandstone with the Flattops One bed, an unnamed sandstone at the base of the section to the Rainbow Forest beds, and the medial mudstone and sandstones to the Jim Camp Wash beds (Fig. 4).

Long and Murry (1995) refer to a prominent hoodoo-forming sandstone in the area as the "goblin sandstone". Re-

cent stratigraphic work has suggested that this sandstone is equivalent to the Painted Desert Sandstone #1 of Johns (1988) (Heather Jones, written commun., 2004; Raucci et al., this volume) (Fig. 4). The mudstone layer directly overlying the "goblin sandstone" contains an early Norian palynoflora (R. Litwin, written commun.).

**Sonsela Member**

*Rainbow Forest beds*.—PFV 098 – Fossil Garden. In 1927, Charles Camp excavated several phytosaur skulls from a sandy flat he named "the fossil garden". Most of this material is indeterminate but at least one of the specimens (UCMP 27181) represents a small individual of *Leptosuchus crosbiensis*. Long and Murry (1995) list the presence of *Desmatosuchus* and *Stagonolepis* from this locality; however, the material is poorly preserved and not diagnostic.

PFP 121 – This locality is in a dark mudstone that is scoured into an underlying sandstone that floors locality PFV 098. *Dinophyton spinosus* is common at this locality. The flora of this site is undescribed but is similar to floras found at localities just above the Rainbow Forest beds in Crystal Forest and along old Highway 180 and contains a Late Carnian palynoflora (R. Litwin, written commun.).

*Jim Camp Wash beds*.—PFV 097 - Saurian Valley. This is the type locality of the phytosaur "*Machaeroprosopus*" *lithodendrorum* (=*Leptosuchus crosbiensis*). Contrary to Long and Murry (1995), *Desmatosuchus haplocerus* and *Stagonolepis wellesi* are not present at this locality; however, *Paratypothorax* sp. is represented by partial paramedian plates (e. g., UCMP 129995).

PFV 099 – Saurian Valley N. This site is situated approximately 8 meters above PFV 097 and is within the top portion of a prominent sandstone capping many of the small benches and buttes in the area. This sandstone contains petrified wood locally and has been correlated to the traditional "Sonsela Sandstone bed" by Murry (1990) and Long and Murry (1995). In 2002, a skull of *Leptosuchus* sp. (PEFO 31218) was collected from this locality.

PFV 100 - This site is at the same stratigraphic horizon as PFV 099. In 1946, the American Museum of Natural History collected a phytosaur skull from this locality, which has not yet been prepared (Long and Murry, 1995). In 1985, a crew from the UCMP collected a metoposaur skull from a few meters east of the AMNH site. In 2005, a skull of *Leptosuchus sp.* (PEFO 34239) was collected a little farther to the east. This specimen represents the same taxon as the skull from PFV 099 and both are either robust specimens of *L. adamanensis* or small specimens of *L. gregorii*. These skulls represent the highest occurrence of *Leptosuchus* in the Devils Playground area.

**Petrified Forest Member**

PFV 037 – Hell Wash. This locality is located above the "goblin sandstone" (Long and Murry, 1995) and contains pseudopalatine phytosaurs, *Typothorax coccinarum*, and *Paratypothorax* sp.

## DISCUSSION

Precise relocation and documentation of fossil specimens and historic localities allows for more accurate determination of stratigraphic ranges of taxa in the Chinle Formation of Petrified Forest National Park. Resolution is still low pending a more rigorous stratigraphic study of the park (Albright et al., in prep) and completion of an accurate geological map (Raucci et al., this volume). Figure 5 shows the ranges of vertebrate taxa considered to have stratigraphic value, not only in PEFO, but regionally and even globally (Hunt and Lucas, 1993; Lucas and Heckert, 1996; Lucas, 1998; Hunt et al., 2005). These taxa are plotted by lowest and highest occurrences by locality and cross-referenced with palynomorph data from Litwin et al. (1991) and a radiometric date from Riggs et al. (2003). Carnian and Norian ages are assigned using the palynomorph data from Litwin et al. (1991); however, new magnetostratigraphic correlations between Europe and the eastern U.S. suggest that both of the palynofloras may be Norian in age (Muttoni et al., 2004).

Hunt et al. (2005) accounted for the newly determined transitional fauna of the Sonsela Member (Woody and Parker, 2004), as well as a recent discovery of pseudopalatine phytosaurs in an Adamanian assemblage in New Mexico (Hunt and Lucas, 2005), by subdividing the Adamanian land-vertebrate faunachron (lvf) into two sub-lvfs. The St. Johnsian and Lamyan sub-lvfs differ in the presence or absence of *Pseudopalatus* and *Typothorax* (Hunt et al., 2005) with the start of the Lamyan defined as the first appearance of *Typothorax antiquum* and the end defined as the first appearance of *Typothorax coccinarum*. These authors hypothesized that all of the Jim Camp Wash beds of Sonsela Member in PEFO were Lamyan in age; however, previous authors defined the beginning of the Revueltian with the first appearance of *Pseudopalatus* (Lucas and Hunt, 1993; Lucas, 1998). Because I do not consider *T. antiquum* to represent a distinct taxon, I do not recognize the Lamyan sub-lvf; however, even if *T. antiquum* is valid, its first occurrence in PEFO would be from the upper portion of the Blue Mesa Member, and the first unambiguous occurrence of *T. coccinarum* would be at PFV 268, which is about 50 meters below the top of the Sonsela Member. This stratigraphic range differs greatly from that presented by Hunt et al. (2005), who considered all of the Jim Camp Wash beds *Typothorax* specimens to assignable to *T. antiquum*, and thus indicative of the Lamyan. Moreover, if the beginning of the Revueltian is defined by the FAD of *Typothorax*, then the upper portion of the Blue Mesa Member and the entire Sonsela Member would be Revueltian. I prefer the original definition placing the beginning of the

Revueltian at the FAD of *Pseudopalatus*; in which case the lowest Jim Camp Wash beds, the Rainbow Forest beds, and the Blue Mesa Member would be Adamanian, not Revueltian. This definition is preferred because it more closely matches what is seen for the palynomorph zones (although I admit that it is not necessary for the fauna and flora records to match), provides a Norian age for the Revueltian as was originally conceived (Lucas and Hunt, 1993), and maximizes stability of the definitions of the lvf system by honoring historical usage.

This study finds that *Desmatosuchus haplocerus* and *Revueltosaurus hunti* are restricted to the Adamanian. *Pseudopalatus* is restricted to the Revueltian (by definition). *Typothorax coccinarum* occurs in the Adamanian and Revueltian. *Leptosuchus* displays a similar pattern, although *L. adamanensis* is more common in the Adamanian, whereas *L. crosbiensis* only occurs in the Revueltian. It is important to note that *Leptosuchus* and *Pseudopalatus* only overlap due to stratigraphic correlation and that these taxa have never been recovered together from the same locality. The occurrence of *Pseudopalatus* in the Los Esteros Member of the Santa Rosa Formation of New Mexico demonstrates that these and overlying strata are Revueltian in age, although nothing precludes the beginning of the Revueltian from being diachronous across the American Southwest. Because *Leptosuchus* has not been documented from strata overlying the Los Esteros Member, there is no reason to modify the lvf scheme to account for this "seemingly low" stratigraphic occurrence (*contra* Hunt et al. 2005).

Vertebrate and palynomorph data suggests that at least the lowest portion of the Sonsela Member is Carnian in age, whereas the upper portion of the member is Norian in age. This contrasts with past studies which have considered the Sonsela to be entirely Norian in age (Heckert and Lucas, 2002) or mostly latest Carnian in age (Hunt et al., 2005). Thus, the Carnian/Norian boundary is located approximately in the lower-middle portion of the member (Fig. 5; Woody and Parker, 2004). Furthermore, a transitional period for both the fauna and flora appears to roughly coincide with this interval. There is no evidence for a sizeable unconformity at the Carnian/Norian boundary (the Tr-4 unconformity of Lucas, 1993) (Woody, this volume). Alternatively, if the recent correlation by Muttoni et al. (2004) is correct, all Chinle Formation strata in the park would be Norian in age. Nonetheless, this study suggests that the boundaries of the proposed Late Triassic faunachrons do not correspond with stratigraphic boundaries in the Chinle Formation as proposed by previous workers (Fig. 5).

## CONCLUSIONS

The Blue Forest Member contains palynomorphs and plant fossils that pertain to palynomorph Zone II of Litwin et al. (1991) and the *Dinophyton* floral zone of Ash (1970), both of which are believed to be Carnian in age. The vertebrate fauna is dominated by the metoposaurid *Buettneria perfecta*, the aetosaur *Stagonolepis wellesi*, and the phytosaur *Leptosuchus adamanensis*. *Desmatosuchus haplocerus*, *Typothorax coccinarum, Revueltosaurus hunti*, and *Vancleavea campi* are also present but rare. A proximal end of a femur from locality PFV 122 represents the earliest unambiguous record of a *Silesaurus*-like dinosauriform in North America.

The lower portion of the Sonsela Member (Rainbow Forest beds and lowest Jim Camp Wash beds) contains a palynomorph fauna that corresponds to palynomorph Zone II of Litwin et al. (1991) and is considered Carnian in age. The fauna of the lower Sonsela Member includes *Stagonolepis wellesi*, *Paratypothorax* sp., *Leptosuchus adamanensis*, *Leptosuchus crosbiensis*, *Pseudopalatus* spp., and *Typothorax coccinarum*.

The upper portion of the Sonsela Member (upper Jim Camp Wash beds and Flattops One bed) contain a palynomorph flora that corresponds to palynomorph Zone III of Litwin and Ash (1991) and is therefore Norian in age. The fauna of the upper Sonsela Member contains *Typothorax coccinarum*, *Paratypothorax* sp., *Leptosuchus adamanensis*, *Pseudopalatus pristinus*, and possibly *Leptosuchus crosbiensis*.

The Petrified Forest Member contains palynomorphs that correspond to Zone III of Litwin et al. (1991) and is therefore Norian in age. The vertebrate fauna is dominated by *Typothorax coccinarum*, *Paratypothorax* sp., *Apachesaurus gregorii*, and *Pseudopalatus* spp. *Revueltosaurus callenderi* and *Vancleavea* sp. are common at several localities in the Painted Desert area but have not been recovered from the Flattops region. *Desmatosuchus smalli*, "*Desmatosuchus*" *chamaensis*, *Coelophysis* sp., and *Chindesaurus bryansmalli* are also present but rare.

Stratigraphic determination of taxon ranges demonstrates that phytosaur taxa are may still be useful as index taxa for the Chinle Formation within PEFO despite evidence of an "Adamanian" pseudopalatine phytosaur in New Mexico. The Revueltian should continue to be defined using the FAD of *Pseudopalatus* following Lucas and Hunt (1993), Lucas (1998), and Lucas et al. (2002), rather than the FAD of *Typothorax coccinarum* as has been advocated by Hunt et al. (2005). Accordingly the Adamanian should be defined as the FAD of *Leptosuchus* as originally conceived. That these taxa overlap in the Sonsela Member simply strengthens the argument for a transitional fauna and flora of the Sonsela Member (Woody and Parker, 2004; Hunt et al., 2005) that may correspond with the Carnian-Norian boundary. *Typothorax "antiquum"* cannot be adequately differentiated from *T. coccinarum* using unambiguous autapomorphies and therefore I consider it to be a junior synonym of *T. coccinarum*. Consequently, I do not recognize the division of the Adamanian lvf into the St. Johnsian and Lamyan sub-lvfs. It appears as if assignment of fragmentary plates to *T. "antiquum"* by past authors (Lucas et al., 2002: Hunt et al., 2005) was biased by a stratophenetic approach rather than determination of diagnosable characters.

This study suggests that aetosaurs may not be as useful for biostratigraphy as previously hypothesized (e.g., Lucas and Hunt, 1993) because *Typothorax* overlaps with both *Stagonolepis* and *Desmatosuchus haplocerus*, and should not be used to define lvfs, although they may have limited use as index taxa. Furthermore, evidence from this study as well as Chatterjee and Lehman (2005), Langer (2005), and Rayfield et al. (2005) show that these lvfs only have local to regional utility and extreme caution should be used when applying them globally.

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