

PLANT MEGAFOSSIL BIOSTRATIGRAPHY AND BIOCHRONOLOGY, UPPER TRIASSIC CHINLE GROUP, WESTERN USA

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Abstract—The Chinle Group in the western United States contains one of the world’s most extensive and intensively studied records of plant megafossils. This has been the basis for a Late Triassic fossil plant biostratigraphy that in the 1980s recognized three units (in ascending order): *Eoginkgoites*, *Dinophyton* and *Sanmiguelia* “floral zones.” However, subsequent collecting demonstrated stratigraphic overlap of the name-bearing (and defining) taxa of these zones. Furthermore, the *Eoginkgoites* floral zone is based on few localities and has so few unique taxa that its distinctiveness is questionable. Therefore, a revised Chinle Group plant megafossil biostratigraphy identifies two assemblage zones – *Dinophyton* assemblage zone, primarily from the lower part of the Chinle Group, which stratigraphically overlaps part of the overlying *Sanmiguelia* assemblage zone, primarily from the upper part of the Chinle Group. The stratigraphic distribution of Chinle Group plant megafossils is the basis for recognition of two biochronological units, for which the term florachron is introduced. The Cinizan florachron is the time interval between the first appearance datum of *Eoginkgoites* and the first appearance datum of *Sanmiguelia*. The Paloduroan florachron is the time interval between the first appearance datum of *Sanmiguelia* and the first appearance datum of the conifer *Saintgeorgia*. Correlation to the Newark Supergroup of eastern North America, corroborated by palynostratigraphy, indicates that the Cinizan is of late Carnian (Tuvanian) age, and the Paloduroan is of Norian age. A more refined Chinle Group plant megafossil biostratigraphy and biochronology will require more detailed stratigraphic ordering of the fossil plant assemblages and a better understanding of Chinle Group plant megafossil taphonomy. Current data suggest that the *Sanmiguelia* assemblage zone represents a Norian taphoflora endemic to relatively well-drained upper Chinle red beds, whereas the “background” paleoflora of wetter facies from late Carnian to Hettangian time is well represented by the *Dinophyton* assemblage zone.

INTRODUCTION

The Chinle Group in the western United States (Fig. 1) contains one of the world’s most extensive and intensively studied fossil records from Upper Triassic nonmarine strata (Lucas, 1997). A significant part of this record is the plant megafossil assemblages (Fig. 1, Appendix 1), which are among the best studied Late Triassic plant megafossils. This record has become the basis for a Late Triassic fossil plant biostratigraphy (Ash, 1980, 1987). My purpose here is to re-evaluate the biostratigraphic distribution of plant megafossils in the Chinle Group, to discuss their biochronological significance and correlation, and to present a prospectus for future refinement of this biostratigraphy and biochronology.

SOME CONCEPTS

Before discussing Chinle Group plant megafossil biostratigraphy and biochronology, I clarify some concepts and terminology essential to the discussion. **Biostratigraphy** studies the distribution of fossils in strata, whereas **biochronology** is the study of the temporal distribution of fossil taxa. Thus, a biostratigraphic unit (usually some kind of zone) is a rock body with a distinctive fossil content, but not an interval of time. A biochronological unit (usually a biochron) is the time interval equivalent to a biostratigraphic unit (Fig. 2).

In terms of fossil plant biostratigraphy, most previous studies have focused on the stratigraphic range of a given taxon (its **range zone**) or the stratigraphic range of a group of taxa, the **assemblage zone**. The time during which a taxon existed is its **biochron**, and the time during which an assemblage of fossil plants (a “flora”) persisted can be called a **florachron** (a new term introduced here). There is thus a direct relationship between biostratigraphy and biochronology because the operational equivalent of a biochron is a range zone, and of a florachron is an assemblage zone (Fig. 2).

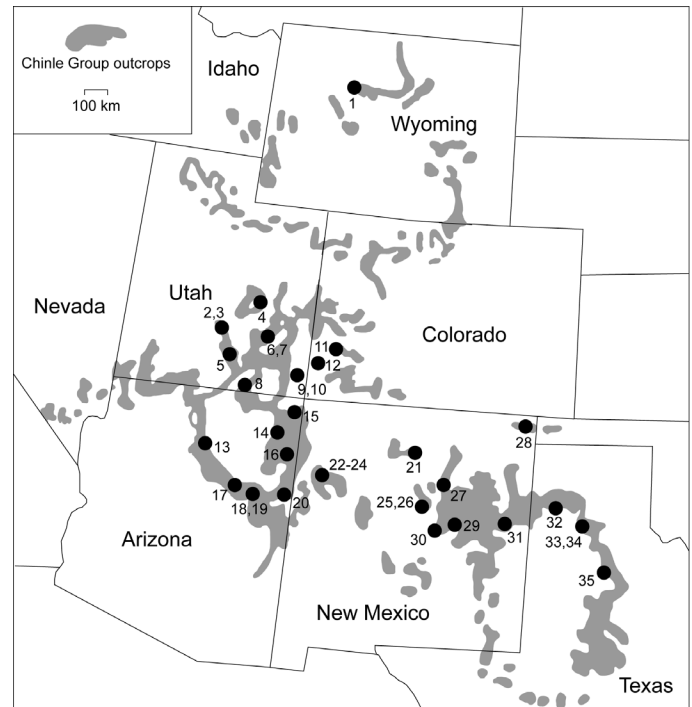


FIGURE 1. Generalized distribution of outcrops of the Chinle Group (after Lucas, 1993) showing principal plant megafossil localities (numbers of localities are those in Appendix 1).

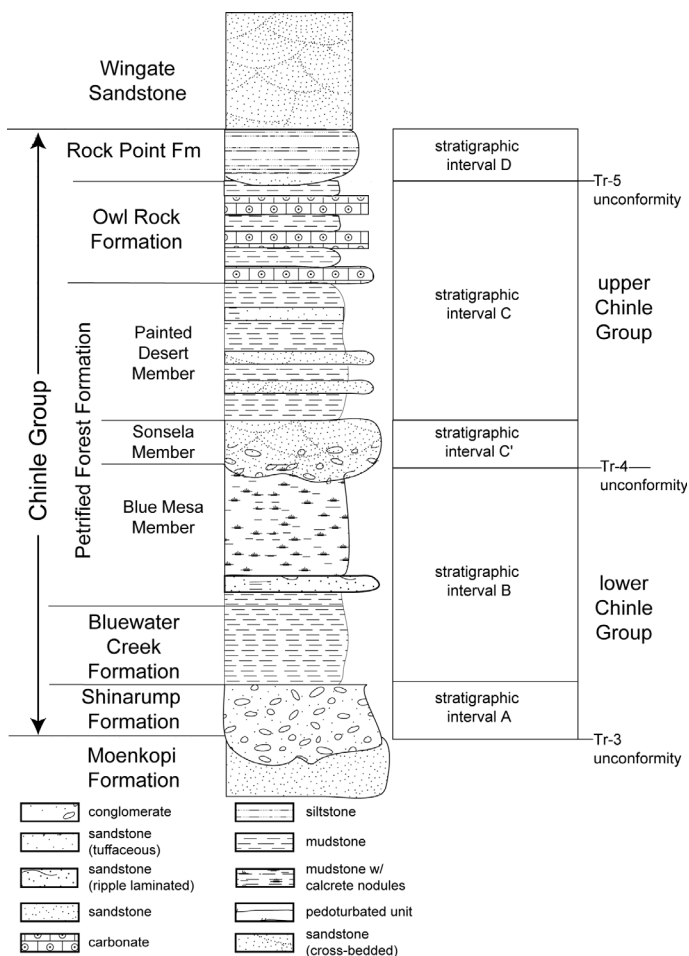


FIGURE 3. Generalized Chinle Group lithostratigraphy in northeastern Arizona showing informal stratigraphic intervals referred to in the text.

Bull Canyon Formation of eastern New Mexico-West Texas). Another unconformity (Tr-5 unconformity of Lucas, 1993) follows, overlain by the sandstone/siltstone-dominated Rock Point Formation (interval D) and correlatives (most prominent is the Redonda Formation of eastern New Mexico: Spielmann and Lucas, 2012). I here refer to intervals A-B as the “lower Chinle Group,” and C, C and D as the “upper Chinle Group” (Fig. 3).

This lithostratigraphic framework allows confident placement of the Chinle Group plant megafossil localities into stratigraphic order (Appendix 1). From this stratigraphic ordering, achieved by using datasets (lithostratigraphy and vertebrate biostratigraphy) independent of plant biostratigraphy, it is possible to determine the biostratigraphic distribution of plant megafossils in the Chinle Group. However, there are few places where Chinle Group plant megafossils are stratigraphically superposed in a single section (the Petrified Forest National Park in Arizona is a notable exception). Instead, most of the Chinle megafossil assemblages can be assigned to a stratigraphic interval, but establishing more precise stratigraphic ordering within intervals is impossible with available data. This is a limitation of Chinle Group plant megafossil biostratigraphy that will be discussed further below.

CHINLE GROUP PLANT MEGAFOSSILS

In 1850, Simpson published the first reference to Chinle Group plant megafossils when he described fossil wood in the vicinity of Canyon de Chelly, Arizona. Since that time, fossil wood, foliage and other kinds of plant megafossils have been described by various authors, as

reviewed by Ash (1972a, 1989a), who summarized the literature up to that time. These plant fossils come primarily from the Four Corners states of Arizona, New Mexico, Colorado and Utah, but Chinle Group plant records also come from Texas and Wyoming (Fig. 1; Appendix 1).

The Chinle paleoflora encompass more than 70 named species here allocated to 54 genera (Fig. 4). Most are known from foliage compressions, but some species are known from impressions, pith casts or petrifications. Conifers, cycadophytes, and ferns and fern-like foliage dominate Chinle Group plant megafossil assemblages. Also present are lycopsids (including *Isoetes*), horsetails, cycadeoids, ginkgoaleans, cordaitaleans and several taxa of uncertain systematic position (Ash, 1989a).

Ash (1980, 1987) developed a Chinle Group plant megafossil biostratigraphy based on the record as it was known in the 1980s (Fig. 5). Since the review by Ash (1989a), various articles on Chinle plant megafossils have been published, mostly by Ash (e.g., 1999, 2001, 2005, 2006; Ash and Litwin, 1996; Axsmith and Ash, 2006; Savidge and Ash, 2006; Watson and Ash, 2006) and a few by others (e.g., Lucas, 2006; Milner, 2006). I rely primarily on this published database for taxonomic identifications and to establish the biostratigraphic distribution of Chinle Group plant megafossils (Fig. 4). Thus, I make no attempt to re-evaluate the alpha taxonomy of Chinle Group plant megafossils. I also note that I have examined firsthand many of the Chinle plant megafossil localities, so their stratigraphic position has been confirmed/established by me in the field (as an example, see Lucas and Hayden, 1989 and Heckert and Lucas, 2002, for the stratigraphy of Chinle Group plant megafossil localities in western New Mexico). Finally, several of the genera of Chinle plant megafossils are almost certainly form genera from the same plant (example *Sanmiguelia* and *Synangispadixis*). Thus, the list of genera somewhat overestimates actual diversity.

CHINLE GROUP PLANT MEGAFOSSIL BIOSTRATIGRAPHY

In presenting a plant megafossil biostratigraphy for what I term Chinle Group strata, Ash (1980) used an older (pre-Lucas, 1993) parochial stratigraphic nomenclature, assigning the plant localities to the Chinle Formation in Arizona, western New Mexico, Utah and part of western Colorado, to the Dockum Group in eastern New Mexico and West Texas, to the Dolores Formation in southwestern Colorado and to the Popo Agie Formation in Wyoming (see Ash, 1980, fig. 5.1). He also included the megafloora of the Santa Clara Formation in Sonora, Mexico, in his analysis, assigning it a Rhaeto-Liassic age younger than the Chinle Group megaflooras. Ash (1980) recognized two stratigraphically successive “floral zones” in the Chinle Group, which are clearly assemblage zones: lower, *Eoginkgoites* floral zone and upper, *Dinophyton* floral zone (Fig. 5). He also recognized these zones in the Newark Supergroup of the eastern USA, using some taxa known only from the Newark to characterize the zones.

In the Chinle Group, the *Eoginkgoites* floral zone is based on plant assemblages in the Shinarump, Temple Mountain and Popo Agie formations (Appendix 1). The zone was originally characterized by the presence of *Eoginkgoites*, the ferns *Phlebopteris* and *Pekinopsis*, the cycad *Leptocycas* (a taxon not known from the Chinle Group, but from presumed correlative strata of the Newark Supergroup in the eastern USA) and the bennettitalean *Ischnophyton* (also a Newark taxon). My current compilation identifies a total of 20 genera in this zone in Chinle Group strata, but only seven are restricted to this zone (Fig. 4, column A).

Ash (1980) characterized the *Dinophyton* floral zone by the presence of that genus and the absence of *Eoginkgoites*. In the western USA, he originally considered this zone to comprise most of the lower Chinle Formation, entire “Dockum Group” in Texas (= lower Chinle) and the “Dolores Formation” of southwestern Colorado (= upper Chinle). However, he later (Ash, 1987) separated out the “Dolores” (and stratigraphically equivalent) paleofloras that yielded the enigmatic plant

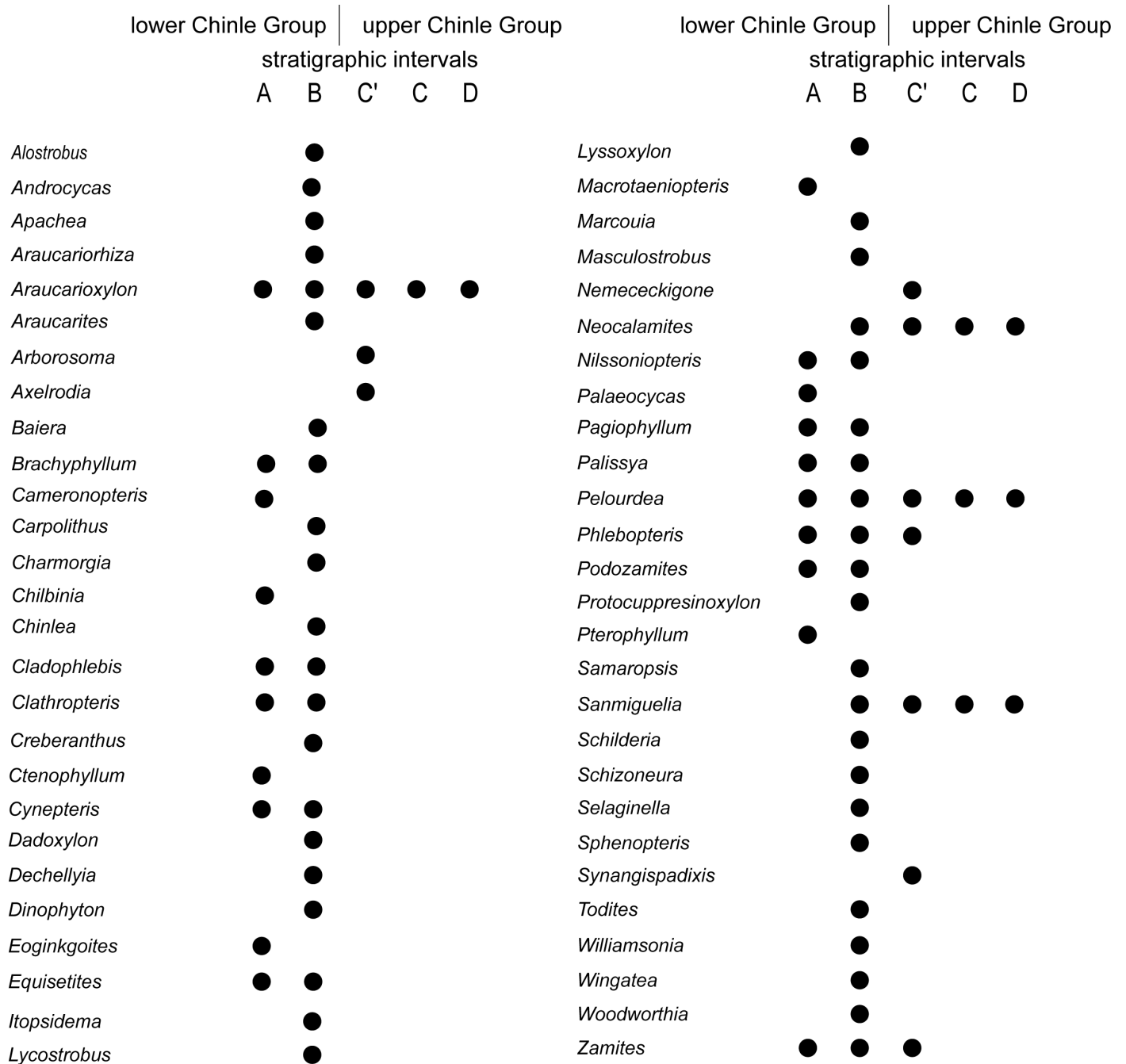


FIGURE 4. Stratigraphic ranges of plant megafossil genera in the Chinle Group based on Ash (1989) and sources cited therein, updated in the light of more recently published literature. Informal stratigraphic units of the Chinle Group are those in Figure 3.

Sanmiguelia and termed them the *Sanmiguelia* floral zone (Fig. 5).

The bulk of the Chinle paleoflora pertains to the *Dinophyton* floral zone. Thus, 43 of the 54 genera of Chinle Group fossil plants are known from the *Dinophyton* floral zone (Fig. 4). According to Ash (1980), the most “noteworthy taxa” are the lycopsid *Selaginella*, the fern *Todites*, the fern-like foliage *Cladophlebis* and *Marcouia*, the benettitalean *Nilssoniopteris* and the enigmatic *Dechellyia*. The “classic” flora is that originally described by Daugherty (1941) from the Blue Mesa Member of the Petrified Forest Formation in the Petrified Forest National Park. Ash (1980) also listed paleofloras from the Chinle Group in Arizona, western New Mexico, eastern New Mexico (Santa Rosa Formation) and West Texas (Tecovas and Trujillo formations) as belonging to his *Dinophyton* “floral zone.” Records of *Dinophyton* in the Sonsela Mem-

ber and Trujillo Formation (stratigraphic interval C’: Fig. 3) are its stratigraphically highest occurrences. Ash (1980) also included the paleoflora of the New Oxford Formation in the Gettysburg basin of Pennsylvania in the *Dinophyton* zone.

As noted above, Ash (1980) recognized an “upper floral zone” in western North America of “?Rhaeto-Liassic” age based on the paleoflora of the Santa Clara Formation of Sonora, Mexico that he equated to an “unnamed floral zone” in the Newark Supergroup that encompasses the megafloora of the Lower Jurassic Shuttle Meadow and Portland formations (see Cornet and Olsen, 1985 for a review of these floras; also see Olsen et al., 1989, 2003, 2005). In eastern Sonora, the Santa Clara Formation is the middle, coal-bearing unit of the Barranca Group (e.g., Stewart and Roldán-Quintana, 1991). The megafossil-plant-bearing strata are




Ash (1980)	Ash (1987)	lithostratigraphy		
<i>Dinophyton</i> floral zone 	<i>Sanmiguelia</i> floral zone 	D	upper	Chinle Group
		C		
		C'		
<i>Eoginkgoites</i> floral zone 	<i>Dinophyton</i> floral zone	B	lower	
		A		
<i>Eoginkgoites</i> floral zone	<i>Eoginkgoites</i> floral zone	A		

FIGURE 5. Development of Chinle Group plant megafossil biostratigraphy. Informal stratigraphic units of the Chinle Group are those in Figure 3.

interbedded with estuarine to shallow marine facies that yield an age-diagnostic marine invertebrate assemblage (especially bivalves and rare ammonoids) of late Carnian age (Alencaster, 1961; Stewart and Roldán-Quintana, 1991; Lucas, 1996). Thus, correlation to the Chinle Group indicates temporal overlap of the Santa Clara megafloora and the *Eoginkgoites* and *Dinophyton* floral zones (the lower Chinle Group is of late Carnian age: Lucas et al., 2012). Dis-similarity of these paleofloras must reflect differences in paleoenvironments, facies and/or taphonomy. These are differences between the coastal swamps of Santa Clara deposition and the inland floodplains of lower Chinle Group deposition. Ash (1980) originally took “*Thaumatopteris*” from the Santa Clara paleofloora to indicate a Liassic age by comparison to paleofloras from Greenland (Harris, 1937). However, in an addendum to the 1980 paper, Ash stated that new work by R. Weber indicated that the Santa Clara paleofloora is equivalent to the *Eoginkgoites* zone (see for example, Weber, 1997).

Lucas (1997) plotted the stratigraphic distribution of Chinle Group megafossil plant genera. I present a similar plot (Fig. 4), having updated it based on literature published since 1997 and range extensions and other observations available since 1997. For example, recent collecting in central New Mexico has yielded an assemblage dominated by *Phlebopteris* (Fig. 6) in interval C', a substantial upward range extension of this taxon in the Chinle Group (Lucas and Spielmann, 2010), though this taxon has long been known from Jurassic strata. The new plot (Fig. 4) shows a segregation of the Chinle Group plant genera into two assemblage zones, not the three floral zones recognized by Ash (1980, 1987).

It also shows the important range extension of *Sanmiguelia* downward (Lucas, 2006), so that its stratigraphic range overlaps that of *Dinophyton*, and there is now stratigraphic overlap of the *Dinophyton* and *Sanmiguelia* floral zones of Ash (1980, 1987). This overlap of *Dinophyton* and *Sanmiguelia* means that the two floral zones of Ash (1987) are no longer stratigraphically distinct. However, the LO of *Sanmiguelia* still is a useful biostratigraphic datum, as it is the characteristic foliage genus found in the upper part of the Chinle Group. Therefore, I retain the *Sanmiguelia* assemblage zone as a useful biostratigraphic construct and simply recognize that it overlaps part of the underlying *Dinophyton* assemblage zone (Fig. 7).

More problematic is the *Eoginkgoites* floral zone of Ash (1980). This zone is based on localities in Arizona, Utah and New Mexico in stratigraphic interval A of the Chinle Group. Only seven genera are confined to the zone, and the other 13 genera extend upward into the *Dinophyton* assemblage zone (or higher: Fig. 4). Regarding these seven genera:

1. *Cameronopteris*, *Chilbinia*, *Macrotæniopteris* and *Palaeocycas* are known from a single locality in stratigraphic interval A in Arizona,

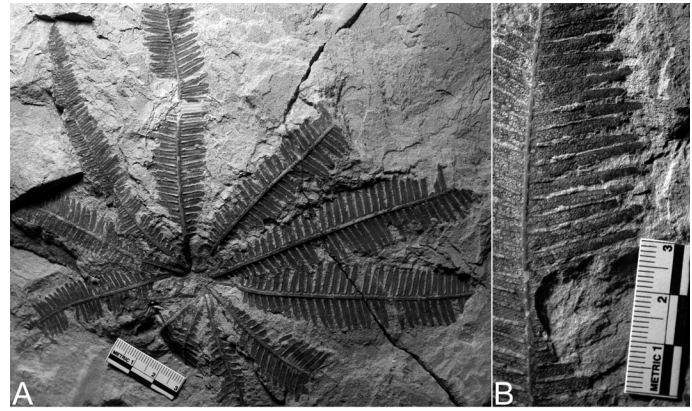


FIGURE 6. Specimens of *Phlebopteris smithi* (Daugherty, 1941) from central New Mexico that represents an upward extension of the stratigraphic range of the genus. These specimens are catalogued as NMMNH (New Mexico Museum of Natural History and Science) P-59951 and are from the Trujillo Formation at NMMNH locality 7843 south of Lamy in Santa Fe County (Lucas and Spielmann, 2010). **A**, Fertile leaf bearing 10 pinnae. **B**, Close-up of part of one fertile pinna showing sori.

recently reported by Ash (2005, 2006). The stratigraphic ranges of these taxa thus are not well established, and their restriction to one locality renders their biostratigraphic significance minimal.

2. *Ctenophyllum* has poorly documented records in stratigraphic interval A in Utah and Arizona (identifications by Roland Brown listed by Stewart et al., 1972), and Ash (1974) judged its supposed New Mexican record to be based on unidentifiable material. This genus thus appears to be rare in the Chinle Group, so its stratigraphic range is not likely to be well established.

3. The name-bearing taxon *Eoginkgoites* co-occurs with *Dinophyton* in the Newark Supergroup (Gensel, 1986; Axsmith and Kroehler, 1989; Litwin and Ash, 1993; Axsmith et al., 1995). Therefore, the current lack of co-occurrence of these genera in the Chinle Group does not reflect true stratigraphic (temporal) separation, but must be due to paleoecological, taphonomic, paleobiogeographic or sampling factor(s).

4. *Pterophyllum* is a stratigraphically long-ranging Mesozoic genus of cycadeoid foliage (e.g., Tidwell, 1998). Its Chinle Group record is from one locality in the Popo Agie Formation of Wyoming (Berry, 1924), so its apparent restriction to stratigraphic interval A is of no significance.

These observations undermine the distinctiveness of the *Eoginkgoites* floral zone, so I abandon it and merge its few assemblages into a more stratigraphically broad *Dinophyton* assemblage zone (Fig. 7). It might still be argued that there is value in recognizing separate *Eoginkgoites* and *Dinophyton* floral zones just in the Chinle Group. However, I would like to see more records and more taxa distinctive of the *Eoginkgoites* zone to demonstrate regional utility of the zone in Chinle strata. I also predict that further collecting will yield a co-occurrence of *Eoginkgoites* and *Dinophyton* in the lower Chinle Group.

CHINLE GROUP PLANT MEGAFOSSIL BIOCHRONOLOGY

Based on the biostratigraphic distribution of fossil plants in the Chinle Group (Fig. 4), I propose a Chinle plant megafossil biochronology (Fig. 7). An important consideration of the biochronology is not using plant assemblage zones as a basis for definition. Instead, the assemblage zones are used to characterize florachrons with boundaries defined by the FAD of a single plant genus. This allows for a single taxon definition of the beginning of the florachron, so that there is no ambiguity in definition (Murphy, 1977). The beginning of a florachron defines the end of the preceding florachron. I have employed a similar method to define land-vertebrate faunachrons in the Chinle Group—intervals of geological time based on vertebrate evolution (e.g., Lucas, 2010). In following that method I use place names for each florachron, so that taxonomic names,






biostratigraphy	biochronology	ranges key taxa	lithostratigraphy		
Sanmiguelia assemblage zone	Paloduroan florachron	 <i>Sanmiguelia</i>  <i>Dinophyton</i>  <i>Eoginkgoites</i>	D	upper	Chinle Group
			C		
			C ₁		
Dinophyton assemblage zone	Cinizan florachron	 <i>Dinophyton</i>  <i>Eoginkgoites</i>	B	lower	
			A		

FIGURE 7. Chinle Group plant megafossil biostratigraphy and biochronology proposed here. Informal stratigraphic units of the Chinle Group are those in Figure 3.

which are typically used for biostratigraphic zones, are not associated with biochronological units. This further enables the separate discussion of biostratigraphy and biochronology regardless of how closely the biostratigraphic units operationalize the biochronological units.

I thus define two biochronological units based on Chinle Group plant megafossils:

1. The Cinizan florachron is the time interval between the FAD of *Eoginkgoites* and the beginning of the Paloduroan florachron (= FAD of *Sanmiguelia*). The name is from the “Lake Ciniza” plant assemblage in the Bluewater Creek Formation of the Chinle Group in western New Mexico (Ash, 1978a, b). This assemblage and the nearby Fort Wingate assemblage are characteristic localities of the *Dinophyton* assemblage zone. The characteristic flora of the Cinizan is the flora of the *Dinophyton* assemblage zone. Much of the lower Chinle Group is of Cinizan age (Fig. 7).

2. The Paloduroan florachron is the time interval between the FAD of *Sanmiguelia* and the FAD of the conifer *Saintgeorgia*. The name is from Palo Duro Canyon, Texas, which has yielded fossil plants of the *Sanmiguelia* assemblage zone from the Trujillo Formation of the Chinle Group (Ash, 1976; Cornet, 1986). The *Sanmiguelia* assemblage zone is the flora characteristic of the Paloduroan. Part of the lower and all of the upper Chinle Group is of Paloduroan age (Fig. 7).

The end of the Paloduroan cannot be defined in Chinle Group strata, because no younger florachron is present. A small paleoflora from uppermost Triassic strata of the Moenave Formation (Tidwell and Ash, 2006) is stratigraphically above the Chinle Group, so I use a taxon from that paleoflora (the conifer *Saintgeorgia*) to define the beginning of an unnamed florachron that follows the Paloduroan. However, there needs to be a closer study of paleofloras that span the Triassic-Jurassic boundary to better define and characterize plant megafossil biostratigraphy and biochronology for this time interval.

PALYNOMORPHS

Upper Triassic palynomorph assemblages have been documented from the Chinle Group since the 1970s (e.g., Dunay and Traverse, 1971; Dunay and Fisher 1979; Fisher and Dunay 1984; Litwin, 1986; Litwin et al., 1991; Cornet, 1993). Litwin et al. (1991) provided the most recent analysis of the Chinle Group palynoflora, organizing it into three zones that correspond rather closely to the floral zones of Ash (1980, 1987) (Fig. 8).

Zone I palynomorphs have a limited distribution in the Chinle Group, known only from a few localities in the Temple Mountain Formation in the San Rafael Swell of Utah. Only two taeniata bisaccate taxa, *Lunatisporites* aff. *L. noviaulensis* and *InfernopolLENITES claustratus*, are restricted to the zone. Judged by Litwin et al. (1991) to be late Carnian, Zone I is not particularly distinct from the overlying Zone II

palynoassemblage, with which it shares many taxa. Indeed, the relationship of palynomorph Zones I and II to each other is very similar to the relationship of the original *Eoginkgoites* and *Dinophyton* floral zones of Ash (1980): the older zone is based on relatively few localities, only a few taxa are restricted to it and most of the taxa of the older zone occur in the younger zone.

Zone II includes the most diverse and abundant palynological assemblages in the Chinle Group, and is characterized by the LOs of *Camarozonosporites rudis*, *Enzonalsporites vigens*, *Heliosaccus dimorphus*, *Ovalipollis ovalis*, *Pseudoenzonalsporites summus* and other taxa (e.g. *Alisporites* spp., *Cycadopites stonei*, *Guthoerlisporites cancellosus*), and the HOs of *Brodispora striata*, *Camerosporites secatus*, *Equisetosporites chinleanus* and *Lagenella martini*. This assemblage closely resembles upper Carnian assemblages from Europe, so Litwin et al. (1991) assigned it a late Carnian (Tuvalian) age. Indeed, the HOs of *Camerosporites secatus*, *Triletes klausii* and *Brodispira striata* confirm that the zone II assemblages are no younger than late Carnian (Lucas et al., 2012).

Founded on the FOs of *Camerosporites verrucosus* and *Kyrptomisporis* spp., zone III was assigned an early Norian age because of the absence of significant Carnian taxa (e.g. *Brodispora striata* and *Camerosporites secatus*) and the presence of *C. verrucosus* and *Pseudoenzonalsporites summus*. Based on this palynostratigraphic zonation, the Norian base in the Chinle Group is close to the base of the upper Chinle Group (= base of the Sonsela Member of the Petrified Forest Formation and its correlatives near the base of stratigraphic interval C'). This placement of the Carnian-Norian boundary is in agreement with correlations based on conchostracan and vertebrate biostratigraphy (Kozur and Weems, 2010; Lucas, 2010; Lucas et al., 2012). The youngest age of the Chinle Group palynoflora-bearing strata is late Norian based on conchostracan and vertebrate biostratigraphy, which is younger than the age assigned to it (early Norian) by Litwin et al. (1991).

CORRELATION TO THE NEWARK SUPERGROUP

The principal paleofloras to which the Chinle paleofloras can be precisely correlated come from the Newark Supergroup basins of eastern North America. The Newark record temporally overlaps the Chinle record and also includes Early Jurassic paleofloras younger than any found in the Chinle Group (e.g., Cornet and Olsen, 1985). The Newark also includes older Late Triassic paleofloras, such as the coal measures flora of the Richmond basin (Ediger, 1986).

The lower Chinle paleofloras are in the *Dinophyton* assemblage zone, which corresponds to the Chinle Zone I-II palynofloras (Fig. 8) and share many taxa with paleofloras in the Newark Supergroup in the middle part of the New Oxford Formation (Gettysburg Basin, Pennsylvania), uppermost Stockton Formation (Newark Basin, New Jersey), Cumnock Formation (Deep River Basin, North Carolina) and Cow Branch Formation (Dan River Basin, North Carolina) (e.g., Bock, 1969; Ash, 1980; Cornet and Olsen, 1985, 1990; Gensel, 1986; Axsmith and Kroehler, 1989; Axsmith et al., 1995; Huber et al., 1993). Therefore, the megaflores equates most of the lower Chinle Group (strata below the HO of *Camerosporites secatus*) to these Newark Supergroup formations, so these lower Newark formations can be said to be of Cinizan age (Fig. 8). An important point is that these lower Newark formations contain *Eoginkgoites* and/or *Dinophyton* (they co-occur in the Stockton Formation in the Newark basin). Indeed, Cornet and Olsen (1990) suggested that *Eoginkgoites* and *Dinophyton* define a single assemblage zone in the lower Newark (also see Axsmith et al., 1995), a conclusion endorsed here.

The younger, Triassic portion of the Newark Supergroup lacks any well-described paleoflora. Most of what is known are a few specimens scattered in the literature, such as *Pagiophyllum simpsoni*-like conifer shoots (e.g., LeTourneau, 2003). Therefore, we could assign the Triassic, upper part of the Newark a Paloduroan age, though there is no

SGCS		biochronology	pollen zones	Chinle basin		Newark basin	Gettysburg Basin	Deep River Basin	Dan River Basin
Late Triassic	Rhaetian	unnamed florachron	?	Moenave Fm.					
	Norian	Paloduroan florachron	III	upper	Chinle Group	Passaic Formation	Gettysburg Formation	Sanford Formation	Stoneville Formation
						Lockatong Formation	New Oxford Formation	Cumnock Formation	Cow Branch Formation
	late Carnian	Cinizan florachron	II	lower					

FIGURE 8. Correlation of the Chinle Group and part of the Newark Supergroup based on plant megafossils and palynology.

direct paleobotanical basis for the age assignment. The plant megafossil record begins again in the Lower Jurassic portion of the Newark in strata within the Newark extrusive zone (Shuttle Meadow Formation) or above it (Portland Formation) (e.g., Cornet and Traverse, 1975; Cornet, 1977; Ash, 1980; Cornet and Olsen, 1985). Ash (1980) referred these floras to his upper zone, and they are slightly younger than the flora from the Moenave Formation in Utah recently described by Tidwell and Ash (2006), which is of latest Triassic (Rhaetian) age (see Lucas and Tanner, 2007; Lucas et al., 2011). Further investigation of plant biostratigraphy and biochronology across the Triassic-Jurassic boundary in North America is needed but beyond the scope of this paper.

FURTHER REFINEMENT

As stated earlier, other than at a few localities (such as the Petrified Forest National Park in Arizona), there is no direct stratigraphic superposition of Chinle paleofloras. Most are known from one or a few stratigraphically proximate localities in a local outcrop area (Appendix 1). Temporal ordering of the Chinle paleofloras is thus certain at the level of resolution of the stratigraphic intervals identified here (Fig. 3, Appendix 1). A more detailed stratigraphic ordering should be achievable with additional stratigraphic work and further collecting. This is one path forward to improve Chinle Group plant megafossil biostratigraphy and biochronology.

A second path forward requires a better understanding of the taphonomy of Chinle plant megafossils. Indeed, one of the great limitations of the Chinle Group plant megafossil record is the general lack of site-specific sedimentological or taphonomic analyses. Little work has been undertaken on Chinle plant megafossil assemblages to determine the facies/taphonomic restrictions on their distribution. Demko et al. (1998) is one of the few such studies and it argued that the stratigraphically lowest Chinle plant megafossil assemblages were formed in incised paleovalleys early in Chinle deposition, and thus were “taphonomically biased toward riparian wetland environments” (p. 1119). However, stratigraphically higher Chinle Group assemblages lack any taphonomic or site-specific sedimentological analysis.

All of the Chinle Group plant megafossil assemblages come from a vast alluvial floodbasin, but they occur in an array of settings, from channel margin to floodplain to lake. Perhaps the degree to which facies and taphonomy are affecting Chinle plant megafossil distribution is best revealed by comparing lower and upper Chinle assemblages. There is a profound facies change approximately in the middle of the Chinle Group (close to the base of stratigraphic interval C) from more poorly-drained

floodplains with local lakes to better-drained floodplains. This is the change to red beds of the upper Chinle Group. This change is marked by a shift in the paleofloras from the *Dinophyton* assemblage zone to the *Sanmiguelia* assemblage zone. Indeed, the *Sanmiguelia* assemblage zone consists mostly of taxa totally endemic to the Chinle Group, and as Ash (1987) noted, plant fossils of this zone are relatively large, durable elements commonly preserved in growth position, quite distinct from plants of the *Dinophyton* assemblage zone. Also, unlike the *Dinophyton* assemblage zone, *Sanmiguelia* zone plant assemblages are of low diversity, typically consisting of *Sanmiguelia* and no other taxa. This leads me to suggest that the *Sanmiguelia* assemblage zone is a distinct taphoflora found primarily in the upper part of the Chinle Group.

Tidwell and Ash (2006) presented preliminary documentation of a plant megafossil assemblage from the Whitmore Point Member of the Moenave Formation in southeastern Utah, strata of latest Triassic age (Lucas et al., 2011). This is a conifer-dominated megafloora that also includes ferns and horsetails. Particularly significant are records of the genera *Araucarites*, *Pagiophyllum* and *Podozamites*, taxa found in the *Dinophyton* assemblage zone of the Chinle Group, but not in the *Sanmiguelia* assemblage zone (Fig. 4). The plant locality in the Moenave Formation is in lake-margin facies (Kirkland and Milner, 2006; Tanner and Lucas, 2007) that more resemble lower Chinle Group lithofacies than upper Chinle Group lithofacies. This suggests to me that the absence of these taxa in the upper Chinle Group and their reappearance in the younger Moenave Formation is facies driven. A more extensive Moenave Formation lake-margin paleoflora would likely share even more taxa with the *Dinophyton* assemblage zone. Indeed, Lower Jurassic plant assemblages from the Newark Supergroup, which are in lake or lake-margin facies, include many genera characteristic of the lower Chinle *Dinophyton* assemblage zone, including *Baiera*, *Brachyphyllum*, *Clathropteris*, *Equisetites*, *Pagiophyllum* and *Podozamites* (e.g., Cornet et al., 1973; Ash, 1980; Cornet and Olsen, 1985).

This suggests that the *Sanmiguelia* assemblage zone is a taphoflora that appears in the Chinle Group because of facies changes, not necessarily because of evolutionary turnover of the paleoflora. The “background” paleoflora of lake-margin paleoenvironments is that of the *Dinophyton* assemblage zone, which “reappears” in the overlying Moenave Formation when lake-margin facies reappear. Note that lake-margin facies persist throughout the Newark Supergroup, and there is no *Sanmiguelia* assemblage zone paleoflora evident there.

If this is correct, then using the Chinle assemblage zones to map plant evolution is problematic. The paleoflora of the late Carnian-

Hettangian wet facies in North America is well represented by the *Dinophyton* assemblage zone, whereas the drier paleoflora of the *Sanmiguelia* assemblage zone is primarily evident in the upper Chinle red beds. The actual temporal range of the *Sanmiguelia* paleoflora remains uncertain, given the evident facies control of its distribution.

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REFERENCES

- Alencaster, G. de Cserna, 1961, Fauna fósil de la Formación Santa Clara (Cárnico) del Estado de Sonora: Universidad Nacional Autónoma de México, Instituto de Geología, Paleontología Mexicana 11, 398 p.
- Arnold, C.A., 1964, *Cordaites*-type foliage associated with palm-like plants from the Upper Triassic of southwestern Colorado: Indian Botanical Society Journal, v. 42A, p. 4-9.
- Ash, S.R., 1967, The Chinle (Upper Triassic) megaflora, Zuni Mountains, New Mexico: New Mexico Geological Society, Guidebook 18, p. 125-31.
- Ash, S.R., 1970a, Ferns from the Chinle Formation (Upper Triassic) in the Fort Wingate area, New Mexico: U.S. Geological Survey, Professional Paper 613D, 40 p.
- Ash, S.R., 1970b, *Pagiophyllum simpsonii*, a new conifer from the Chinle Formation (Upper Triassic) of Arizona: Journal of Paleontology, v. 44, p. 945-952.
- Ash, S.R., 1970c, *Dinophyton*, a problematical new plant from the Upper Triassic of the southwestern United States: Palaeontology, v. 13, p. 646-664.
- Ash, S.R., 1972a, The search for plant fossils in the Chinle Formation; in Breed, W.J. and Breed, C.S., eds., Investigations in the Triassic Chinle Formation: Museum of Northern Arizona, Bulletin 47, p. 45-58.
- Ash, S.R., 1972b, Upper Triassic Dockum flora of eastern New Mexico and Texas: New Mexico Geological Society, Guidebook 23, p. 124-128.
- Ash, S.R., 1972c, Late Triassic plants from the Chinle Formation in north-eastern Arizona: Palaeontology, v. 15, p. 598-618.
- Ash, S.R., 1973, Two new Late Triassic plants from the Petrified Forest of Arizona: Journal of Paleontology, v. 47, p. 46-53.
- Ash, S.R., 1974, Upper Triassic plants of Cañon del Cobre, New Mexico: New Mexico Geological Society, Guidebook 25, p. 179-184.
- Ash, S.R., 1975a, *Zamites powelli* and its distribution in the Upper Triassic of North America: Palaeontographica B, v. 139, p. 139-152.
- Ash, S.R., 1975b, The Chinle (Upper Triassic) flora of southeastern Utah: Four Corners Geological Society, Guidebook 8, p. 143-147.
- Ash, S.R., 1976, Occurrence of the controversial plant fossil *Sanmiguelia* in the Upper Triassic of Texas: Journal of Paleontology, v. 50, p. 799-804.
- Ash, S.R., 1977, An unusual bennettitalean leaf from the Upper Triassic of the southwestern United States: Palaeontology, v. 20, p. 641-659.
- Ash, S.R., 1978a, Summary of the fossils in the Ciniza Lake Beds: Brigham Young University Geological Studies, v. 25, part 2, p. 21-22.
- Ash, S.R., 1978b, Plant megafossils: Brigham Young University Geological Studies, v. 25, part 2, p. 23-42.
- Ash, S.R., 1980, Upper Triassic floral zones of North America; in Dilcher, D.L. and Taylor, T.M., eds., Biostratigraphy of fossil plants: Stroudsburg, Pa., Dowden, Hutchinson and Ross, Inc., p. 153-270.
- Ash, S.R., 1985, A short thick cycad stem from the Upper Triassic of Petrified Forest National Park, Arizona and vicinity: Museum of Northern Arizona, Bulletin 54, p. 17-32.
- Ash, S.R., 1987, The Upper Triassic red bed flora of the Colorado Plateau, western United States: Journal of the Arizona-Nevada Academy of Science, v. 22, p. 95-105.
- Ash, S.R., 1988, Chapter C - Fossil plants from the mudstone member of the Santa Rosa Formation at the principal reference section: U.S. Geological Survey, Bulletin 1804, p. 19-25.
- Ash, S.R., 1989a, A catalogue of Upper Triassic plant megafossils of the western United States through 1988; in Lucas, S.G. and Hunt, A.P., eds., Dawn of the age of dinosaurs in the American Southwest: Albuquerque, New Mexico Museum of Natural History, p. 189-222.
- Ash, S.R., 1989b, The Upper Triassic Chinle flora of the Zuni Mountains, New Mexico: New Mexico Geological Society, Guidebook 40, p. 225-230.
- Ash, S.R., 1997, Evidence of arthropod-plant interactions in the Upper Triassic of the southwestern United States: Lethaia, v. 29, p. 237-248.
- Ash, S.R., 1999, An Upper Triassic upland flora from north-central New Mexico, U. S. A.: Review of Palaeobotany and Palynology, v. 105, p. 183-199.
- Ash, S.R., 2001, New cycadophytes from the Upper Triassic Chinle Formation of the southwestern United States: PaleoBios, v. 21, p. 15-28.
- Ash, S.R., 2005, A new Upper Triassic flora and associated invertebrate fossils from the basal beds of the Chinle Formation, near Cameron, Arizona: PaleoBios, v. 25, p. 17-34.
- Ash, S.R., 2006, *Chilbinia* gen. nov., an archaic seed fern in the Late Triassic Chinle Formation of Arizona, USA: Palaeontology, v. 49, p. 237-245.
- Ash, S.R. and Litwin, R.J., 1996, Two new species of the pinnate microsporophyll *Pramelreuthia* from the Upper Triassic of the southwestern United States: American Journal of Botany, v. 83, p. 1091-1099.
- Axsmith, B.J. and Ash, S.R., 2006, Two rare fossil cones from the Upper Triassic Chinle Formation in Petrified Forest National Park, Arizona, and New Mexico: Museum of Northern Arizona, Bulletin 62, p. 82-94.
- Axsmith, B.J. and Kroehler, P.A., 1989, Upper Triassic *Dinophyton* zone plant fossils from the Stockton Formation in southeastern Pennsylvania: The Mosasaur, v. 4, p. 45-47.
- Axsmith, B.J., Taylor, T.N., Delevoryas, T. and Hope, R.C., 1995, A new species of *Eoginkgoites* from the Upper Triassic of North Carolina, USA: Review of Palaeobotany and Palynology, v. 85, p. 189-198.
- Berry, E.F., 1924, Fossil plants and unios in the red beds of Wyoming: Journal of Geology, v. 32, p. 488-497.
- Berry, E.F., 1927, Cycads in the Shinarump Conglomerate of southern Utah: Journal of the Washington Academy of Science, v. 27, p. 3030-307.
- Bock, W., 1969, The American Triassic flora and global distribution: Geological Center Research Series, v. 3-4, 406 p.
- Brown, R.W., 1956, Palmlike plants from the Dolores Formation (Triassic) southwestern Colorado: U. S. Geological Survey, Professional Paper 274-H, p. 205-209.
- Cornet, B., 1977, The palynostratigraphy and age of the Newark Supergroup [Ph.D. dissertation]: State College, Pa., Pennsylvania State University, 505 p.
- Cornet, B., 1986, The leaf venation and reproductive structures of a Late Triassic angiosperm, *Sanmiguelia lewisii*: Evolutionary Theory, v. 7, p. 231-309.
- Cornet, B., 1993, Applications and limitations of palynology in age, climatic and paleoenvironmental analyses of Triassic sequences in North America: New Mexico Museum of Natural History and Science, Bulletin 3, p. 73-93.
- Cornet, B. and Olsen, P.E., 1985, A summary of the biostratigraphy of the Newark Supergroup of eastern North America with comments on provinciality; in Weber, R. III, ed., Congreso Latinoamericano de Paleontología Mexicana, simposio sobre floras del Triasico Tardio, su fitogeografía y paleoecología: UNAM, Instituto de Geología, Mexico City, p. 67-81.
- Cornet, B. and Olsen, P.E., 1990, Early to middle Carnian (Triassic) flora and fauna of the Richmond and Taylorsville basins, Virginia and Mary-

- land, U. S. A.: Virginia Museum of Natural History, Guidebook 1, 83 p.
- Cornet, B. and Traverse, A., 1975, Palynological contributions to the chronology and stratigraphy of the Hartford basin in Connecticut and Massachusetts: *Geoscience and Man*, v. 11, p. 1-33.
- Cornet, N., Traverse, A. and McDonald, N.G., 1973, Fossil spores, pollen, fishes from Connecticut indicate Early Jurassic age for part of the Newark Group: *Science*, v. 182, p. 1243-1247.
- Daugherty, L.H., 1941, The Upper Triassic flora of Arizona: Carnegie Institution of Washington, Publication 526, 108 p.
- Daugherty, L.H., 1963, Triassic roots from the Petrified Forest National Park: *American Journal of Botany*, v. 50, p. 802-805.
- Demko, T.M., Dubiel, R.F. and Parrish, J.T., 1998, Plant taphonomy in incised valleys: Implications for interpreting paleoclimate from fossil plants: *Geology*, v. 26, p. 1119-1122.
- Dickinson, W.R. and Gehrels, G.E., 2008, U-Pb ages of detrital zircons in relation to paleogeography: Triassic paleodrainage networks and sediment dispersal across southwest Laurentia: *Journal of Sedimentary Research*, v. 78, p. 745-764.
- Dubiel, R.F., 1987, Sedimentology of the Upper Triassic Chinle Formation, southeastern Utah: Paleoclimatic implications: *Journal of the Arizona-Nevada Academy of Science*, v. 22, p. 35-45.
- Dunay, R.E. and Fisher, M.J., 1974, The Triassic palynofloras of North America and their European correlatives: Review of Paleobotany and Palynology, v. 17, p. 179-186.
- Dunay, R.E. and Fisher, M.J., 1979, Palynology of the Dockum Group (Upper Triassic), Texas: Review of Paleobotany and Palynology, v. 28, p. 61-92.
- Dunay, R.E. and Traverse, A., 1971, Preliminary report on Triassic spores and pollen of the Dockum Group, Texas Panhandle: *Geoscience and Man*, v.3, p. 65-68.
- Ediger, V.S., 1986, Paleopalynological biostratigraphy, organic matter deposition, and basin analysis of the Triassic-Jurassic(?) Richmond rift basin, VA [Ph.D. dissertation]: State College, Pa., Pennsylvania State University, 547 p.
- Fisher, M.J. and Dunay, R.E., 1984, Palynology of the Petrified Forest Member of the Chinle Formation (Upper Triassic), Arizona, U.S.A.: *Pollen et Spores*, v. 16, p. 241-284.
- Fontaine, W.M. and Knowlton, F.H., 1890, Notes on Triassic plants from New Mexico: U.S. National Museum Proceedings, v. 13, p. 281-285.
- Gensel, P., 1986, Plant fossils of the Upper Triassic Deep River basin; *in* Gore, P.J.W., ed., Depositional framework of a Triassic rift basin: The Durham and Sanford sub-basins of the Deep River basin, North Carolina: Society of Economic Paleontologist and Mineralogists, Field Trip 3, p. 82-86.
- Harris, T.M., 1937, The fossil flora of Scoresby Sound, east Greenland. Part 5. Stratigraphic relations of the plant beds: *Meddelelser om Grønland*, v. 112, 114 p.
- Heckert, A.B. and Lucas, S.G., 2002, Lower Chinle Group (Upper Triassic: Carnian) stratigraphy in the Zuni Mountains, west-central New Mexico: *New Mexico Museum of Natural History and Science, Bulletin* 21, p. 51-72.
- Holt, E.L., 1947, Upright trunks of *Neocalamites* from the Upper Triassic of western Colorado: *Journal of Geology*, v. 55, p. 511-513.
- Huber, P., Lucas, S.G. and Hunt, A.P., 1993, Revised age and correlation of the Upper Triassic Chatham Group (Deep River basin, Newark Supergroup), North Carolina: *Southeastern Geology*, v. 33, p. 171-193.
- Kirkland, J.I. and Milner, A.R.C., 2006, The Moenave Formation at the St. George Dinosaur Discovery Site at Johnson Farm, St. George, southwestern Utah: *New Mexico Museum of Natural History and Science, Bulletin* 37, p. 289-309.
- Knowlton, F.H., 1890, A revision of the genus *Araucarioxylon* of Kraus, with the compiled descriptions and partial synonymy of the species: U.S. National Museum Proceedings, v. 12, p. 601-617.
- Kozur, H.W. and Weems, R.E., 2010, The biostratigraphic importance of conchostracans in the continental Triassic of the northern hemisphere; *in* Lucas, S.G., ed., The Triassic timescale: Geological Society, London, Special Publication 334, p. 315-417.
- Lawton, T.H., 1994, Tectonic setting of Mesozoic sedimentary basins, Rocky Mountain region, United States; *in* Caputo, M.V., Peterson, J.A. and Franczyk, K.J., eds., Mesozoic systems of the Rocky Mountain region, USA: Denver, RMS-SEPM, p. 1-25.
- LeTourneau, P.M., 2003, Tectonic and climatic controls on the stratigraphic architecture of the Late Triassic Taylorsville basin, Virginia and Maryland; *in* LeTourneau, P.M. and Olsen, P.E., eds., The great rift valleys of Pangea in eastern North America. Volume 2. Sedimentology, stratigraphy, and paleontology: New York, Columbia University Press, p. 12-58.
- Litwin, R.H., 1986, The palynostratigraphy and age of the Chinle and Moenave formations, southwestern U.S.A. [Ph. D. thesis]: State College, Pa., Pennsylvania State University, 256 p.
- Litwin, R.J. and Ash, S.R., 1993, Revision of the biostratigraphy of the Chatham Group (Upper Triassic), Deep River basin, North Carolina, USA: Review of Palaeobotany and Palynology, v. 77, p. 75-95.
- Litwin, R.J., Traverse, A. and Ash, S.R., 1991, Preliminary palynological zonation of the Chinle Formation, southwestern U.S.A., and its correlation to the Newark Supergroup (eastern U.S.A.): Review of Palaeobotany and Palynology, v. 68, p. 269-287.
- Lucas, S.G., 1993, The Chinle Group: Revised stratigraphy and biochronology of Upper Triassic nonmarine strata in the western United States: Museum of Northern Arizona, *Bulletin* 59, p. 27-50.
- Lucas, S.G., 1996, Correlation and tectonic significance of Lower Jurassic conglomerates in Sonora, Mexico: Museum of Northern Arizona, *Bulletin* 60, p. 497-501.
- Lucas, S.G., 1997, Upper Triassic Chinle Group, western United States: A nonmarine standard for Late Triassic time; *in* Dickins, J.M., Yang, Z., Yin, H., Lucas, S.G. and Acharyya, S.K., eds., Late Palaeozoic and early Mesozoic circum-Pacific events and their global correlation: Cambridge, Cambridge University Press, p. 209-228.
- Lucas, S.G., 1998, Global Triassic tetrapod biostratigraphy and biochronology: Palaeogeography, Palaeoclimatology, Palaeoecology, v. 143, p. 347-384.
- Lucas, S.G., 2006, *Sanmiguelia* from the Upper Triassic Chinle Group, east-central New Mexico, and its biostratigraphic significance: *New Mexico Museum of Natural History and Science, Bulletin* 37, p. 407-409.
- Lucas, S.G., 2010, The Triassic timescale based on nonmarine tetrapod biostratigraphy and biochronology; *in* Lucas, S.G., ed., The Triassic timescale: Geological Society, London, Special Publication 334, p. 447-500.
- Lucas, S.G. and Hayden, S.N., 1989, Triassic stratigraphy of west-central New Mexico: *New Mexico Geological Society, Guidebook* 40, p. 191-211.
- Lucas, S.G. and Huber, P., 1994, Sequence stratigraphic correlation of Upper Triassic marine and nonmarine strata, western United States and Europe; *in* Embry, A.F., Beauchamp, B. and Glass, D.J., eds., Pangea: Global environments and resources: Canadian Association of Petroleum Geologists, *Memoir* 17, p. 241-254.
- Lucas, S.G. and Huber, P., 2003, Vertebrate biostratigraphy and biochronology of the nonmarine Late Triassic; *in* Letourneau, P.M. and Olsen, P.E., eds., The great rift valleys of Pangea in eastern North America. Volume 2. Sedimentology, stratigraphy, and paleontology: New York, Columbia University Press, p. 143-191.
- Lucas, S.G. and Hunt, A.P., 1993, Tetrapod biochronology of the Chinle Group (Upper Triassic), western United States: *New Mexico Museum of Natural History and Science, Bulletin* 3, p. 327-329.
- Lucas, S.G. and Spielmann, J.A., 2010, Exceptionally preserved paleoflora from the Upper Triassic Chinle Group, Santa Fe County, New Mexico: *New Mexico Geology*, v. 32, p. 66.
- Lucas, S.G. and Tanner, L.H., 2007, The nonmarine Triassic-Jurassic boundary in the Newark Supergroup of eastern North America: *Earth Science Reviews*, v. 84, p. 1-20.
- Lucas, S.G., Heckert, A.B. and Hunt, A.P., 2001, Triassic stratigraphy, biostratigraphy and correlation in east-central New Mexico: *New Mexico Geological Society, Guidebook* 52, p. 85-102.
- Lucas, S.G., Hunt, A.P. and Hayden, S.N., 1987, The Triassic System in the Dry Cimarron Valley, New Mexico, Colorado and Oklahoma: *New Mexico*

- Geological Society, Guidebook 38, p. 97-117.
- Lucas, S.G., Hunt, A.P. and Kietzke, K.K., 1985, *Neocalamites* forest in the Upper Triassic of Bull Canyon, New Mexico: New Mexico Geological Society, Guidebook 36, p. 8-9.
- Lucas, S.G., Hunt, A.P., Heckert, A.B., and Spielmann, J.A., 2007, Global Triassic tetrapod biostratigraphy and biochronology: 2007 status: New Mexico Museum of Natural History and Science, Bulletin 41, p. 229-240.
- Lucas, S.G., Tanner, L.H., Kozur, H.W., Weems, R.E. and Heckert, A.B., 2012, The Late Triassic timescale: Age and correlation of the Carnian-Norian boundary: *Earth-Science Reviews*, v. 114, p. 1-18.
- Lucas, S.G., Tanner, L.H., Donohoo-Hurley, L.L., Geissman, J.W., Kozur, H.W., Heckert, A.B. and Weems, R.E., 2011, Position of the Triassic-Jurassic boundary and timing of the end-Triassic extinctions on land: Data from the Moenave Formation on the southern Colorado Plateau, USA: *Palaeogeography, Palaeoecology, Palaeoclimatology*, v. 302, p. 194-205.
- Miller, C.N., Jr., 1968, The lepidophytic affinities of the genus *Chinlea* and *Osmundites walkeri*: *American Journal of Botany*, v. 35, p. 109-115.
- Milner, A.C., 2006, Plant fossils from the Owl Rock or Church Rock members, Chinle Formation, San Juan County, Utah: New Mexico Museum of Natural History and Science, Bulletin 37, p. 410-413.
- Murphy, M.A., 1977, On time-stratigraphic units: *Journal of Paleontology*, v. 51, p. 213-219.
- Newberry, J.S., 1876, Geological report; in Report of exploring expedition from Santa Fe, New Mexico, to the junction of the Grand and Green Rivers of the great Colorado of the west, in 1859, under Capt. J. N. Macomb: U.S. Army, Engineers Report, p. 9-118.
- Olsen, P.E., Schlische, R.W. and Gore, P.J.W., eds., 1989, Tectonic, depositional and paleoecological history of early Mesozoic rift basins, eastern North America: 28th International Geological Congress, Field Trip Guidebook T351: Washington, D. C., American Geophysical Union, 174 p.
- Olsen, P.E., Whiteside, J.H. and Huber, P., 2003, Causes and consequences of the Triassic-Jurassic mass extinction as seen from the Hartford basin; in Brady, J.B. and Cheney, J.T., eds., Guidebook for field trips in the Five College Region, 95th New England Intercollegiate Geological Conference: Northampton, Massachusetts, Department of Geology, Smith College, p.B5-1-B5-41.
- Olsen, P.E., Whiteside, J.H., LeTourneau, P.M. and Huber, P., 2005, Jurassic cyclostratigraphy and paleontology of the Hartford basin; in Skinner, B.J. and Philpotts, A.R., eds., 97th New England Intercollegiate Geological Conference: Department of Geology and Geophysics, Yale University, New Haven, Connecticut, p. A4-1-A4-51.
- Pipiringos, G.N. and O'Sullivan, R.B., 1978, Principal unconformities in Triassic and Jurassic rocks, Western Interior United States—A preliminary survey: U. S. Geological Survey, Professional Paper 1035A, p. 1-29.
- Savidge, R.A. and Ash, S.R., 2006, *Arboramosa semicircumtrachea*, an unusual Late Triassic tree, Petrified Forest National Park, Arizona, USA: Museum of Northern Arizona, Bulletin 62, p. 65-81.
- Simpson, J.H., 1850, Journal of a military reconnaissance from Santa Fe, New Mexico to the Navaho Country made in 1849: U.S. 31st Congress, 1st session, Senate Executive Document 64, p. 56-131, 148-149.
- Smith, J.F., Huff, L.C. Hinrichs, E.N. and Luedke, R.G., 1963, Geology of the Capitol Reef Area, Wayne and Garfield counties, Utah: U.S. Geological Survey, Professional Paper 363, 102 p.
- Spielmann, J.A. and Lucas, S.G., 2012, Tetrapod fauna of the Upper Triassic Redonda Formation, east-central New Mexico: The characteristic assemblage of the Apachean land-vertebrate faunachron: New Mexico Museum of Natural History and Science, Bulletin 55, 119 p.
- Stewart, J.H. and Roldán-Quintana, J., 1991, Upper Triassic Barranca Group: Nonmarine and shallow-marine rift basin deposits of northeastern Mexico: Geological Society of America, Special Paper 254, p. 19-36.
- Stewart, J.H., Poole, F.G. and Wilson, R.F., 1972, Stratigraphy and origin of the Chinle Formation and related Upper Triassic strata in the Colorado Plateau region: U.S. Geological Survey, Professional Paper 690, 336 p.
- Tanner, L.H. and Lucas, S.G., 2006, Calcareous paleosols of the Upper Triassic Chinle Group, Four Corners region, southwestern United States: Climatic implications; in Alonso-Zarra, A.M. and Tanner, L.H., eds., Paleoenvironmental record and applications of calcretes and palustrine carbonates: Geological Society of America, Special Paper 416, p. 53-74.
- Tanner, L.H. and Lucas, S.G., 2007, The Moenave Formation: Sedimentologic and stratigraphic context of the Triassic-Jurassic boundary in the Four Corners area, southwestern U.S.A.: *Palaeogeography, Palaeoclimatology, Palaeoecology*, v. 244, p. 111-125.
- Tanner, L.H. and Lucas, S.G., 2012, Carbonate facies of the Upper Triassic Ojo Huelos Member, San Pedro Arroyo Formation (Chinle Group), southern New Mexico: Paleoclimatic implications: *Sedimentary Geology*, v. 273-274, p. 73-90.
- Tidwell, W.D., 1998, Common fossil plants of western North America (second edition): Washington, D. C., Smithsonian Institution Press, 299 p.
- Tidwell, W.D. and Ash, S.R., 2006, Preliminary report on the Early Jurassic flora from the St. George Dinosaur Discovery Site, Utah: New Mexico Museum of Natural History and Science, Bulletin 37, p. 414-420.
- Tidwell, W.D., Simper, A.D. and Thayn, G.F., 1977, Additional information concerning the controversial Triassic plant *Sanmiguelia*: *Palaeontographica B*, v. 163, p. 143-151.
- Watson, J. and Ash, S.R., 2006, A rare bipinnate microsporophyll attributable to the Cycadales from the Late Triassic Chinle Formation, Petrified Forest National Park, Arizona: Museum of Northern Arizona, Bulletin 62, p. 95-105.
- Weber, R., 1997, How old is the late Triassic flora of Sonora and Tamaulipas and news on Leonardian floras in Puebla and Hidalgo, Mexico: *Revista Mexicana de Ciencias Geológicas*, v. 14, p. 225-243.

APPENDIX 1

Locality number	Locality name	Stratigraphic unit	Stratigraphic interval(s) and assemblage zone	Selected reference(s)
Wyoming:				
1.	Lander (Wind River Mountains)	Popo Agie Formation	A, <i>Dinophyton</i>	Berry (1924), Ash (1980)
Utah:				
2.	Capitol Reef National Park	Shinarump Formation	A, <i>Dinophyton</i>	Smith et al. (1963), Ash (1975b, 1978b), Dubiel (1987)
3.	Capitol Reef National Park	Owl Rock Formation	C, <i>Sanmiguelia</i>	Ash (1975b; 1987); Dubiel (1987)
4.	San Rafael Swell	Temple Mountain and Monitor Butte Formations	A and B, <i>Dinophyton</i>	Stewart et al (1972); Ash (1975b)
5.	Circle Cliffs	Shinarump and Monitor Butte formations	A-B, <i>Dinophyton</i>	Berry (1927); Ash (1975b, 1977, 1997)
6.	White Canyon	Shinarump Formation	A, <i>Dinophyton</i>	Stewart et al. (1972); Ash (1975b)
7.	Elk Ridge	Shinarump	A, <i>Dinophyton</i>	Stewart et al. (1972); Ash (1975b)
8.	Monitor Butte	Monitor Butte Formation	B, <i>Dinophyton</i>	Stewart et al. (1972); Ash (1975b)
9.	Big Indian Wash	Rock Point Formation	D, <i>Sanmiguelia</i>	Ash (1987)
10.	Lisbon Valley	Rock Point Formation	D, <i>Sanmiguelia</i>	Milner (2006)
Colorado:				
11.	San Miguel River (Placerville area)	Rock Point Formation	D, <i>Sanmiguelia</i>	Brown (1956), Arnold (1964), Tidwell et al. (1977), Ash (1987)
12.	Bedrock	Rock Point Formation?	D?, <i>Sanmiguelia</i>	Holt (1947)
Arizona:				
13.	Cameron	Shinarump Formation	A, <i>Dinophyton</i>	Ash (1970c, 2005, 2006)
14.	Canyon DeChelly	Monitor Butte Formation	B, <i>Dinophyton</i>	Ash (1972b, c, 1997)
15.	Red Rock Trading Post	Rock Point Formation	D, <i>Sanmiguelia</i>	Ash (1987)
16.	Nazlini	Monitor Butte Formation?	B, <i>Dinophyton</i>	Daugherty (1941); Stewart et al. (1972); Ash (1975a)
17.	Joseph City	Blue Mesa Member?	B, <i>Dinophyton</i>	Ash (1985)
18.	PEFO	Blue Mesa Member, Sonsela Member	B-C', <i>Dinophyton</i>	Knowlton (1890), Daugherty (1941, 1963); Miller (1968); Ash (1973, 1975a, b, 1976, 1997); Axsmith and Ash (2006); Savidge and Ash (2006); Watson and Ash (2006)
19.	PEFO	Painted Desert Member	C, <i>Sanmiguelia</i>	Ash (1970b)
20.	St Johns	Shinarump/ Bluewater Creek Formation, Blue Mesa Member?	A-B, <i>Dinophyton</i>	Daugherty (1941); Stewart et al. (1972); Ash (1975a, 1977, 1989a)
New Mexico:				
21.	El Cobre Canyon	Shinarump	A, <i>Dinophyton</i>	Newberry (1876); Fontaine and Knowlton (1890); Ash (1974)
22.	Lake Ciniza	Bluewater Creek Formation	B, <i>Dinophyton</i>	Ash (1967, 1978a, b, 1989b)
23.	Fort Wingate	Bluewater Creek Formation	B, <i>Dinophyton</i>	Ash (1967, 1970a, 1989b)
24.	Cottonwood Creek	Blue Mesa Member?	B, <i>Dinophyton</i>	Ash (1989b)
25.	South of Lamy (A)	Garita Creek Formation	B, <i>Dinophyton</i>	Ash (1999)
26.	South of Lamy (B)	Trujillo Formation	C' <i>Sanmiguelia</i>	Lucas and Spielmann (2010)

27.	Las Vegas	Garita Creek Formation	B, <i>Dinophyton</i>	Lucas (2006)
28.	Dry Cimarron Valley	Sloan Canyon Formation	D, <i>Sanmiguelia</i>	Lucas et al. (1987)
29.	Bull Canyon	Bull Canyon Formation	C, <i>Sanmiguelia</i>	Lucas et al. (1985); Lucas (2006)
30.	Santa Rosa	Los Esteros Member of Santa Rosa Formation	B, <i>Dinophyton</i>	Ash (1972c, 1988)
31.	Quay County	Bull Canyon Formation	C, <i>Sanmiguelia</i>	Lucas (2006)
Texas:				
32.	Canadian River Valley	Tecovas	B, <i>Dinophyton</i>	Ash (1972c, 1975a)
33.	Palo Duro Canyon A	Tecovas	B, <i>Dinophyton</i>	Ash (1975a)
34.	Palo Duro Canyon B	Trujillo	C', <i>Sanmiguelia</i>	Ash (1976); Cornet (1986)
35.	Kalgary	Tecovas	B, <i>Dinophyton</i>	Ash (1972c, 1975a)