

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).

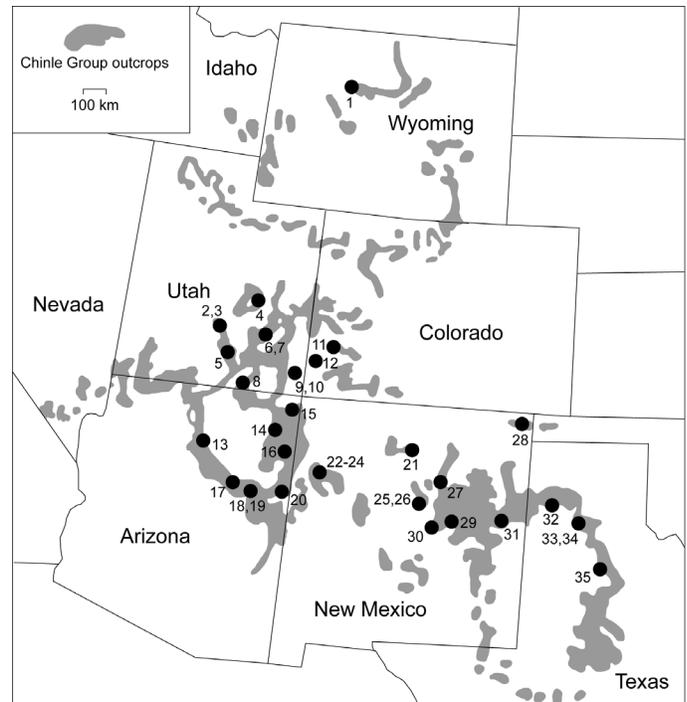


FIGURE 1. Generalized distribution of outcrops of the Chinle Group (after Lucas, 1993) showing principal plant megafossil localities (numbers of localities are those in Appendix 1).

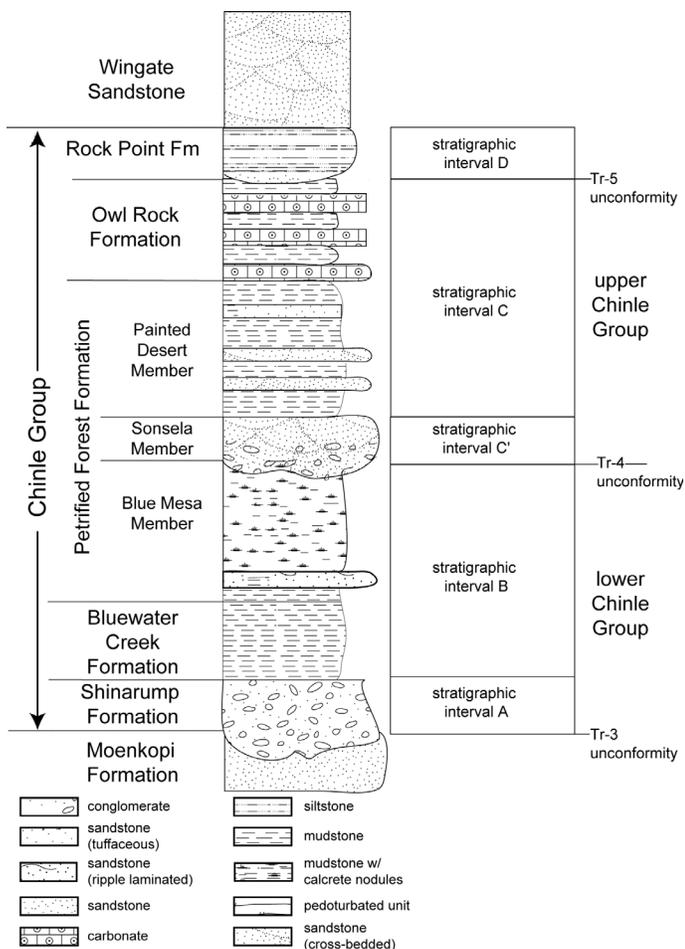


FIGURE 3. Generalized Chinle Group lithostratigraphy in northeastern Arizona showing informal stratigraphic intervals referred to in the text.

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

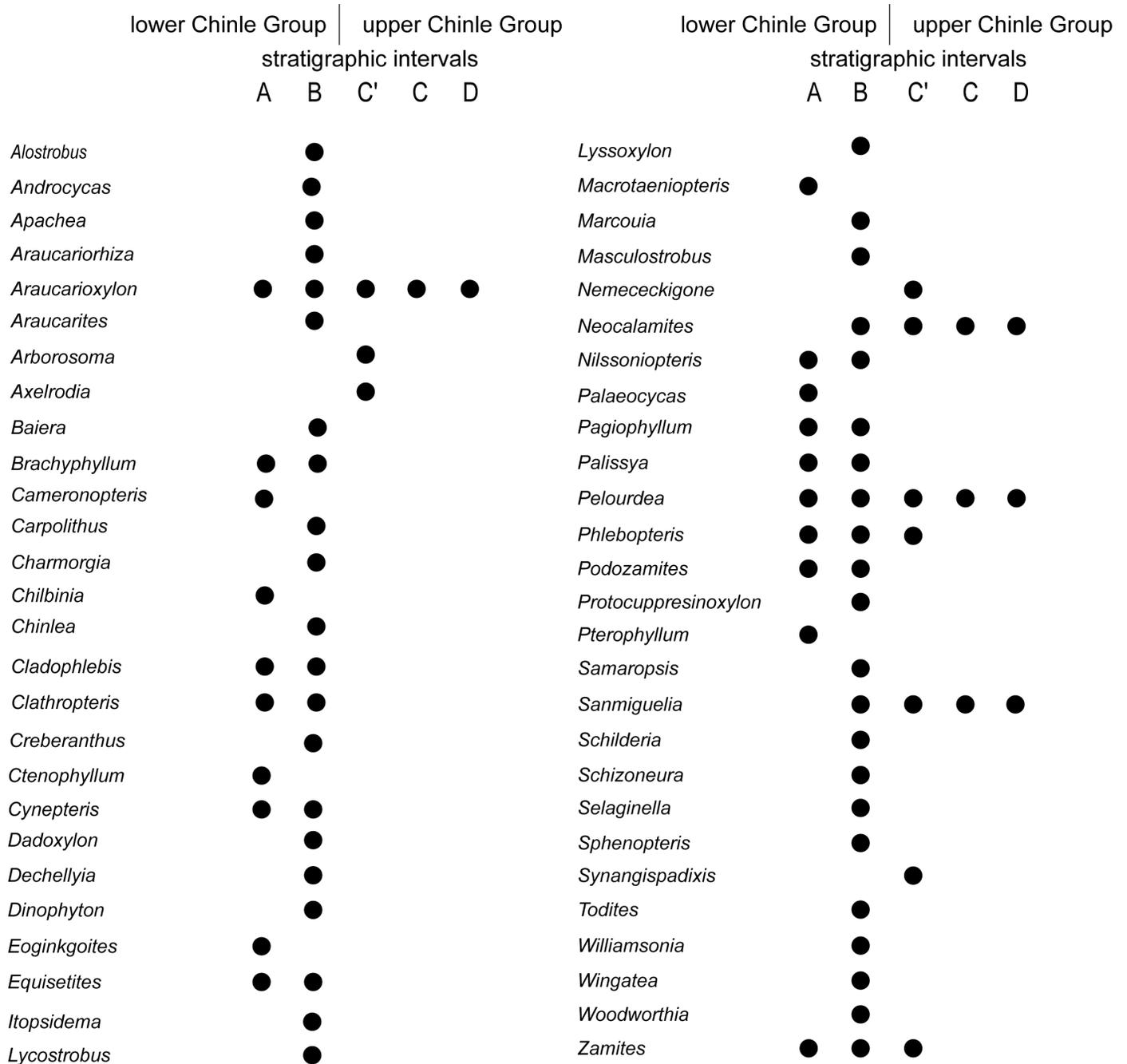


FIGURE 4. Stratigraphic ranges of plant megafossil genera in the Chinle Group based on Ash (1989) and sources cited therein, updated in the light of more recently published literature. Informal stratigraphic units of the Chinle Group are those in Figure 3.

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,

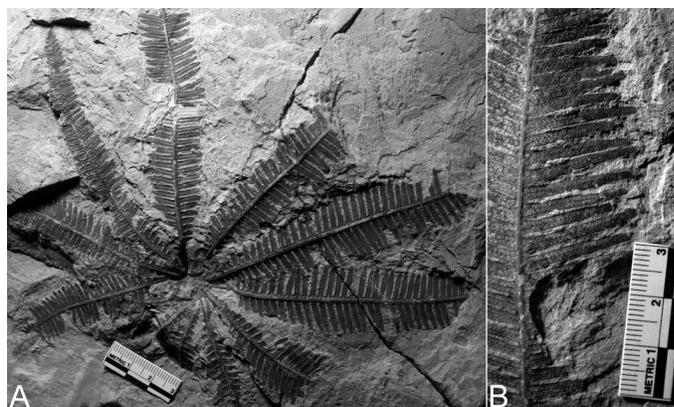


FIGURE 6. Specimens of *Phlebopteris smithi* (Daugherty, 1941) from central New Mexico that represents an upward extension of the stratigraphic range of the genus. These specimens are catalogued as NMMNH (New Mexico Museum of Natural History and Science) P-59951 and are from the Trujillo Formation at 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> | 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 *Brodisporea 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 *Brodisporea 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 *Kyrtomisporis* spp., zone III was assigned an early Norian age because of the absence of significant Carnian taxa (e.g. *Brodisporea 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 |
| | late Carnian | | II | lower | | Lockatong Formation | New Oxford Formation | Cumnock Formation | Cow Branch Formation |
| | | Cinizan florachron | I | | | Stockton Formation | | Pekin Formation | Pine Hall Formation |
| | | | | | | | | | |

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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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) |

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|---------------|-----------------------|--|------------------------|-----------------------------------|
| 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) |