

## 23 Upper Triassic Chinle Group, western United States: a nonmarine standard for late Triassic time

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Nonmarine Triassic strata have wide distributions on all the world's continents. Their precise correlation is an obvious step towards better elucidating the Triassic history of physical and biological events on land. At present, Triassic chronology has been developed almost exclusively on the basis of marine rocks and fossils. To that end, standard sections of strata and stratotype sections have been identified for the Triassic portion of the Standard Global Chronostratigraphic Scale (SGCS) (Tozer, 1984). Although much work remains to be done on the Triassic portion of the SGCS, a workable Triassic biochronology, based principally on ammonoids and conodonts, is already in place, rooted in standard and stratotype sections of marine strata.

In regard to the nonmarine stratigraphic terranes of the Triassic, quite a different situation exists. No such standard or stratotype rock sections have been identified for nonmarine Triassic strata, and their correlations are made either by direct (though usually imprecise) reference to the marine SGCS or by nonmarine biochronologic constructs such as the *Lystrosaurus* "Zone." Recently, however, Lucas (1992) and Lozovsky (1993) have suggested that standard sections of nonmarine Triassic strata be identified for use in correlation. These would not be intended to be the stratotypes of stages, but rather reference sections to aid in the correlation of nonmarine Triassic strata. Here, I follow their lead, arguing that the Upper Triassic nonmarine Chinle Group of the western United States (Figure 23.1) provides an excellent standard section for Upper Triassic nonmarine chronology. To develop this argument, I shall first briefly review the Upper Triassic portion of the SGCS to make clear my use of terms such as Carnian, Norian, and Rhaetian. I shall also discuss briefly the geochronometric and magnetostratigraphic calibration of the Upper Triassic SGCS. I shall then review the Chinle Group lithostratigraphy and biostratigraphy/biochronology, with special emphasis on the biochronologic utility of Chinle Group fossils. Finally, I shall argue that the Chinle Group, despite some failings, meets the criteria by which any standard section of rocks to be used as a basis for correlation should be judged.

### Late Triassic SGCS

Tozer (1984) has reviewed the historical development of the Upper Triassic SGCS in some detail. With the exception of the Rhaetian Stage, my use of late Triassic stage and substage definitions and terminology follows his recommendations (Figure 23.2).

A long and sometimes acrimonious debate about the validity of the Rhaetian Stage was recently ended by a nearly unanimous vote of the IUGS Subcommittee on Triassic Stratigraphy to recognize the Rhaetian as the youngest Triassic stage (Visscher, 1992). Nevertheless, there is as yet no agreement on a definition for the base of the Rhaetian. Here, my definition of the Rhaetian is an operational one. It refers to the time represented by the post-Knollenmergel Triassic strata of the German Keuper, essentially the Contorta and Triletes beds of northern Mecklenburg and their correlatives (Kozur, 1993, table 4b). Only this definition has any biostratigraphic/biochronologic utility when discussing nonmarine correlations, especially those based on tetrapods.

### Late Triassic geochronometry and magnetostratigraphy

One of the largest problems of the Triassic time scale is the general dearth of reliable radiometric age determinations that can be unambiguously related to precise biochronology. The result of this has been wide variance in the numerical ages that have been assigned to Triassic, especially late Triassic, stage boundaries (Figure 23.3). Forster and Warrington (1985) provided the most exacting review of the available radiometric age constraints for the Triassic time scale. They identified only seven reliable numerical age determinations relevant to the boundaries of the late Triassic stages, and fewer than 10 ages relevant to numerical calibration of the Triassic–Jurassic boundary. Their boundary determinations for the Ladinian–Carnian ( $230 \pm 5$  Ma), Carnian–Norian ( $220 \pm 5$  Ma), Norian–Rhaetian ( $210 \pm 5$  Ma), and Rhaetian–Jurassic ( $205 \pm 5$  Ma) are close to the boundary determinations of Harland et al. (1990) used here.

Late Triassic magnetostratigraphy has been studied in both

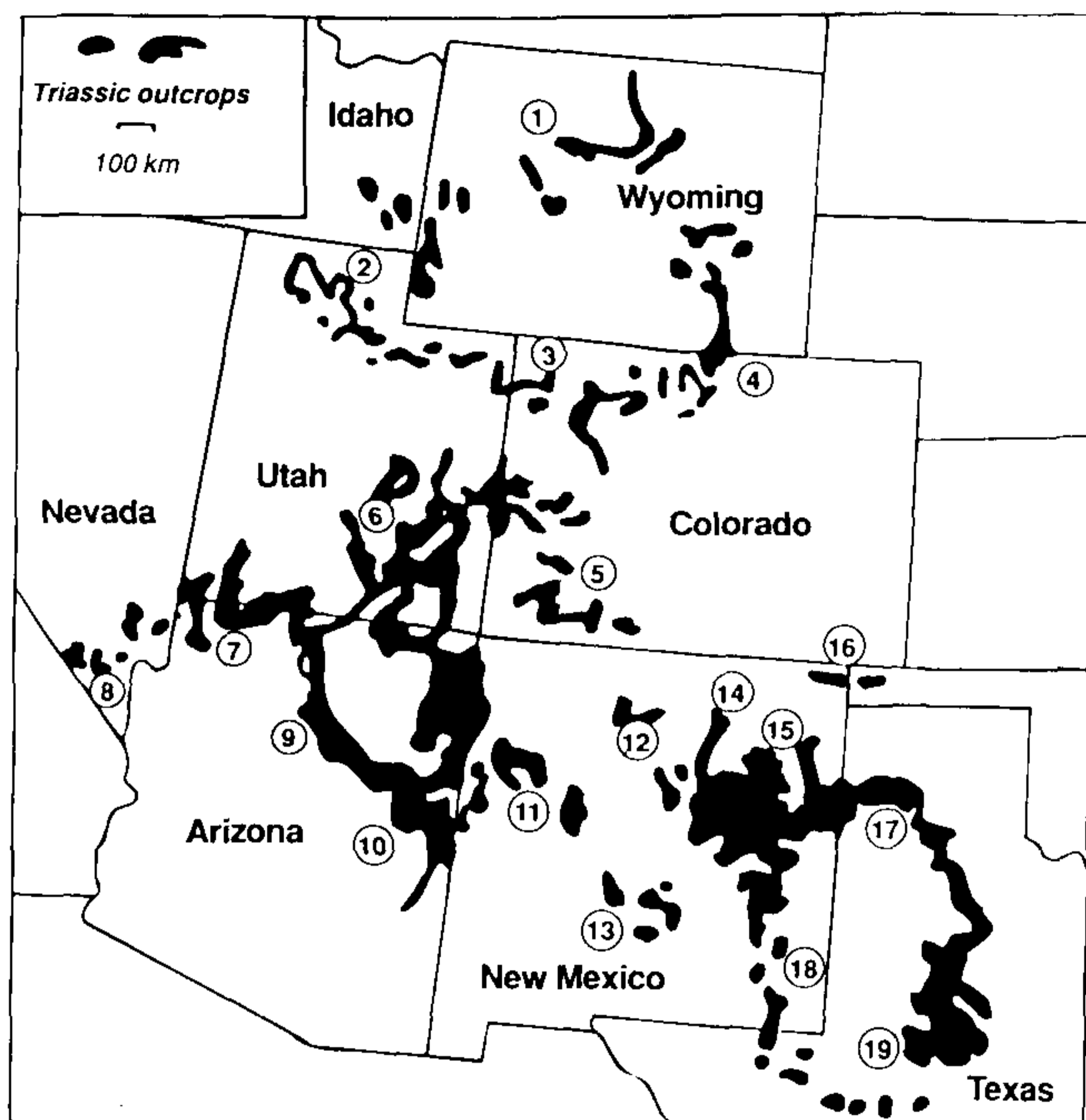


Figure 23.1. Distribution of Upper Triassic nonmarine strata of the Chinle Group in the western United States. Numbers serve to locate the stratigraphic columns shown in Figure 23.5.

SERIES	STAGES	SUBSTAGES	AMMONITE ZONES/ BIOCHRONS
LATE TRIASSIC	RHAETIAN		<i>Choristoceras marshi</i>
	NORIAN	Upper (Sevatian)	<i>Cochloceras amoenum</i>
			<i>Gnomohalorites cordilleranus</i>
		Middle (Alaunian)	<i>Himavavites columbianus</i>
			<i>Drepanites rutherfordi</i>
		Lower	<i>Juvavites magnus</i>
			<i>Malayites dawsoni</i>
	CARNIAN	Upper (Tuvalian)	<i>Stikinoceras kerri</i>
			<i>Klamathites macrolobatus</i>
			<i>Tropites welleri</i>
		Lower (Julian)	<i>Tropites dilleri</i>
			<i>Austrotrachyceras obesum</i>
<i>Trachyceras desatoyense</i>			

Figure 23.2. The late Triassic SGCS used in this chapter. (Adapted from Tozer, 1984.)

marine and nonmarine strata, especially in North America. Molina-Garza et al. (1991, 1993) have reviewed the publications on late Triassic magnetostratigraphy (Figure 23.4). Their review reveals reasonable consistency between the magnetization of the Chinle Group and those of other strata. Witte, Kent, and Olsen (1991) and Kent, Witte, and Olsen (1993) reported briefly on the magnetostratigraphy of the Upper Triassic–Lower Jurassic strata of the Newark Supergroup in the Newark Basin in Pennsylvania and New Jersey (USA). When the magnetostratigraphy of the

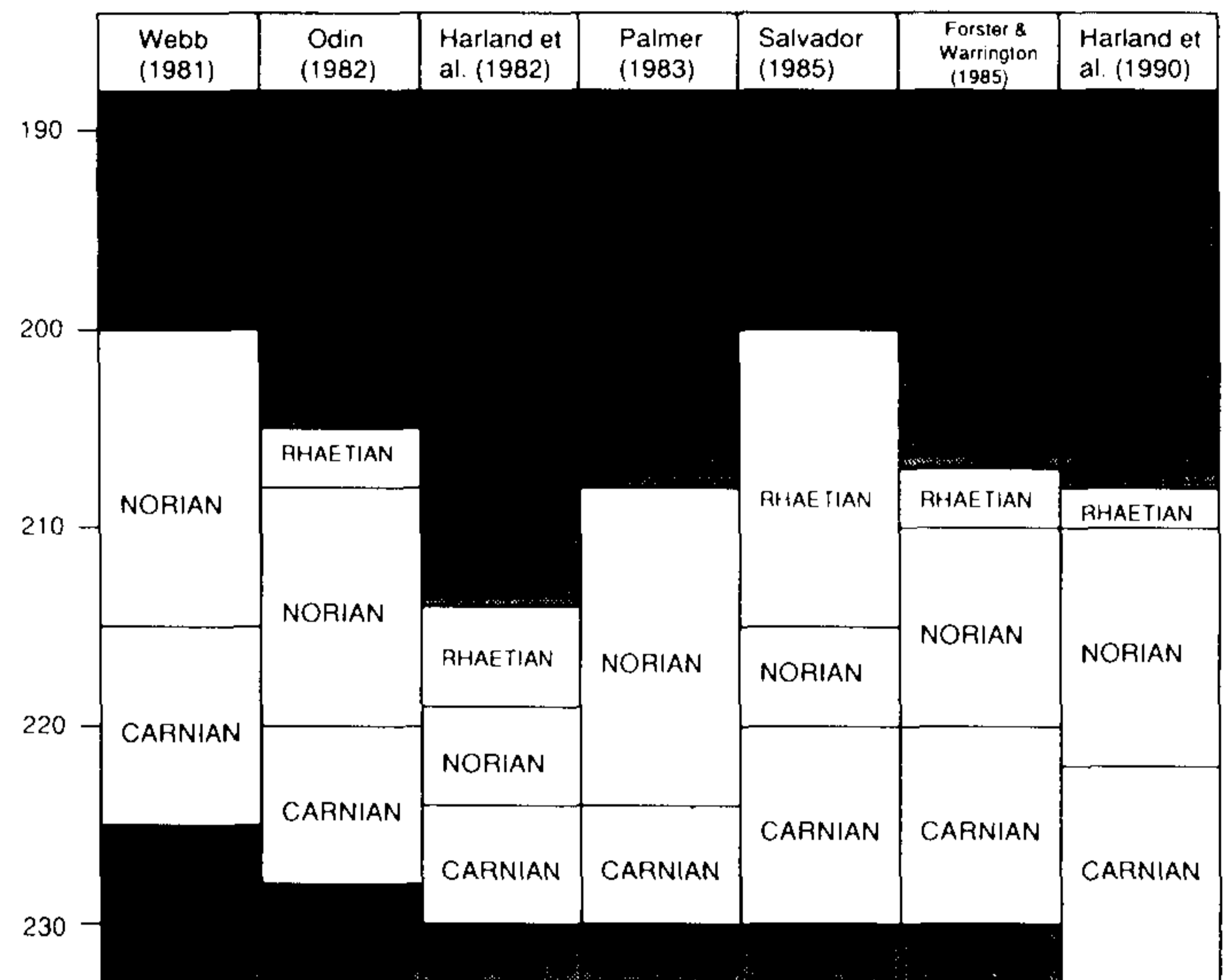


Figure 23.3. Comparison of recently proposed numerical time scales for the late Triassic.

5.5-km-thick core recovered from the Newark Basin is published in detail, it should provide a strong basis for magnetostratigraphic characterization of most of the Upper Triassic.

#### Chinle Group lithostratigraphy

Upper Triassic nonmarine strata are exposed in the western United States from northern Wyoming to West Texas and from southeastern Nevada to northwestern Oklahoma (Figure 23.1). Those strata, exposed over an area of about 2.3 million km<sup>2</sup>, were deposited in a single depositional basin (Chinle Basin), with a palaeoslope down to the west-northwest (Lucas, 1993). They are assigned to the Chinle Group of late Carnian–Rhaetian age. The Chinle Group strata are mostly redbeds, though some portions are variegated blue, purple, olive, yellow, and grey. The sandstones are mostly fluvial-channel deposits that range from mature quartz arenites to very immature litharenites and greywackes. The conglomerate clasts can be extrabasinal (silica pebbles and Palaeozoic limestone pebbles) or intrabasinal (mostly nodular calcrete rip-ups), or a mixture of both. Most of the mudstones are bentonitic, except in the youngest Triassic strata. The extensive lacustrine deposits encompass analcimolite and pisolitic limestone. Within that variety one can see overall sandstone immaturity, red colouration, textures and sedimentary structures of fluvial origin, and a general abundance of volcanic detritus, lending the Chinle Group strata a lithologic character that facilitates their ready identification.

Lucas (1993) reviewed in detail the lithostratigraphy of the Chinle Group and presented a comprehensive correlation of all Chinle strata based on lithostratigraphy and biostratigraphy (Figure 23.5). About 50 lithostratigraphic terms are presently applied to strata of the Chinle Group. To simplify discussion in this chapter, I identify five regionally extensive stratigraphic

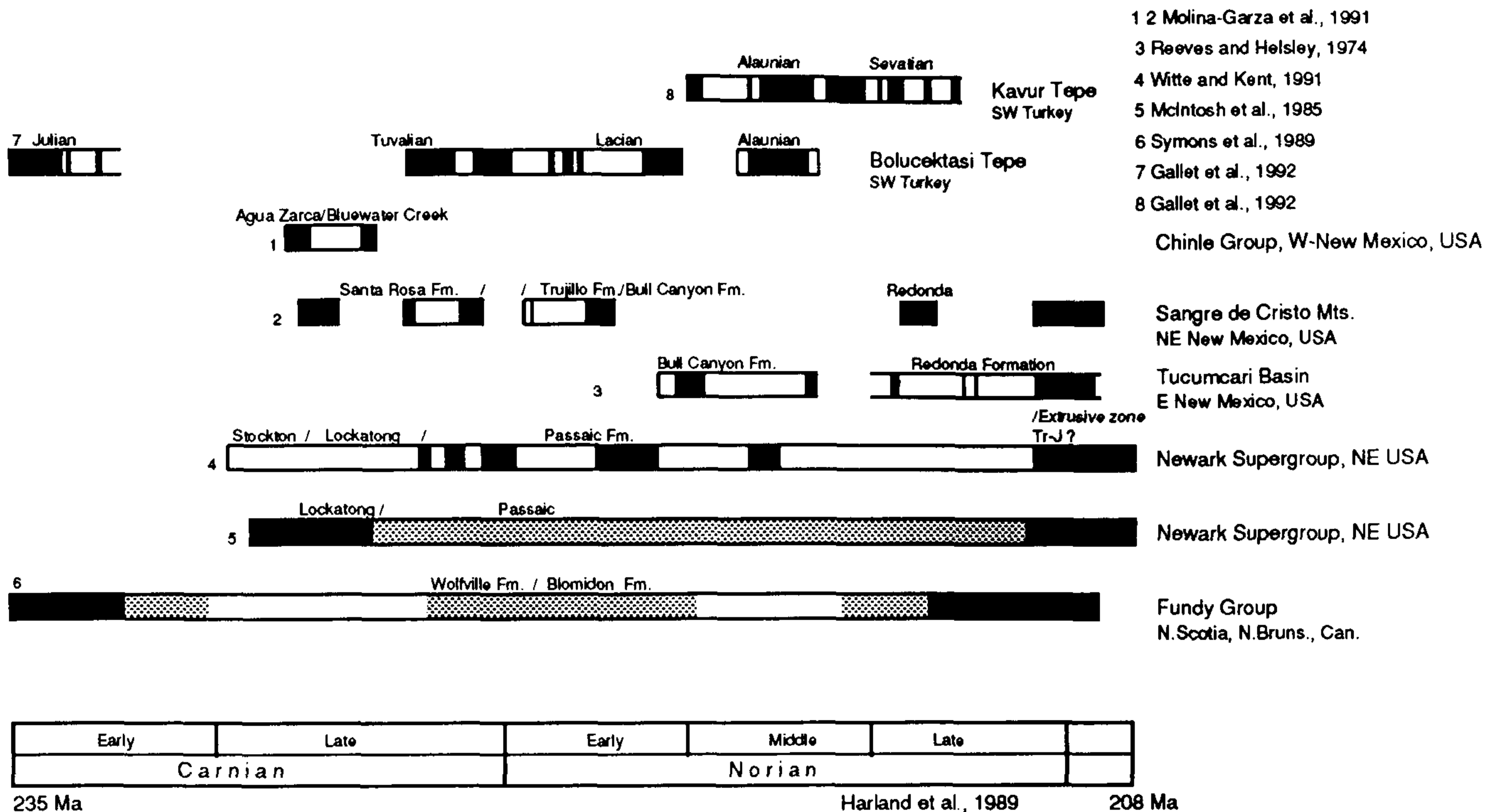


Figure 23.4. Global magnetostratigraphic correlation of the late Triassic. Normal-polarity intervals are black; grey indicates intervals of mixed polarity. (From Molina-Garza et al., 1993, with permission.)

intervals in the Chinle Group and label them A, B, C', C, and D (Figure 23.5). In terms of the classic Chinle Group stratigraphy of the Colorado Plateau, interval A refers to the Shinarump Formation and its correlatives, B to the Monitor Butte Formation plus the Blue Mesa member of the Petrified Forest Formation and their correlatives, C' to the Sonsela member of the Petrified Forest Formation and its correlatives, C to the Painted Desert member of the Petrified Forest Formation plus the Owl Rock Formation and their correlatives, and D to the Rock Point Formation and its correlatives.

#### Chinle Group sequence stratigraphy

Lithostratigraphic and biostratigraphic correlation of Chinle Group strata has identified two intra-Chinle Group unconformities that delimit three depositional sequences (Figure 23.5). The oldest Chinle Group sequence is the Upper Carnian Shinarump-Blue Mesa sequence. It begins with sandstones and silica-pebble conglomerates (stratigraphic interval A) that rest unconformably on older Triassic or Palaeozoic strata. Above the sandstones and conglomerates are variegated mudrock, sandstone, and minor carbonate (lower part of stratigraphic interval B). Those strata are overlain by mudrock-dominated lithofacies (upper part of stratigraphic interval B) that show extensive pedogenic modification (Lucas, 1993).

The Lower-Middle Norian second sequence of the Chinle

Group is the Moss Back-Owl Rock sequence. It begins with pervasive intrabasinal conglomeratic sandsheets (stratigraphic interval C') that rest disconformably on rocks at the top of stratigraphic interval B or older Chinle Group strata. Above stratigraphic interval C' are fluvial- and floodplain-deposited redbeds (majority of stratigraphic interval C). These redbeds are gradationally overlain by carbonate-siltstone strata of the Owl Rock Formation, which is restricted to the Colorado Plateau region of the Chinle Group outcrop area (Dubiel, 1989; Lucas, 1993).

The upper Chinle Group sequence is the Rhaetian Rock Point sequence (stratigraphic interval D). The base of the Rock Point sequence is everywhere defined by an unconformity that truncates various formations of the underlying sequences. The Rock Point lithofacies are varied, but consist mostly of repetitive, laterally persistent beds of siltstone, litharenite, and minor carbonate. The Rock Point sequence is unconformably overlain by formations of the Lower Jurassic Glen Canyon Group or younger strata.

On the Colorado Plateau, the basal Chinle Group locally consists of the late(?) Carnian Spring Mountains Formation (southeastern Nevada) and Temple Mountain Formation (east-central Utah) and a palaeo-weathering zone informally termed "mottled strata," which is variably present in other parts of the Chinle Basin (Stewart, Poole, and Wilson, 1972; Lucas, 1991a, 1993; Lucas and Marzolf, 1993). Those strata are as much as 35 m thick and may represent a depositional sequence older than

stratigraphic intervals	sequences	1 N and SW Wyoming	2 NE Utah/ SE Idaho	3 NW Colorado	4 S-C Wyoming/ N-C Colorado	5 SW Colorado	6 SE Utah/ NE Arizona	7 NW Arizona/ SW Utah	8 SE Nevada	9 NE Arizona (Cameron)
D	Rock Point sequence	Bell Springs Formation	Bell Springs Formation	Bell Springs Formation	Bell Springs Formation	Rock Point Formation	Rock Point Formation			
Tr-5 unconformity								Owl Rock Fm.	Owl Rock Fm.	Owl Rock Fm.
C	Moss Back-Owl Rock sequence					Petrified Forest Formation	Petrified Forest Formation	Petrified Forest Formation	Painted Desert Member	Painted Desert Member
C'						Moss Back Formation	Moss Back Formation			
Tr-4 unconformity								Petrified Forest Formation	Petrified Forest Formation	Petrified Forest Formation
B	Shinarump-Blue Mesa sequence							Blue Mesa Member	Blue Mesa Member	Blue Mesa Member
A		Popo Agie Formation	Popo Agie Formation	Popo Agie Formation	Gartra Formation		Cameron Formation	Monitor Butte Formation	Cameron Formation	Cameron Formation
			Gartra Formation	Gartra Formation		Shinarump Formation	Shinarump Formation	Shinarump Formation	Shinarump Formation	Shinarump Formation
								Spring Mts. F.		

10 NE Arizona (St. Johns)	11 W-Central New Mexico	12 N-Central New Mexico	13 S-Central New Mexico	14 Front Range NM-CO	15 E-Central New Mexico	16 NE NM/ NW Oklahoma	17 Texas Panhandle	18 Southeast New Mexico	19 Southwest Texas	strat. intervals
	Rock Point Formation	Rock Point Formation		Redonda Formation	Redonda Formation	Sheep Pen Ss. Sloan Canyon F. Traverser F.				D
Owl Rock Fm.	Owl Rock Fm.									
Petrified Forest Formation	Painted Desert Member	Painted Desert Member	Petrified Forest Formation	Bull Canyon Fm.	Bull Canyon Formation		Bull Canyon Member			C
	Sonsela Member	Sonsela Member	Poleo Fm.	Trujillo Fm.	Trujillo Formation	Cobert Canyon Sandstone	Trujillo Mbr.			C'
	Blue Mesa Member	Blue Mesa Member		Garita Creek Formation	Garita Creek Formation					
Mesa Redondo Formation	Bluewater Creek Formation	Salitral Formation	San Pedro Arroyo Formation	Tres Lagunas Mbr.	Tres Lagunas Mbr.	Baldy Hill Formation	Dockum Formation	Tecovas Member	San Pedro Arroyo Formation	
Shinarump Formation	Shinarump Formation	Agua Zarca Formation		Los Esteros Member	Los Esteros Member	Santa Rosa Formation				Iatan Member
			Santa Rosa Fm.	Tecolotito Member	Tecolotito Member		Camp Springs Member	Santa Rosa Fm.	Camp Springs Member	A

Figure 23.5. Correlation of nonmarine Upper Triassic strata of the Chinle Group. See Figure 23.1 for locations of numbered columns. Five

informal stratigraphic intervals (A, B, C', C, and D) identified here are used in the text and in subsequent figures.

and disconformably overlain by the Shinarump-Blue Mesa sequence (Marzolf, 1993). However, the detailed stratigraphic relationships of those oldest Chinle strata and weathering horizons have not been well studied. At present, I consider them to represent early, incised valley fills of the Shinarump-Blue Mesa sequence.

In the Mesozoic marine province of northwestern Nevada, shelf and basinal rocks are juxtaposed along the trace of the late Mesozoic Fencemaker thrust fault (Speed, 1978a,b; Oldow, 1984; Oldow, Bartel, and Gelber, 1990). Lucas and Marzolf

(1993; cf. Lupe and Silberling, 1985) considered the Cane Spring Formation of the Star Peak Group and overlying strata of the Auld Lang Syne Group to be correlative and genetically related to Chinle Group strata (Figure 23.6).

In the northeastern part of the Star Peak outcrop area, the base of the Cane Spring Formation contains chert-pebble conglomerate, cobble conglomerate, and planar-crossbedded conglomeratic sandstone, up to 100 m thick (Nichols and Silberling, 1977), containing lenses of deeply weathered clastic rocks (Nichols, 1972). Those basal clastics closely resemble the

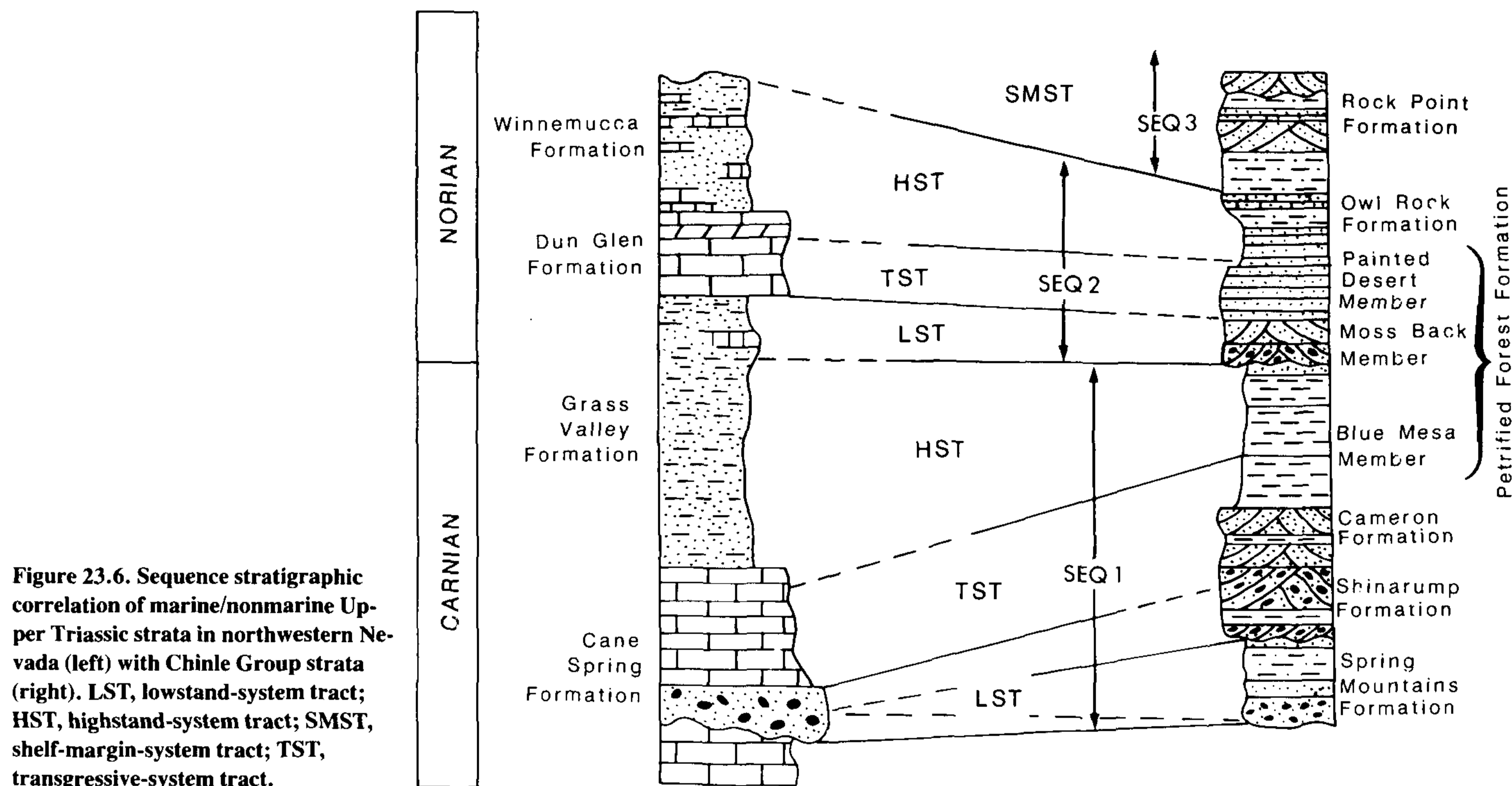


Figure 23.6. Sequence stratigraphic correlation of marine/nonmarine Upper Triassic strata in northwestern Nevada (left) with Chinle Group strata (right). LST, lowstand-system tract; HST, highstand-system tract; SMST, shelf-margin-system tract; TST, transgressive-system tract.

Shinarump Formation of the Chinle Group and were deposited on a subaerially eroded, channelized and karsted surface developed on the underlying Middle Triassic Smelser Pass member of the Augusta Mountain Formation.

The basal coarse clastics are overlain by bioclastic wackestone up to 300–400 m thick (Nichols and Silberling, 1977). In the western part of the Star Peak outcrop area, those carbonates have been informally divided into a lower, brownish-weathering, evenly bedded silty and argillaceous limestone and an upper, more massive and thickly bedded grey limestone.

The latter is overlain by the Grass Valley Formation or the equivalent Osobb Formation. Those two formations represent a voluminous influx of siliciclastic sediment, interpreted by Silberling and Wallace (1969) as a deltaic system. Palaeocurrent indicators and a westward increase in mud-to-sand ratio indicate that distributaries transported sand from delta plains in the east to delta fronts and prodeltas in the west. Wood fragments and logs are locally abundant in the fine-to-coarse sandstones of the eastern sections.

The deltaic sediments of the Grass Valley/Osobb formations are conformably overlain by massive, thick-bedded dolostone and limestone of the Dun Glen Formation. The Dun Glen is uniform in composition and thickness across its outcrop area. Its fossils suggest a shallow-water depositional environment. The Dun Glen is gradationally overlain by mixed siliciclastic and carbonate sediments of the Winnemucca Formation. The Winnemucca contains a much higher proportion of carbonate, compared with sandstone and clay, than do the deltaic sediments of the Grass Valley Formation and is the stratigraphically highest unit of the shelf sequence.

Ammonoids provide a reasonably precise biochronology for the shelfal strata of the Cane Spring Formation and Auld Lang Syne Group (Silberling, 1961; Silberling and Tozer, 1968; Silberling and Wallace, 1969; Nichols, 1972; Burke and Silberling, 1973; Nichols and Silberling, 1977). The lower Cane Spring Formation clastics approximate the *dilleri* Zone, and the Lower Norian *kerri* Zone is found in basal calcareous beds of the Osobb Formation. *Magnus* Zone ammonites are present in the uppermost Grass Valley Formation and the Dun Glen Formation, and the Winnemucca Formation probably is as young as the *columbianus* Zone.

Recent refinements of Chinle Group stratigraphy and biochronology prompted Lucas (1991b; Lucas and Marzolf, 1993) and Marzolf (1993) to reexamine the Lupe and Silberling (1985) proposal for a possible genetic relationship between deposition of Chinle Group strata and upper Star Peak–Auld Lang Syne Group strata (Figure 23.6). As noted earlier, the Chinle Group is composed of three third-order cycles that are bounded by unconformities. The criteria that define the regional extents of those unconformities are (1) evidence of extensive, subaerial weathering and channeling at the base of each depositional sequence, (2) major shifts in dominant lithologies (and facies) at the base of each sequence, (3) correlative rocks immediately above each unconformity that overlie rocks of different ages in different regions, and (4) each unconformity corresponding to a significant reorganization of the biota (Lucas, 1991b, 1993).

The conglomeratic sandsheets at the bases of the Shinarump–Blue Mesa and Moss Back–Owl Rock sequences were deposited in a broad alluvial basin characterized by extensive palaeovalley

incision and prolonged subaerial exposure during periods of nondeposition (e.g., Blakey and Gubitosa, 1983; Lucas, 1991a; Lucas and Anderson, 1993). In each sequence, the basal sandsheets are overlain by fluvial and/or lacustrine facies throughout the Chinle depositional basin. Each sequence is capped by paludal carbonate and siltstone that show evidence of channeling and subaerial weathering prior to deposition of the overlying sequence.

Lucas (1991a,b, 1993; Lucas and Marzolf, 1993) interpreted the basal sandsheets as lowstand-system tracts (LSTs) whose deposition occurred in response to initial coastal onlap at the onset of a transgressive–regressive cycle. The overlying fluvial and fluviolacustrine siliciclastics represented transgressive-system tracts (TSTs), and the highstand-system tracts (HSTs) were defined as aggradational deposits of paludal-lacustrine siltstone and carbonate.

In Nevada, the Shinarump equivalent is the Cane Spring conglomerate (LST), which is overlain by shelfal, dolomitized carbonate that represents the TST. Overlying basal clastics of the Grass Valley Formation are identified as representing the HST. The lowstand surface of the next sequence is an unconformity in the Grass Valley Formation. Because the Osobb Formation contains basal Norian ammonoids (*kerri* Zone) and thus straddles the Carnian–Norian boundary, I suggest that it and its correlative, the Grass Valley Formation, contain an unconformity that reflects a basinward strand-line shift that accompanied the regression–transgression cycle that defines the Carnian–Norian boundary on the Colorado Plateau.

The Dun Glen Formation is a platform carbonate that was interpreted to represent the TST, where the transgressing base level entrapped sediment landward of the deepening shelf, and it is correlated to most of the upper Petrified Forest Formation. The Winnemucca and Owl Rock thus represent homotaxial highstand deposits. The shelf sequence, however, does not preserve age-correlative strata of the Rock Point sequence.

The importance of the sequence stratigraphic correlations just outlined lies not only in their suggestion that eustasy was a driving force in Chinle Group sedimentation but also in the fact that they provide a rationale for correlating selected Upper Triassic ammonoid zones to Chinle Group strata (Lucas, 1991b; Lucas and Luo, 1993). Those correlations are consistent with the palynologic and tetrapod-based correlations of the Chinle Group outlined later. They identify the base of the Chinle Group as approximately equivalent to the Upper Carnian (Tuvalian) *dilleri* Zone. The Carnian–Norian boundary (base of the *kerri* Zone) is about at the base of stratigraphic interval C'. Stratigraphic interval C is no younger than the Middle Norian *columbianus* Zone. Chinle Group stratigraphic interval D has no equivalent in the Nevada shelfal terrane.

#### Chinle Group biostratigraphy and biochronology

The first fossils from the Chinle Group brought to scientific attention were petrified logs reported by Simpson (1850). In the more than 140 years since the first discoveries by Simpson, fossils

Chinle strata	Palynomorph Zones	Megafossil plant zones
D	Zone III	<i>Sanmiguelia</i> Zone
C		
C'		
B	Zone II	<i>Dinophyton</i> Zone
A		
	Zone I	<i>Eoginkgoites</i> Zone

Figure 23.7. Comparison of the three palynomorph zones of Litwin et al. (1991) with the megafossil plant zones defined by Ash (1980, 1987).

of enormous diversity and abundance have been collected from Chinle Group strata across its outcrop belt. The volumes edited by Lucas and Hunt (1989) and Lucas and Morales (1993) review much of that record and the massive literature that it has prompted, obviating the need for any historical review of those discoveries here. Instead, my focus is to evaluate the biostratigraphic and biochronologic utility of each taxonomic group represented by Chinle Group fossils.

#### Palynology

Litwin, Traverse, and Ash (1991) and Cornet (1993) have reviewed Chinle Group palynostratigraphy in some detail. Palynomorphs are abundant and well preserved throughout the Chinle Group and have been studied for at least 30 years. Litwin et al. (1991) defined three palynomorph zones that nearly parallel the megafossil plant zones of Ash (1980, 1987), discussed later (Figure 23.7). Zone I, from the Temple Mountain Formation, is characterized by two taeniata bisaccate taxa, *Lunatisporites* aff. *L. noviaulensis* and *Infernopollenites claustratus* (the latter is also found in the Shinarump Formation). Zone II is widely distributed and is characterized by more than 100 taxa. Key taxa are *Brodipora striata*, *Michrocachrydites doubingeri*, *Lagenella martinii*, *Samaropollenites speciosus*, *Plicatisaccus badius*, *Camerosporites secatus*, and *Infernopollenites claustratus*. Zone II includes a large number of FADs (first-appearance datums) and LADs (last-appearance datums). This zone is of Tuvalian age, based on correlation to European palynomorph zones and cross-correlation to Tuvalian ammonite-bearing strata with palynomorphs (Dunay and Fisher, 1974, 1979). The youngest zone II assemblage is at or near the base of stratigraphic interval C'.

The overlying zone III assemblage encompasses all of the upper Chinle Group (stratigraphic intervals C', C, and D). This zone lacks many common-to-cosmopolitan late Carnian palynomorphs, and the FADs of several taxa – *Foveolatitriteles pottoniei*, *Kyrtomisporeis speciosus*, *K. laevigatus*, and *Camerosporites verucosus* – indicate a Norian age (Litwin et al., 1991).

Litwin et al. (1991) claimed that the presence of *Pseudenzonalasporites summus* indicates an early Norian age for all of zone III, citing Visscher and Brugman (1981) as authority for an early Norian age of *P. summus*. However, Visscher and Brugman (1981) indicate that *P. summus* extends into the late Norian. Indeed, *P. summus* is known from the youngest Triassic (Rhaetian) strata of the Newark Supergroup in eastern North America (upper Passaic Formation) (Cornet, 1993; Huber, Lucas, and Hunt, 1993a), so it cannot be considered indicative of only an early Norian age. Litwin et al. (1991, p. 280) also claimed that the absence of *Corollina* (= *Classopollis*), *Triancoraesporites ancorae*, *Rhaetipollis germanicus*, *Ricciisporites tuberculatus*, and *Heliosporites reissingeri* in zone III "precludes a younger age assignment for the Chinle because these palynomorphs occur commonly in late Norian (i.e., 'Rhaetian') strata in Europe, the North Atlantic (Greenland) and the Arctic." Nevertheless, *Classopollis*, *R. tuberculatus*, *H. reissingeri*, and other supposed Rhaetian index palynomorphs are known from ammonoid-bearing early Norian strata in Svalbard, calling into question their validity as Rhaetian index taxa (Smith, 1982). Furthermore, I do not consider the absence of taxa to be as strong an indicator of age as the presence of taxa, so the absence of a few so-called Rhaetian index palynomorphs from zone III is of doubtful biochronologic significance. I thus conclude that the zone III palynomorph assemblage of Litwin et al. (1991) is post-late Carnian Triassic, but I do not believe that it can provide a more precise correlation within the Norian–Rhaetian interval.

Cornet (1993) recently presented an extensive data set of palynomorphs from two wells drilled in Chinle Group strata in West Texas (stratigraphic intervals A and B). His data largely reinforce the conclusion of Litwin et al. (1991) that zones I and II are late Carnian.

Palynomorphs thus provide an important means by which Chinle Group strata are correlated. Particularly significant is the potential that palynomorphs may provide for direct linkage to the marine SGCS, thus allowing precise assignment of the Chinle Group strata to the late Carnian, the Carnian–Norian boundary, and the post-late Carnian Triassic. Clearly, the frontier for Chinle Group palynostratigraphy is in the upper part of the group, the zone III assemblage of Litwin et al. (1991). This assemblage needs more extensive documentation to subdivide it and/or arrive at a more precise, palynomorph-based correlation of the upper Chinle Group.

#### Megafossil plants

Study of Chinle Group fossil plants extends back to 1850, but the works of Daugherty (1941) and Ash (1989) and the sources they cite provide most of our knowledge of Chinle Group megafossil plants. Ash (1980, 1987) proposed that three floral zones can be recognized in Chinle Group strata: (1) the *Eoginkgoites* Zone, from stratigraphic interval A, (2) the *Dinophyton* Zone, from stratigraphic interval B, and (3) the *Sanmiguelia* Zone, from stratigraphic intervals C', C, and D.

When the stratigraphic ranges of all Chinle megafossil plant

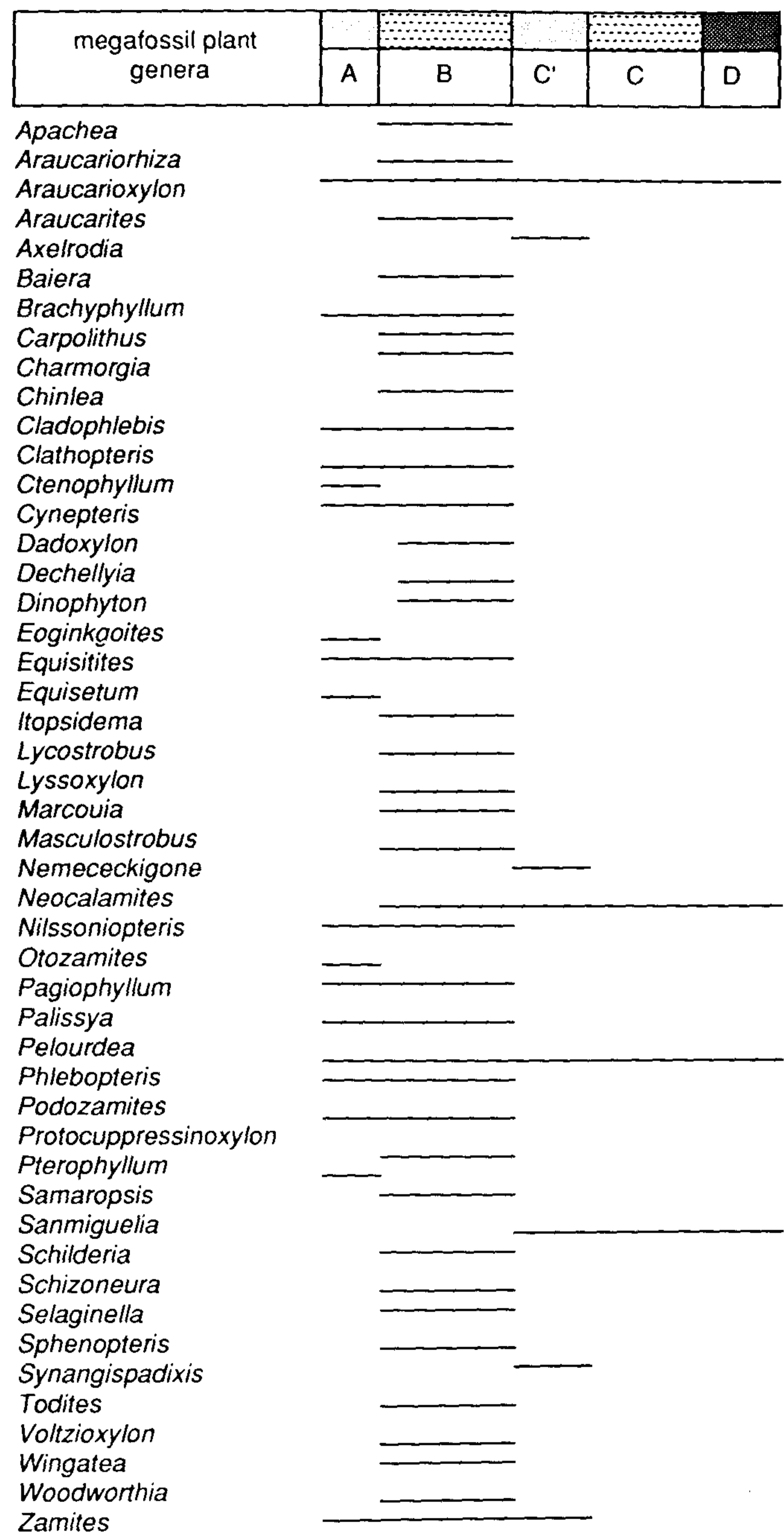


Figure 23.8. Stratigraphic ranges of megafossil plant genera in the Chinle Group, based on the work of Ash (1989) and the sources cited therein.

genera are plotted (Figure 23.8), some clear patterns emerge: (1) the majority of genera (26 of 49, or 53%) are confined to stratigraphic interval B; (2) very few genera (8 of 49, or 16%) are found in stratigraphic intervals C', C, and D; and (3) a minority of genera (18 of 49, or 37%) are found in interval A, of which only 5 are restricted to that interval. *Eoginkgoites* is restricted to interval A, but the other genera in that interval either are rare or are known only from one locality.

The *Dinophyton* Zone of Ash (1980) is confined to stratigraphic interval B. *Dinophyton* and several other genera are restricted to that zone. Clearly, that accounts for the bulk of the Chinle megafossil flora, probably because of preservational biases. Ash's *Sanmiguelia* Zone corresponds to stratigraphic intervals C', C, and D (Ash, 1987). *Nemececkigone* is a possible seed of *Sanmiguelia*, and *Synangispadix* is its possible pollen-bearing organ (Cornet, 1986); so these two taxa in interval C' are redundant of *Sanmiguelia*. Clearly, the *Sanmiguelia* Zone cannot be characterized except for the presence of *Sanmiguelia*, which is known from about half a dozen localities and is endemic to the Chinle Group.

The two older Chinle Group megafossil plant zones do allow internal correlations of Chinle Group strata that reinforce tetrapod-based correlations (i.e., the *Eoginkgoites* Zone is of Otischalkian age, and the *Dinophyton* Zone is of Adamanian age, as discussed later). Furthermore, those two zones can be correlated to strata in several of the Newark Supergroup basins, correlations that are consistent with tetrapod-based correlations (Ash, 1980; Axsmith and Kroehler, 1988; Lucas and Huber, 1993; Huber et al., 1993b). I conclude that Chinle Group late Carnian plants provide a strong basis for correlation, but that the Norian–Rhaetian megafossil flora of the Chinle Group needs further collection and study before it can be of much biostratigraphic/biochronologic utility.

#### Charophytes

Charophytes are well preserved and locally abundant in Chinle Group strata, but have been little studied. Kietzke (1987) first described Chinle Group charophytes – specimens of *Stellatochara* and *Altochara*. Lucas and Kietzke (1993) described *Porochara abjecta* Saidakovsky from the Petrified Forest National Park, Arizona. There are other reports of Chinle Group charophytes in the literature, but these are the only two documented occurrences. At present, these identified Chinle Group charophytes are from the upper part (Norian–Rhaetian) of the group: *Altochara* and *Stellatochara* from the Bull Canyon Formation, *Porochara abjecta* from the Painted Desert member of the Petrified Forest Formation, and *Stellatochara* from the Sloan Canyon Formation. Those three taxa had relatively long temporal ranges, and it is presently uncertain how useful charophytes will be in the biostratigraphy/biochronology of the Chinle Group.

#### Invertebrate trace fossils

Tracks, trails, burrows, and other trace fossils of invertebrates are common in most Chinle Group strata. Limuloid trackways (*Kouphichnium*) and crayfish burrows (*Camborygma*) have been studied in some detail (Caster, 1938, 1944; Hunt et al., 1993a,b; Hasiotis and Mitchell, 1993; Hasiotis and Dubiel, 1993a,b). Other, less well studied trace fossils represent a typical nonmarine ichnofacies dominated by *Scoyenia*, *Skolithos*, and other unornamented burrows (e.g., Lucas, Hunt, and Hayden, 1987; Hester, 1988; Hasiotis and Dubiel, 1993a). Much work needs to be undertaken on Chinle Group invertebrate trace

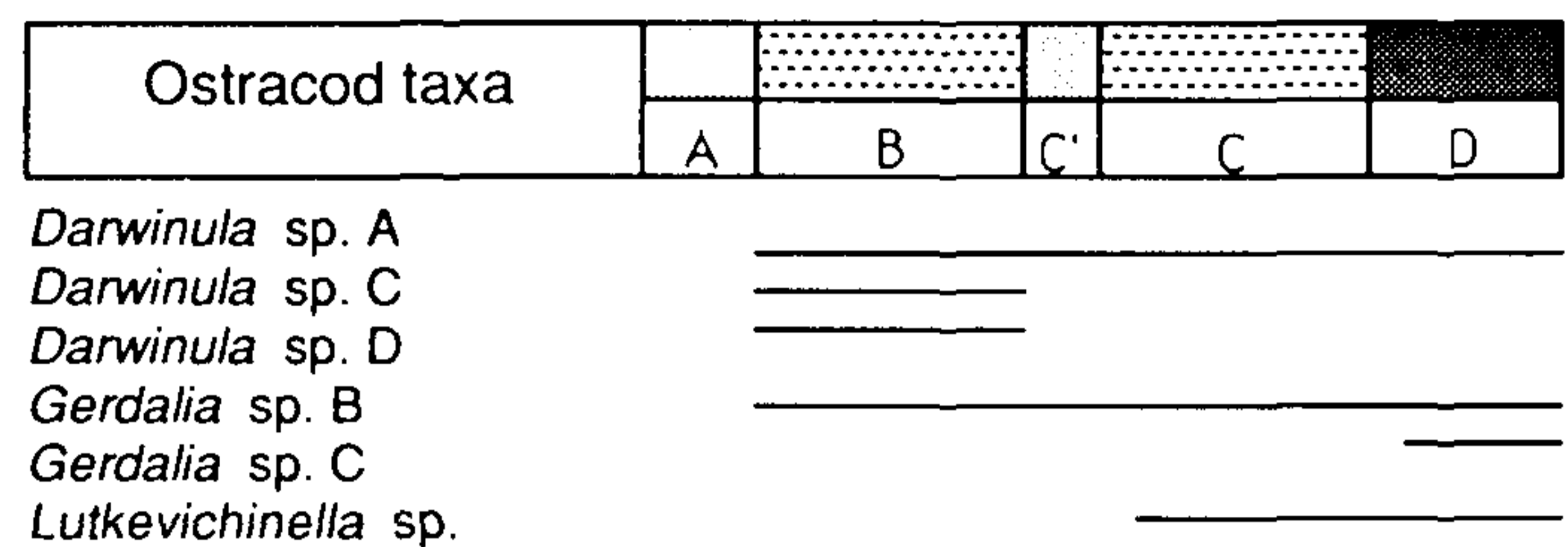


Figure 23.9. Stratigraphic distribution of ostracods in the Chinle Group (data primarily from Kietzke, 1989).

fossils as an aid to sedimentologic and palaeoecologic interpretations. Whether these fossils will be of any biostratigraphic/biochronologic utility remains to be seen.

#### Ostracods

Like charophytes and conchostracans, Chinle Group ostracods are widely distributed and locally abundant, but relatively little studied. Thus far, Kietzke (1987, 1989), Kietzke and Lucas (1991a), and Lucas and Kietzke (1993) have provided all of the published descriptions of Chinle Group ostracods. These ostracods are darwinulaceans, except for the cytheracean *Lutkevichinella* (Figure 23.9).

Permian–Recent darwinulaceans are unornamented nonmarine ostracods of limited biochronologic utility, because they essentially lack structural diversity beyond basic shape characteristics. Crushing and plastic deformation often are difficult to detect in these ostracods and frequently confuse proper identification. Vast taxonomic diversities among Triassic darwinulaceans have been recognized in China (e.g., Pang, 1993) and Russia (e.g., Belousova, 1961) and have been employed in biostratigraphy/biochronology, though I am skeptical of much of the alpha taxonomy on which that is based.

Instead, Kietzke and I have taken a very conservative approach to Chinle Group ostracod taxonomy, recognizing three genera encompassing six unnamed species. Two ostracod zones can be recognized in the Chinle Group: (1) the lower Chinle zone (stratigraphic intervals A and B), characterized by a large *Darwinula* associated with *Gerdalia* and a small *Darwinula*, and (2) the upper Chinle zone (stratigraphic intervals C and D), characterized by small *Darwinula* similar to *D. liulingchuanensis*, *Gerdalia*, and *Lutkevichinella*. This biozonation divides the Chinle Group into late Carnian and post–late Carnian portions, but the ostracod distribution is too patchy to be of great biostratigraphic/biochronologic significance. Broad correlations with, for example, Chinese late Triassic ostracods – the *Tongchuania-Darwinula-Lutkevichinella* assemblage of Xu (1988) and Pang (1993) – are obvious, but no more precise correlations are possible.

#### Conchostracans

Conchostracans are known from a variety of Chinle Group strata: the Tecovas member of the Dockum Formation in West



Texas, the Monitor Butte Formation in southeastern Utah, the Bluewater Creek Formation in west-central New Mexico, the Blue Mesa and Sonsela members of the Petrified Forest Formation in northeastern Arizona, the Redonda Formation in east-central New Mexico, and the Bell Springs Formation in northwestern Colorado. However, only those from the Bluewater Creek Formation have been described and illustrated. Tasch (1978) named those conchostracans "*Cyzicus (Lioestheria) wingatella*." This is a late Carnian record, but the lack of a late Triassic conchostracan biostratigraphy/biochronology makes it impossible to use Chinle Group conchostracans for correlation. Further work on Chinle Group conchostracans is needed, as is work on the extensive conchostracan record from the Newark Supergroup of eastern North America, to develop a useful conchostracan biostratigraphy/biochronology for the late Triassic.

#### Insects

Insect fossils are present in the Bluewater Creek Formation at Fort Wingate, west-central New Mexico, and in the Sonsela member of the Petrified Forest Formation in the Petrified Forest National Park, Arizona, but no specimens have been described or illustrated. Insect-body fossils appear to be so rare and so poorly preserved in Chinle Group strata that I expect them to be of little biostratigraphic/biochronologic utility.

#### Decapod crustaceans

Crayfish-body fossils are known from Chinle Group strata in Utah and Arizona (Miller and Ash, 1988; Hasiotis and Mitchell, 1989). Miller and Ash (1988) identified a specimen from the Blue Mesa member of the Petrified Forest Formation in Arizona as *Enoploclytia porteri*. At present, Chinle Group crayfish-body fossils are too rare to be of biostratigraphic/biochronologic utility.

#### Bivalves and gastropods

Nonmarine mollusks (unionid bivalves and prosobranch mesogastropods) are widespread in the Chinle Group and were among the first Chinle Group fossils described (Good, 1989, 1993a,b). As Lucas (1991b, 1993) and Good (1993a,b) indicated, these fossils are much more abundant in the upper Chinle Group (stratigraphic intervals C and D) than in the lower. That probably is because of differences in favourable living habitats and preferential preservation in the more oxidized upper Chinle Group sediments. Kietzke (1987, 1989) reported "spirorbids" from the Chinle Group, but more likely they were vermiform gastropods (Weedon, 1990; Kietzke and Lucas, 1991b).

Good (1993a,b) recognized two "molluskan faunas" based on Chinle Group nonmarine mollusks that I shall refer to as "zones" (Figure 23.10): (1) a lower zone (stratigraphic interval B) characterized by two unionid taxa, *Uniomerus(?) hanleyi* and

nonmarine molluscs					
	A	B	C'	C	D
<i>Diplodon gregoryi</i>					
<i>Uniomerus? hanleyi</i>		_____			
<i>Antediplodon tenuiconchis</i>		_____			
<i>Antediplodon gaciliratus</i>				_____	
<i>Antediplodon dockumensis</i>				_____	
<i>Antediplodon gallinensis</i>				_____	
<i>Antediplodon cristonensis</i>				_____	
<i>Antediplodon thomasi</i>				_____	
<i>Lioplacodes pilsbryi</i>				_____	
<i>Lioplacodes latispira</i>				_____	
<i>Lioplacodes assiminoides</i>				_____	
<i>Ampullaria gregoryi</i>				_____	

Figure 23.10. Stratigraphic distribution of nonmarine mollusks in the Chinle Group. (Adapted from Good, 1993b.)

Fish taxa					
	A	B	C'	C	D
<i>Xenacanthus moorei</i>					
<i>Lissodus humblei</i>					
<i>Acrodus</i> sp.				_____	
<i>new hybrid</i>				_____	
<i>Lissodus</i> sp. nov.					_____
<i>Arganodus</i> spp.					
<i>Chinlea</i> sp.					
<i>Chinlea</i> sp. nov.				_____	
<i>Chinlea sorenseni</i>					_____
cf. <i>Turseodus</i> sp.					
<i>Turseodus dolorensis</i>					_____
<i>Tanaocrossus</i> sp.					
<i>Synorichthys-Lasalichthys</i>					
<i>Cionychthys</i> sp.					
<i>Cionychthys greeni</i>					
<i>Cionychthys dunklei</i>					_____
Colobodontidae					
<i>Semionotus</i> aff. <i>S. brauni</i>				_____	
<i>Semionotus</i> sp.					_____
cf. <i>Hemicalypterus</i> sp.					
<i>Hemicalypterus weiri</i>					_____

Figure 23.11. Stratigraphic distribution of fishes in the Chinle Group (data from Huber et al., 1993c).

*Antediplodon hanleyi*, and (2) an upper zone (stratigraphic intervals C', C, and D) of various species of *Antediplodon*, and with gastropods of the genera *Lioplacodes* and *Ampullaria*. *Diplodon gregoryi* is known from one problematic specimen from the Shinarump Formation (Reeside, 1927) and is of no biostratigraphic/biochronologic utility. The gastropod-dominated interval without unionids in uppermost Chinle Group strata (Figure 23.11) reflects more arid facies and may prove to be of biostratigraphic/biochronologic utility.

Unionids and gastropods provide a robust internal correlation of Chinle Group strata into two time intervals. They are more abundant than ostracods and are more useful in Chinle Group correlations. However, no effort has been made to compare Chinle Group nonmarine mollusks from other Upper Triassic nonmarine strata; so their utility in broader correlations remains to be tested.

### Vertebrate coprolites

The Chinle Group has a prolific record of vertebrate coprolites, some of which have been described (e.g., Case, 1922; Ash, 1978; Lucas, Oakes, and Froehlich, 1985). This type of record is not uncommon in nonmarine Triassic redbeds Pangaea-wide (e.g., Rusconi, 1949; Ochev, 1974; Jain, 1983). The principal problem with interpretation of Chinle Group vertebrate coprolites, as with all vertebrate coprolites, is identification of their perpetrators.

Despite this, two coprolite morphologies are restricted to the late Carnian portion of the Chinle Group section (stratigraphic intervals A and B) (Hunt, 1992): (1) heteropolar spiral coprolites that usually are less than 3 cm long, taper to blunt points, and have four to six spirals at the wider end (Case, 1922, fig. 33A-B; Ash, 1978, fig. 2h; Hunt, 1992, fig. 4A-B); (2) broad, large (6–9-cm long) coprolites with no external features (Hunt, 1992, fig. 4C). Other morphologies of vertebrate coprolites occur throughout the Chinle Group section. Thus, a crude biostratigraphy of two zones can be based on Chinle Group vertebrate coprolites.

### Fishes

Chinle Group fossil fishes range from isolated scales to complete articulated skeletons and are found at a wide variety of outcrops throughout the stratigraphic range of the Chinle Group. Huber et al. (1993c) provided a comprehensive review of Chinle Group fishes and identified three assemblages (Figure 23.11): (1) a late Carnian (stratigraphic intervals A and B) assemblage with cf. *Turseodus*, *Tanaocrossus* sp., *Cionychthys greeni*, representatives of the *Synorichthys-Lasalichthys* complex, indeterminate colobodontids, cf. *Hemicalypterus*, *Chinlea* sp. *Arganodus* sp., *Xenacanthus moorei* and *Lissodus humblei*; (2) an early–middle Norian assemblage with cf. *Turseodus*, *Tanaocrossus* sp., indeterminate redfieldiids and colobodontids, *Semionotis* cf. *S. brauni*, *Chinlea* n. sp. and *Chinlea* sp., *Arganodus*, and *Acrodus*; (3) a Rhaetian assemblage with *Turseodus dolorensis*, *Tanaocrossus kalliokoski*, *Cionychthys dunklei*, *Synorichthys stewarti*, *Lasalichthys hillsi*, indeterminate colobodontids, *Semionotis* sp., *Hemicalypterus weiri*, *Chinlea sorenseni*, *Arganodus* sp., and *Lissodus* n. sp. Most of those taxa either were long-ranging or unique to a particular assemblage; so they are of little biostratigraphic/biochronologic utility. I do not expect that outlook to change with further collecting and study, although much work remains to be done on Chinle Group fossil fishes.

### Tetrapods

**Tetrapod biochronology.** Tetrapod vertebrates (amphibians and reptiles) provide one of the strongest and most refined means for correlating Upper Triassic nonmarine strata. The Chinle Group has an extensive tetrapod-fossil record that has long played a key role in late Triassic correlations. Lucas and Hunt (1993b) recently organized Chinle Group tetrapod stratigraphic ranges to define four land-vertebrate faunachrons (lvfs) of late Triassic age (Figure 23.12). These lvfs rely heavily on the distributions of four groups of abundant, widespread late Triassic tetrapods: metopo-

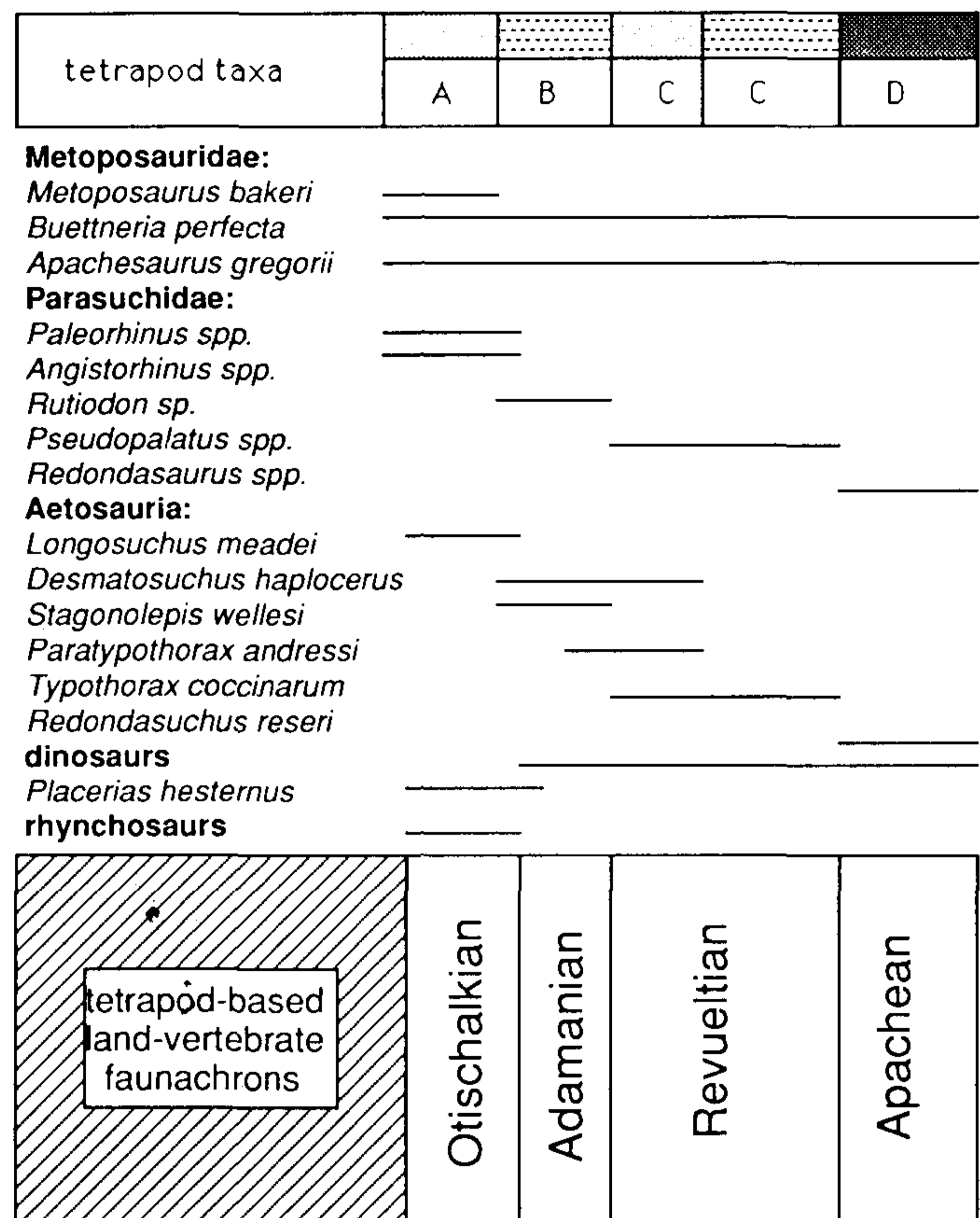


Figure 23.12. Stratigraphic distribution of biostratigraphically/biochronologically significant tetrapods in the Chinle Group and their relationships to the land-vertebrate faunachrons of Lucas and Hunt (1993b).

saur, phytosaurs, aetosaurs, and dicynodonts. Their biostratigraphy/biochronology is reviewed here, as is that of Chinle Group tetrapod footprints. At present, other Chinle Group tetrapods are less useful biostratigraphically/biochronologically because of inadequate sampling and/or confused taxonomy, in dire need of revision. Fraser (1993) has well emphasized the need to document better the distribution and taxonomy of small tetrapods of late Triassic age, especially sphenodontians, as an aid to correlation. This work is well under way by several palaeontologists and promises further reinforcement and refinement of Chinle Group tetrapod biochronology.

**Metoposauridae.** All Chinle Group temnospondyl amphibians are metoposaurids. Hunt (1993b) revised the metoposaurids and identified three biochronologically useful Chinle Group taxa (Figure 23.13): (1) *Metoposaurus bakeri*, known only from Otischalkian-age strata in West Texas; (2) *Buettneria perfecta*, known mostly from Otischalkian–Adamanian-age strata, though it occurs less frequently in Revueltian–Apachean-age strata; and (3) *Apachesaurus gregorii*, most common in Revueltian–Apachean-age strata, but also present less frequently in Otischalkian–Adamanian-age strata. Thus, the Otischalkian–Adamanian is an acme zone for *B. perfecta*, whereas the

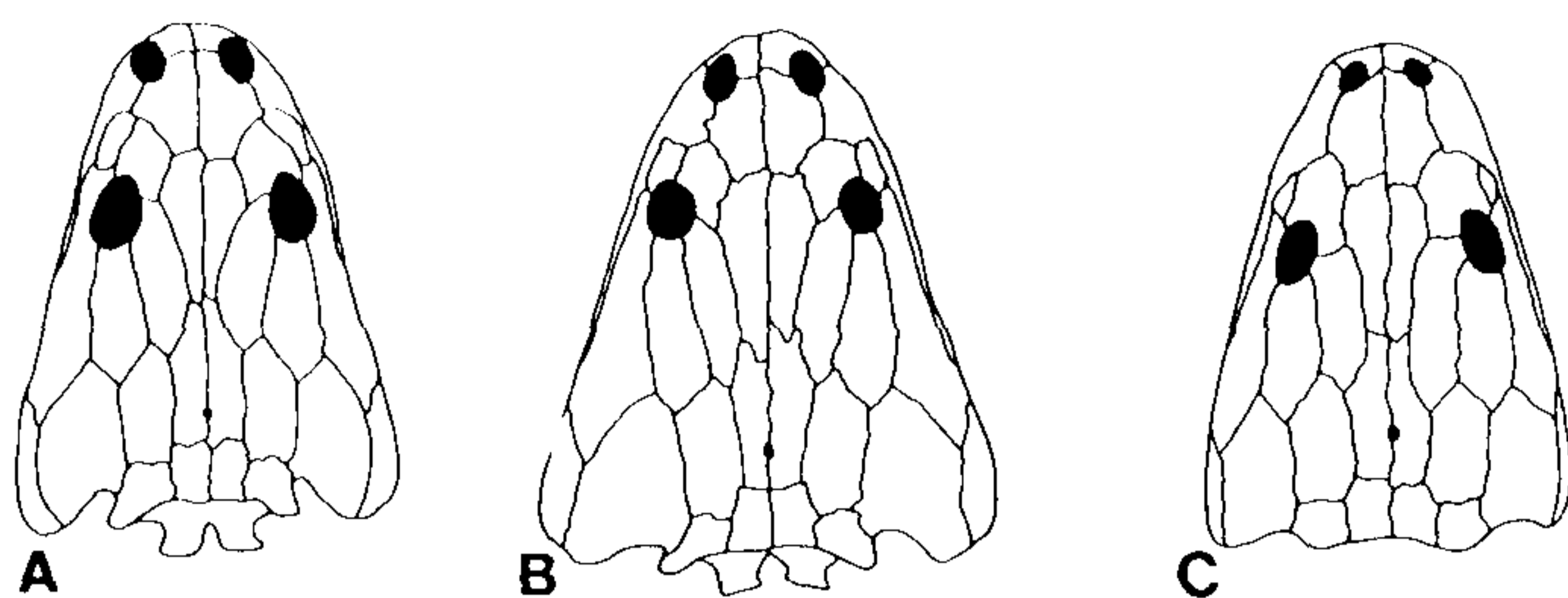


Figure 23.13. Dorsal skull roofs of Chinle Group metoposaurids: A, *Metoposaurus bakeri* Case; B, *Buettneria perfecta* (Case); C, *Apachesaurus gregorii* Hunt. Not drawn to scale. (From Hunt, 1993b, with permission.)

Revueltian–Apachean is an acme zone for *A. gregorii* (Hunt and Lucas, 1993a).

**Phytosauria.** The use of phytosaurs in Chinle Group biostratigraphy/biochronology has a long tradition (e.g., Camp, 1930; Gregory, 1957; Colbert and Gregory, 1957), and their fossils are abundant. Phytosaurs had a broad distribution across late Triassic Pangaea. Ballew (1989) most recently revised the taxonomy of the phytosaurs, and based on her revision five biochrons (Figure 23.12) can be defined using Chinle Group phytosaurs; for details, see Hunt (1991) and Hunt and Lucas (1991a, 1993a):

1. *Paleorhinus* biochron: *Paleorhinus* is the most primitive phytosaur. All Chinle Group occurrences of *Paleorhinus*, except its youngest occurrence in eastern Arizona,

are of Otischalkian age. *Paleorhinus* occurs in marine Tuvanian strata in Austria (Opponitzer Schichten), and its other occurrences (Figure 23.14) are generally considered to be of late Carnian age (Hunt and Lucas, 1991a). It provides important evidence of the Tuvanian age of the base of the Chinle Group and an important cross-correlation between Chinle Group nonmarine biochronology and the marine late Triassic SGCS. *Angistorhinus* co-occurs with *Paleorhinus* in the Chinle Group.

2. Overlap biochron of *Paleorhinus*, *Angistorhinus*, and *Rutiodon*: The oldest Chinle Group localities of Adamanian age in eastern Arizona and northern New Mexico produce rare *Paleorhinus* and *Angistorhinus* and more common *Rutiodon*.
3. The remainder of the Adamanian has produced only one phytosaur genus, *Rutiodon* (*sensu* Ballew, 1989).
4. Revueltian-age strata of the Chinle Group have produced only one phytosaur genus, *Pseudopalatus* (*sensu* Ballew, 1989). The German Stubensandstein of early–middle Norian age produces phytosaurs that Ballew (1989) identified as *Belodon*, *Mystriosuchus*, and *Nicrosaurus*. Some of those specimens appear to be congeneric with North American specimens she termed *Pseudopalatus*. This supports a Revueltian–Stubensandstein correlation and assignment of an early–middle Norian age to the Revueltian.
5. The youngest Chinle Group phytosaur, of Apachean age, is *Redondasaurus* (Hunt and Lucas, 1993b). This endemic taxon is the most evolutionarily advanced

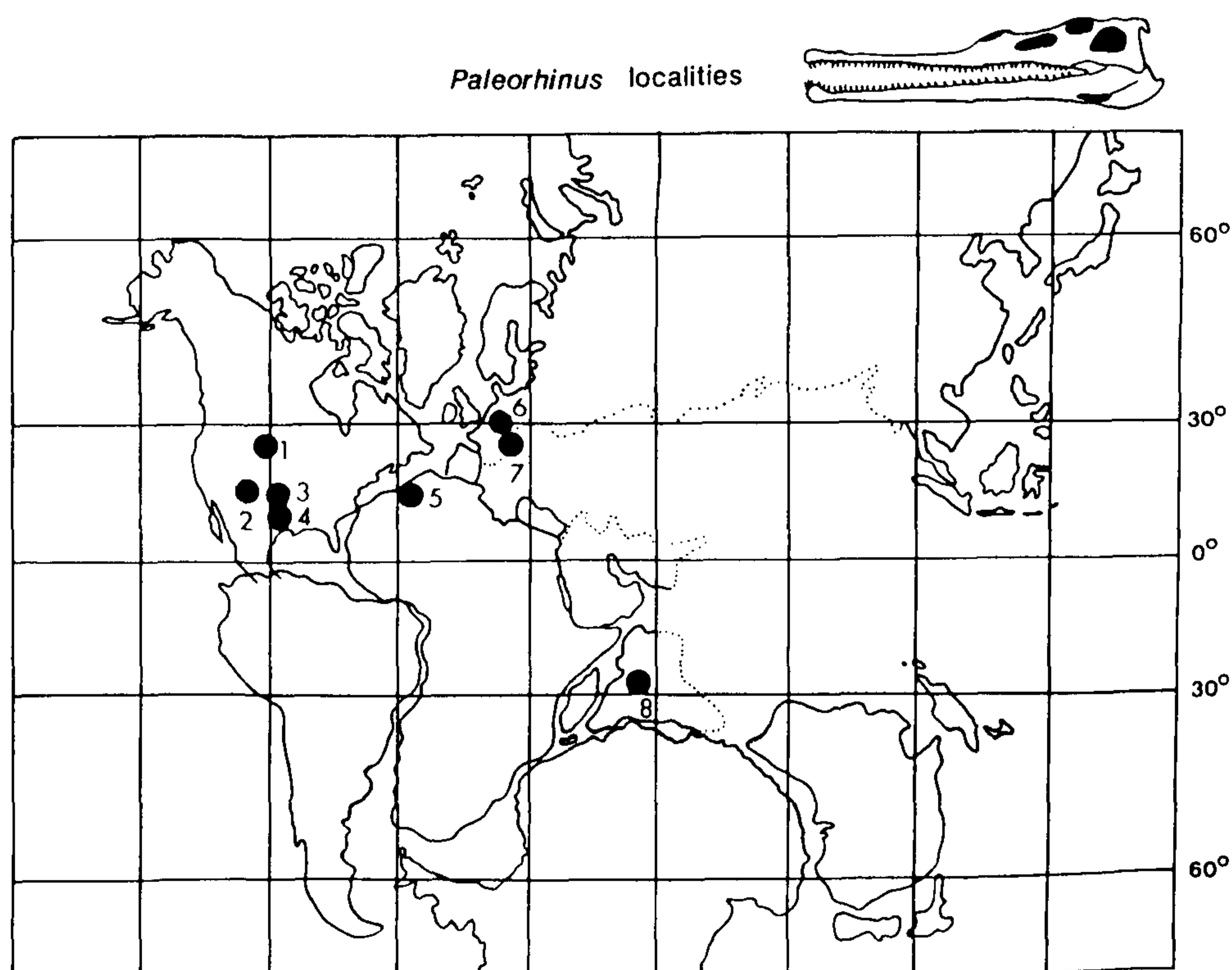


Figure 23.14. *Paleorhinus* localities of the late Triassic Pangaeon supercontinent: 1, Popo Agie Formation, central Wyoming, USA; 2, lowermost Blue Mesa member of Petrified Forest Formation, east-central Arizona, USA; 3, Camp Springs member of Dockum Formation, West Texas, USA; 4, Iatan member of Dockum Formation, West Texas, USA; 5, Argana Formation, Morocco; 6, Blasensandstein, Germany; 7, Opponitzer Schichten, Austria; 8, Maleri and Tiki formations, India.

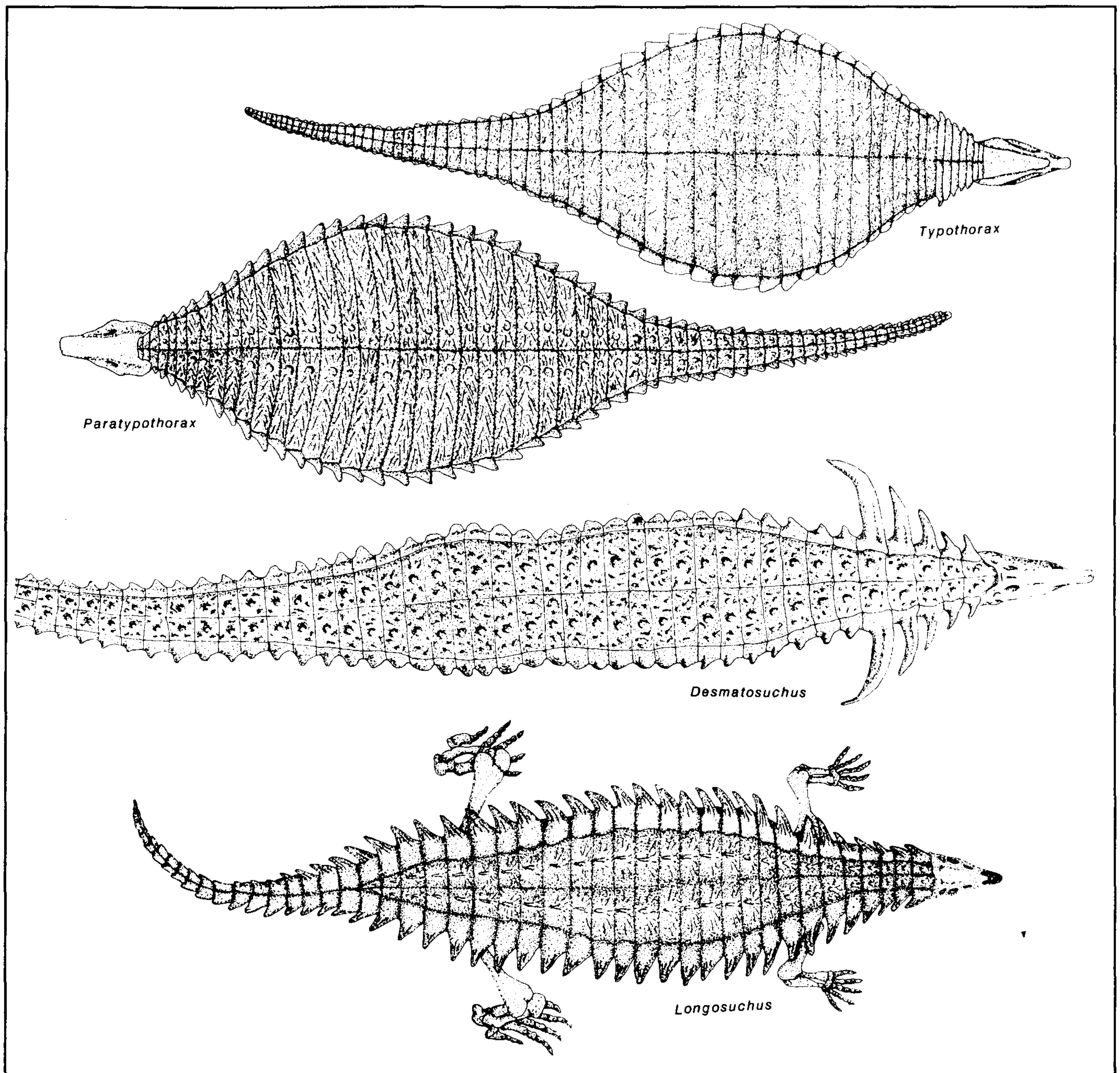


Figure 23.15. Some common Chinle Group aetosaurs (dorsal views of skeletons, not to scale). (Drawing by Randy Pence.)

phytosaur and thus suggests that the Apachean is of late Norian or Rhaetian age.

Hunt (1993a) has recently completed, but not yet published, a revision for the phytosaurs that somewhat alters the taxonomy of Ballew (1989). However, his taxonomy does not change the phytosaur-based biochronology and the correlations outlined here. The problems posed by phytosaurs as index fossils reside in the need to have a nearly complete phytosaur skull to arrive at

precise identification, thus rendering the vast majority of phytosaur fossils, which are isolated bones, teeth, and skull fragments, useless for correlation. Despite that, sufficient numbers of phytosaur skulls are known from the Chinle Group and elsewhere to continue their long-standing use in late Triassic tetrapod biochronology.

*Aetosauria.* Aetosaur fossils (Figure 23.15) are at least as abundant as phytosaur fossils in strata of the Chinle Group.

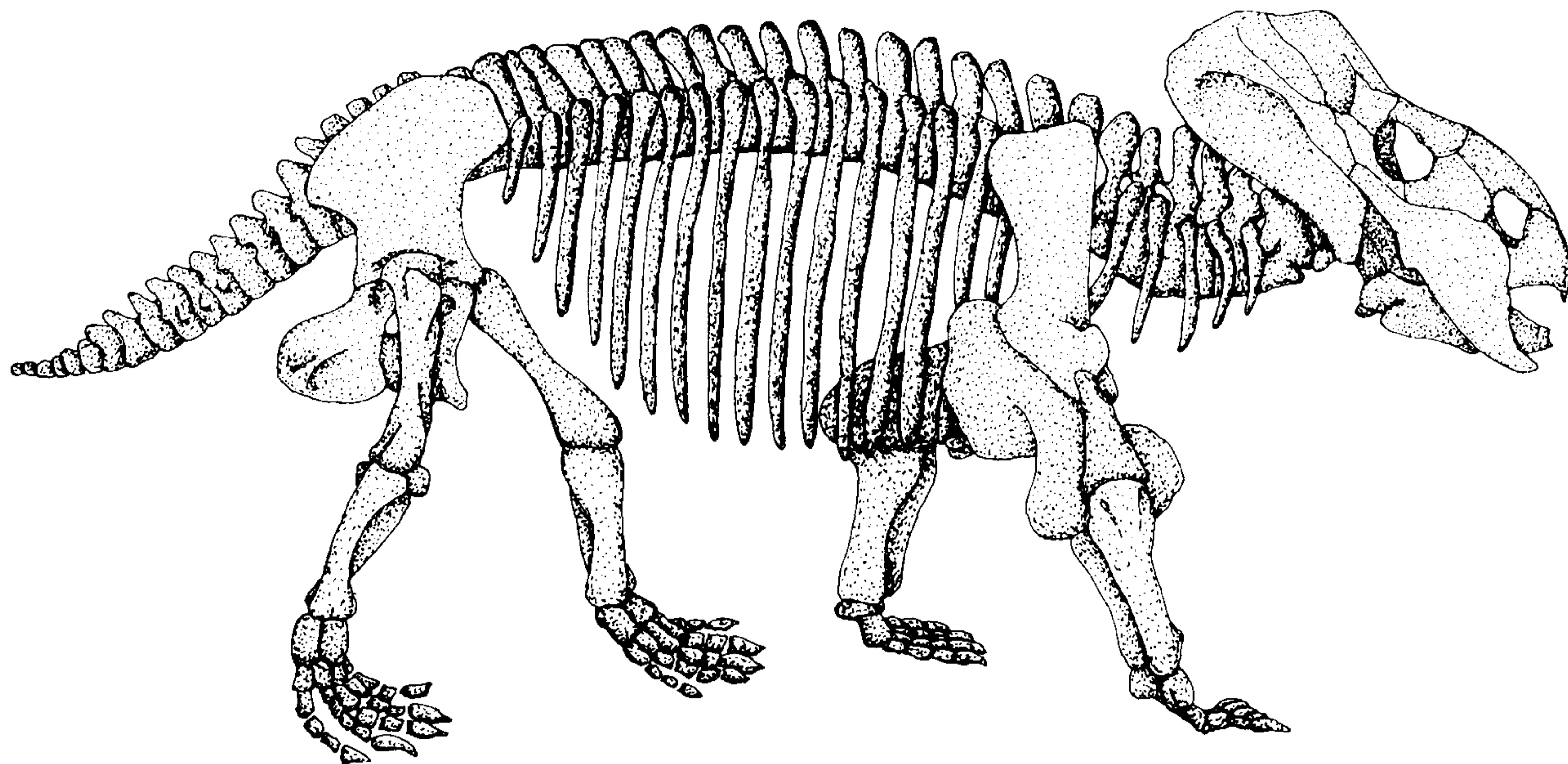


Figure 23.16. Skeletal reconstruction of the 2-m-long dicynodont *Placerias*. (Drawing by Randy Pence.)

Furthermore, a genus-level identification of an aetosaur can be made from an isolated armor plate or fragment of a plate. For example, the syntype specimens of *Typothorax coccinarum* Cope, a common upper Chinle Group aetosaur, are only fragments of paramedian plates, but they are diagnostic (Lucas and Hunt, 1992). Skulls are not needed; so aetosaurs provide index fossils that are much easier to identify than those of phytosaurs. Aetosaurs also had a broad distribution across late Triassic Pangaea, and some aetosaur genera found in the Chinle Group (i.e., *Longosuchus*, *Stagonolepis*, *Desmotosuchus*, and *Paratypothorax*) are also known from the Newark Supergroup and/or western Europe. Aetosaurs thus provide an important basis for correlating Chinle Group strata and other nonmarine late Triassic strata.

Six aetosaur biochrons can be identified in the Chinle Group (Figure 23.12):

1. *Longosuchus* biochron: *Longosuchus* is of Otischalkian age and co-occurs in the lowermost Chinle Group with *Desmotosuchus*, a co-occurrence also documented in the late Carnian Pekin Formation of the Newark Supergroup (Hunt and Lucas, 1990).
2. *Stagonolepis* (= *Calyptosuchus*) biochron: *Stagonolepis* is confined to strata of Adamanian age in the Chinle Group. It is also known from the late Carnian Lossiemouth Sandstone of Scotland (Hunt and Lucas, 1991b).
3. *Paratypothorax* biochron: *Paratypothorax* in the Chinle Group ranges in age from Adamanian to Revueltian (Hunt and Lucas, 1992a). In Germany it has a shorter temporal range, being known only from the early Norian Lower Stubensandstein (Long and Ballew, 1985).

4. *Desmotosuchus* biochron: *Desmotosuchus* ranges in age from Otischalkian to early Revueltian in the Chinle Group.
5. *Typothorax* biochron: This endemic Chinle Group aetosaur is of Revueltian age.
6. *Redondasuchus* biochron: This endemic Chinle Group taxon (Hunt and Lucas, 1991c) is of Apachean age.

*Dicynodonts.* Non-archosauromorph reptiles and mammals are rare in the Chinle Group, with the exception of the dicynodont *Placerias* (Figure 23.16). The Chinle Group dicynodonts are *Placerias hesternus* (= *P. gigas*) and cf. *Ischigualastia* sp. *Placerias* is known from Otischalkian–Adamanian strata in Arizona and Wyoming, whereas the possible *Ischigualastia* is known from earliest Adamanian strata in New Mexico (Lucas and Hunt, 1993a). *Placerias* (= *Mohgreberia*) is also known from the Pekin Formation of North Carolina and the Argana Formation of Morocco. Its occurrences in Wyoming, Arizona, North Carolina, and Morocco define a *Placerias* biochron of late Carnian age. The possible *Ischigualastia* in the Chinle Group suggests a possible direct correlation to Argentinian and Brazilian strata of late Carnian age that contain this large dicynodont (Cox, 1965; Araujo and Gonzaga, 1980; Rogers et al., 1993).

*Tetrapod footprints.* Tetrapod footprints are abundant in the uppermost strata of the Chinle Group, stratigraphic interval D (Hunt and Lucas, 1992b). Only a handful of tetrapod footprints are known from older Chinle Group strata (Hunt et al., 1993a); so they are of no biostratigraphic/biochronologic significance.

The tetrapod ichnofauna of stratigraphic interval D is dominated by the ichnotaxa *Brachychirotherium*, *Grallator*, *Pseudotet-*

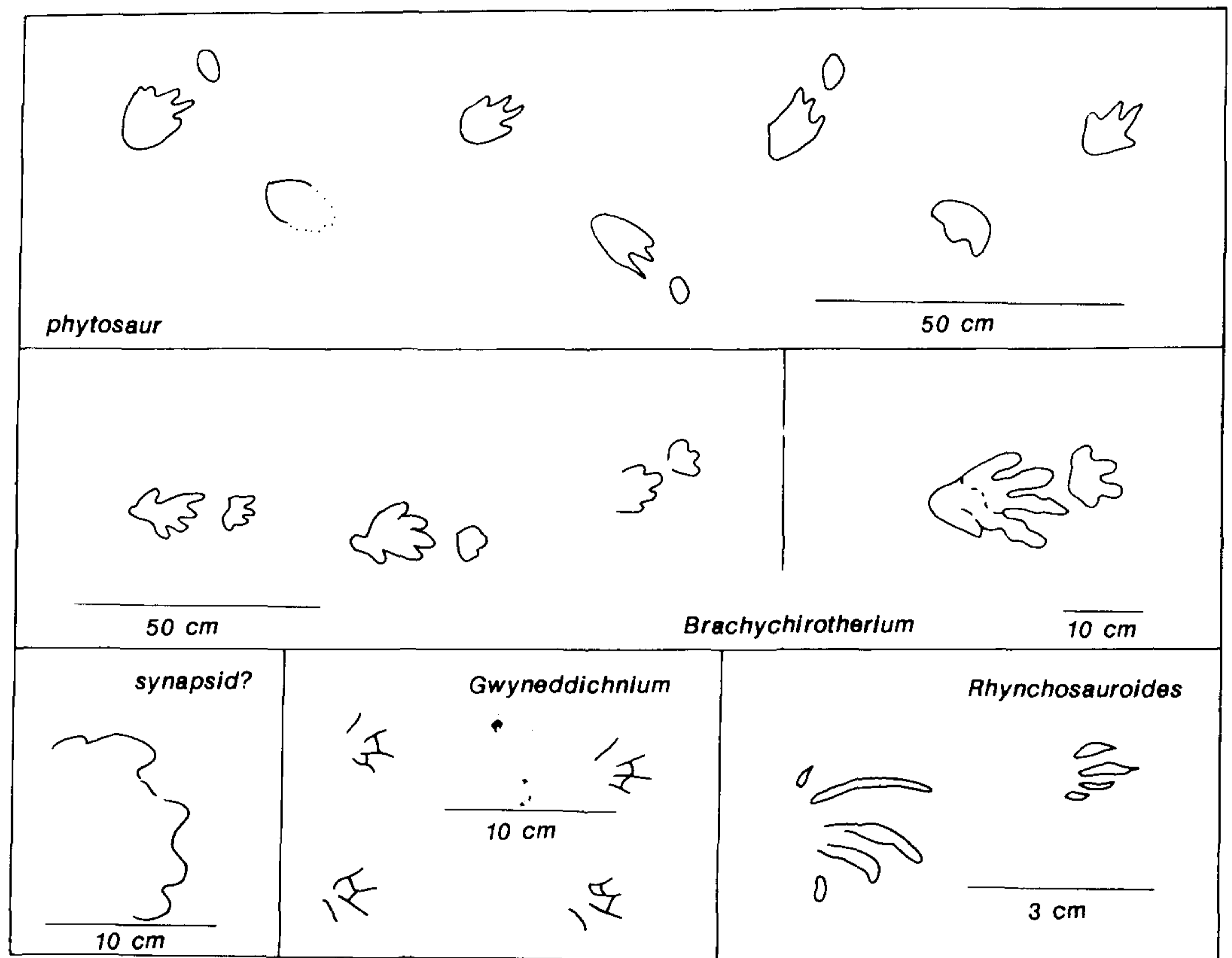


Figure 23.17. Characteristic Chinle Group tetrapod footprints from stratigraphic interval D.

(after Lockley)

*rasauropus*, *Tetrasauropus*, and *Gwyneddichnium* (e.g., Lockley et al., 1992; Hunt et al., 1989, 1993a,b) (Figure 23.17). These footprints provide a basis for intra-Chinle correlation of strata of interval D in Wyoming, Utah, Colorado, New Mexico, and Oklahoma. They also indicate a late Triassic age, by comparison with tetrapod-footprint assemblages in eastern North America, Europe, and South Africa. Most significant is the prosauropod footprint *Tetrasauropus*. Prosauropod footprints are also known from the lower Elliott Formation (lower Stormberg Group) of South Africa (Ellenberger, 1970; Olsen and Galton, 1984) and marginal marine strata of Rhaetian age in Switzerland (Furrer, 1993). Their distribution may define a *Tetrasauropus* biochron of Rhaetian age recognizable across much of Pangaea.

#### Chinle Group geochronometry and magnetostratigraphy

Large numbers of radiometric age determinations have been reported from Chinle Group rocks, mostly from uranium ores on the Colorado Plateau (e.g., Miller and Kulp, 1963; Young, 1964; Stewart et al., 1986; Ash, 1992). Those ages are either too young or too old (well outside the 230–200-Ma time span within which Chinle Group deposition falls by any numerical time scale). Most of the Chinle Group contains mudstones and sandy mudstones rich in volcanic detritus, consisting of rounded grains of altered tuff, lava fragments, euhedral biotite, sanidine, and plagioclase

(Allen, 1930; Waters and Granger, 1953; Cadigan, 1963; Schultz, 1963). Basal conglomerates of the Chinle Group also contain local deposits of a few pebbles and cobbles of volcanic rocks (Stewart et al., 1972; Dodge, 1973). Little effort has been made to obtain numerical ages from this volcanic detritus. It may hold promise for direct numerical calibration of Chinle Group deposition.

Molina-Garza et al. (1991, 1993) summarized the published Chinle Group magnetostratigraphy, which has largely been undertaken on outcrops in New Mexico. Their cumulative magnetostratigraphy for the Chinle Group (Figure 23.18) will be evaluated further by ongoing and unpublished research by D. Bazard, D. Kent, M. Steiner, and others. Rocks of the Chinle Group have characteristic well-defined high-temperature magnetizations carried by hematite. These are early acquired chemical-remnant magnetizations that identify Chinle Group strata as reliable sources of late Triassic magnetic-polarity history (Bazard and Butler, 1991; Molina-Garza et al., 1991, 1993).

#### A nonmarine standard

As a first step toward developing more precise correlations of nonmarine Triassic strata, we need to consider those stratigraphic sections that can serve as standards from which to correlate other sections, and then ultimately correlate those standards to the marine SGCS. Such standards can then serve as

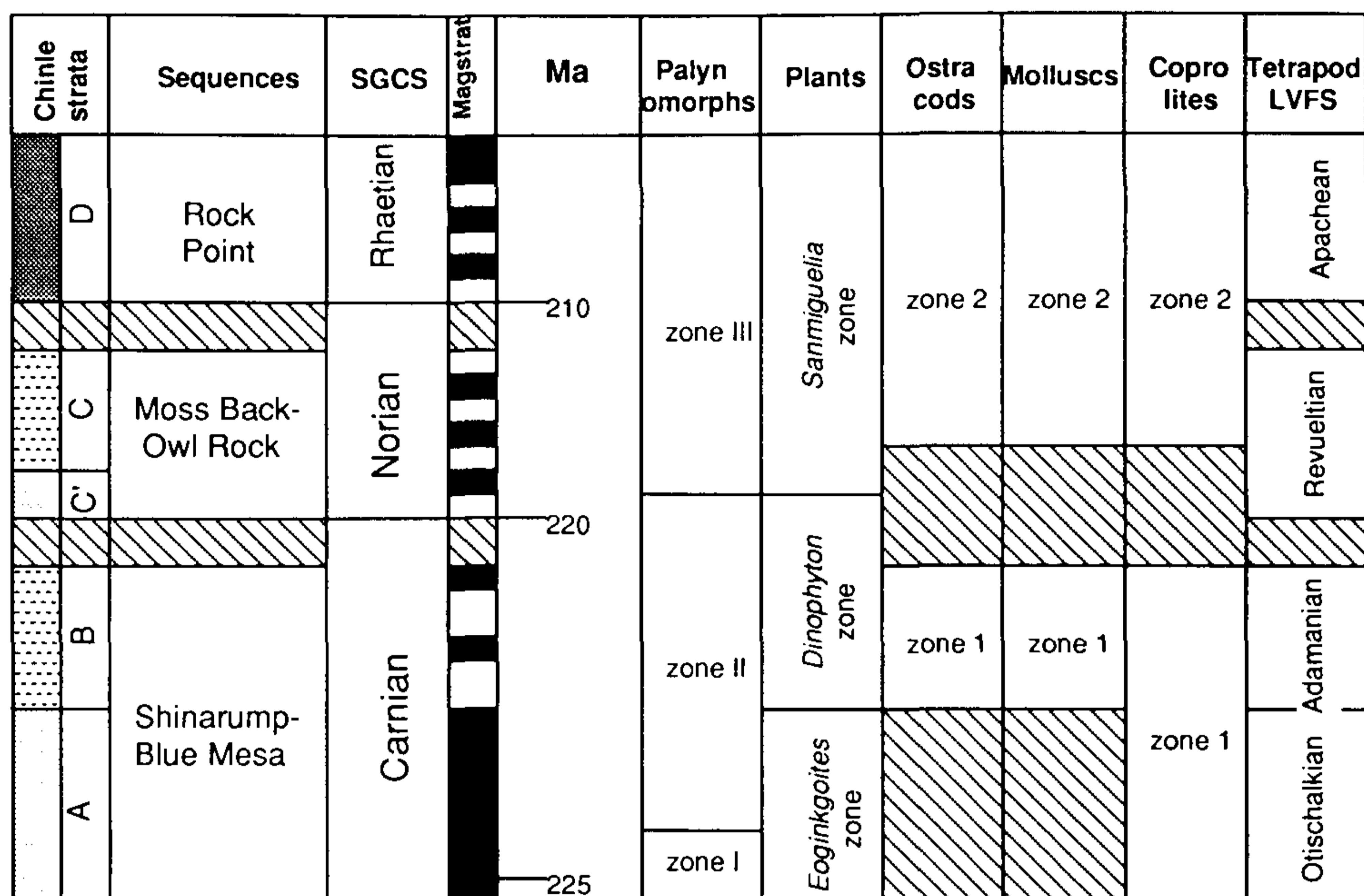


Figure 23.18. Summary of Chinle Group lithostratigraphy, biostratigraphy/biochronology, and magnetostratigraphy (numerical time scale from Harland et al., 1990).

the hubs of correlation networks for nonmarine Triassic strata. Ultimately, when it comes time to establish GSSPs (global stratotype sections and points) for the important nonmarine intervals of Triassic time, they will most likely be in the standard sections.

To establish standard sections, we must have strata that meet the following criteria: (1) extensive outcrops, (2) ready accessibility, (3) abundantly and diversely fossiliferous, (4) amenable to dating methods other than biochronology (i.e., geochronometry, magnetostratigraphy), and (5) complete temporal representation. The Chinle Group certainly has an extensive outcrop area (Figure 23.1). Most Chinle Group outcrops are on lands owned by the U.S. government, ensuring continuous access. Such access is by paved roads or all-weather unpaved roads to most outcrops. The foregoing summary indicates the abundance, diversity, and biostratigraphic/biochronologic utility of Chinle Group fossils (Figure 23.18). The chemical-remnant magnetizations of Chinle Group rocks faithfully record part of late Triassic magnetic-polarity history, and the abundant volcanic detritus in much of the Chinle Group may represent unrealized potential for radiometric dating.

Despite these great advantages as a standard, the Chinle Group does not represent all of late Triassic time. That is its greatest drawback as a standard. No early Carnian time is represented, and the two intragroup unconformities (Figures 23.5 and 23.18) are definite hiatuses of uncertain duration. Furthermore, most of the Chinle deposition was by fluvial processes, which produced strata riddled with numerous hiatuses of varying duration. Such incompleteness is typical of most Upper Triassic nonmarine sequences, and the Chinle Group has superior temporal representation when compared with them. An exception to this is the Newark Supergroup, in eastern North

America, which contains thick sequences of lacustrine strata that record more of late Triassic time than do Chinle Group strata. Yet, in regard to most other criteria (extent of outcrop, accessibility, fossil record), the Newark Supergroup is vastly inferior to the Chinle Group. Thus, in most respects the Chinle Group is an ideal nonmarine standard for late Triassic time, although it does not record all of the late Triassic.

### Summary

Nonmarine Upper Triassic strata of the Chinle Group are exposed over a 2.3-million km<sup>2</sup> outcrop area in the western United States (Idaho, Wyoming, Utah, Nevada, Colorado, Oklahoma, Texas, New Mexico, and Arizona). Chinle Group strata were deposited during most of the late Triassic (late Carnian–Rhaetian) in a single depositional basin (Chinle Basin) with a regional palaeoslope down to the west-northwest. The Chinle Group is as much as 600 m thick and consists of fluvial, lacustrine, and minor eolian facies of siliciclastic sediments that are mostly redbeds. Chinle Group fossils have been collected for more than 140 years and include palynomorphs, megafossil plants, charophytes, invertebrate trace fossils, ostracods, conchostracans, insects, decapod crustaceans, bivalves, gastropods, tetrapod footprints, fishes, and tetrapod-body fossils. Magnetostratigraphic characterization of many Chinle Group intervals has been undertaken, but Chinle volcanic detritus has not provided reliable syn-depositional numerical ages.

Lithostratigraphy supported by diverse biostratigraphy provides a precise correlation of Chinle Group strata across their outcrop belt. This correlation identifies three intragroup depositional sequences bounded by basinwide unconformities. The two older sequences have a genetic relationship to late Carnian–

middle Norian marine shelfal rocks in northwestern Nevada. This relationship allows selected late Triassic ammonite zones to be correlated to Chinle Group strata. Nonmarine biochronology, especially of palynomorphs, megafossil plants, and tetrapod vertebrates, and magnetostratigraphy indicate that the oldest Chinle strata are of late Carnian (Tuvanian) age. Younger Chinle Group strata are of early Norian–Rhaetian age. The Chinle Group has an extensive outcrop area, is relatively thick, and is very accessible. However, it does not represent all of late Triassic time – no early Carnian (Julian) strata are present, and the two intragroup unconformities represent hiatuses of unknown duration. Nevertheless, its extensive fossil record, replicatable magnetostratigraphy, and potential for numerical age dating make the Chinle Group an excellent standard for correlation of the nonmarine Upper Triassic strata of Pangaea.

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