

THE TETRAPOD-BEARING CONTINENTAL TRIASSIC SEDIMENTS OF SOUTH AMERICA

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ABSTRACT. The Triassic period marked one of the most important transitions in the history of tetrapods: the change from a therapsid dominated fauna to one dominated by archosaurs. Yet because of a general lack of sediments representing the transitional period, documentation of the change has been difficult and controversial. The recent discoveries of highly fossiliferous sequential continental strata in western Argentina together with the previously known sediments of Brazil and East Africa may hold the key for documenting this transition. Interpretation of the new discoveries is still unsettled, but it is apparent that part and perhaps most of the Middle and Upper Triassic is represented. Differences of opinion about correlation exist between and among geologists and paleontologists, depending on the emphasis given to vertebrate remains, fossil plants, and regional stratigraphy. More field studies and fossil discoveries are needed to evaluate accurately the temporal position of the sediments.

INTRODUCTION

The Triassic constitutes one of the more enigmatic chapters in the history of tetrapod evolution. Early Triassic faunas were essentially continuations of Late Permian mammal-like reptile and amphibian faunas with the addition of a few primitive archosaurs. In contrast, the Late Triassic was marked by the first stage of the great archosaur radiation that was to dominate the remainder of the Mesozoic. Tetrapod-bearing sediments of definite Middle Triassic age are lacking in most parts of the world or are represented only by marine strata. As the early and late faunas are radically different from each other, this serious gap in our knowledge of terrestrial life has veiled one of the major events in tetrapod evolution.

Although continental deposits, bearing faunas in part intermediate between the Early and Late Triassic assemblages, have long been known—for example, Manda, Maleri, Elgin, and Santa Maria Formations—these are relatively isolated in terms of vertical and horizontal continuity, making correlation difficult and long a matter of dispute. The recent discoveries in Argentina of sequential tetrapod-bearing sediments representing at least part, and perhaps most, of the Middle Triassic promises to provide the key for documenting the faunal transition of the “Triassic interregnum”. Unfortunately, translation of the biological information into a time sequence to match the European or Tethyan type areas is still a matter of discussion. There is some disagreement between and among paleozoologists, paleobotanists, and geologists regarding the interpretation of the South American Triassic. But it is a dynamic disagreement, serving to stimulate further study and exploration. Because of the potential importance of the South American Triassic in resolving the long-standing problem of the therapsid-to-archosaur transition, and because of the divergent interpretations of the new discoveries, a review and synthesis of current work is desirable.

THE TECTONIC FRAMEWORK

The South American basins of terrestrial sedimentation owe their origin to the interplay of major tectonic units that date from the Precambrian. According to Herrero Ducloux (1963) and Harrington (1962) these units constitute the rather simple structural framework of the continent, which consists of three major elements: (1) the Precambrian shields of Brazil and the Guianas, (2) the transitional area between the shields and the geosyncline, and (3) the mobile geosynclinal belt on the west coast. Until recently the Pampean and Patagonian massifs of Argentina were included in the Precambrian structural framework of South America. However, detailed geological work and numerous radiometric dates have shown that all the crystalline rocks in Argentina previously considered Precambrian are in reality of Paleozoic or Mesozoic age (Stipanovic and others, 1968; and Stipanovic and Linares, oral commun.) Continental sedimentation occurred in basins formed in the shield areas or in troughs formed by tectonic movements along the transitional zone between the shields and the geosynclinal belt (see Kummel and Fuchs, 1953, for a summary of Triassic sedimentation in South America). At the close of the Paleozoic nearly all South America was emergent. Well developed structural basins were present on the Precambrian shield in the Paraná and Parnaíba (and probably Amazon) regions. These were essentially continuations of basins that had existed since the early Paleozoic. At the northern and western edges of the shield a downwarping of the transitional area gave rise during the Triassic to the Roraima Basin of northern Brazil, which extended into parts of Colombia, Venezuela, and the Guianas. In western Argentina intermontane basins of late Paleozoic age continued into the Triassic in some areas, with numerous new basins developing at various times throughout the period.

In the Middle Triassic a minor transgression of the sea from the west produced marine deposits near the Argentine-Chilean border (Corvalán-Díaz, 1965), and the resultant subsidence may have been responsible for the fresh-water swamp deposits in the Mendoza area of Argentina.

During the late Triassic there was a widespread transgression of the sea, extending from central Peru north to Colombia and south to Bolivia. This produced a mixed continental-marine facies in the Roraima Basin but apparently did not reach eastern Peru (Kummel and Fuchs, 1953).

Volcanic activity was almost continuous throughout the Triassic, consisting largely of acidic and mesosilicic lava flows and associated tuffs (Stipanovic, 1957). The vast Serra Geral basaltic flows of Brazil, Argentina, Uruguay, and Paraguay are no longer considered Triassic, recent radiometric dating having established a Cretaceous age for most of the series and Late Jurassic for the remainder (Stipanovic, 1967a; McDougall and Rüegg, 1966).

Of the various areas of continental Triassic sedimentation, tetrapod remains are found only in the Paraná Basin and in the western Argentinian localities. The other areas, located along the transitional belt, consist of apparently unfossiliferous units of sandstones, conglomerates, and

arkoses.¹ Fish fragments representing the genera *Lepidotus* and *Semionotus* have been found in the Roraima and Parnaíba basins, and tetrapod footprints have been reported from the latter area (Maury, 1934).

TETRAPOD-BEARING AREAS

The Paraná Basin represents a large intracratonic depression covering southern Brazil and parts of Uruguay, Argentina, and Paraguay. The area was apparently an active basin of continental deposition throughout most of the Paleozoic and Mesozoic. Triassic sediments are represented by the Santa Maria and perhaps by parts of the Botúcatú members of the Sao Bento Series. Outcrops of these extend in a narrow east-west arc across the southern part of the state of Rio Grande do Sul. The Santa Maria consists of a lower unit composed mainly of sandstone with some red shales in the upper part and an upper unit of red shale and mudstone with some crossbedded sandstone lenses. The Botúcatú is a well-sorted crossbedded sandstone of aeolian origin. Its relation to the Santa Maria is not clear; in some areas it is apparently conformable, but in others it is unconformable on the Santa Maria and intertongues with Jurassic lavas of the Serra Geral. It may represent a long period of accumulation in a desertic environment. However, there may be a misinterpretation of sedimentary units; the conformable sandstone on the Santa Maria may actually be a sandstone unit of the Santa Maria rather than part of the Botúcatú depositional regime. Recently Padula and Mingramm (oral commun.) considered the Botúcatú to be unrelated to Triassic sedimentary history. Fossil vertebrates are found only in the Santa Maria; this unit was the major, and indeed practically the only, source of Triassic tetrapods in South America until recent years (see Colbert, 1952). Fossil plants of the *Dicroidium* flora are found in the lower unit of the Santa Maria (see table 2). Tetrapod fossils are known only from a limited number of localities in the shales and mudstones of the upper unit (see table 1). A few invertebrates are also known from the Santa Maria: the crustaceans *Euestheria*, *Estherites*, and *Estheriina*, and the insect *Sanctipaulus* (Pinto, 1956). The major tetrapod discoveries were made by von Huene during his expedition of 1928-29, and his descriptive work has been the basis for most of the interpretation of South American Triassic reptiles. No fish or amphibians have been found in the Santa Maria, a fact that, together with the nature of the sediments, suggests an upland environment.

In Argentina continental basins now considered to be of Triassic age have been known since the turn of the century (Bodenbender, 1896, 1897, 1911; Stappenbeck 1910; et cetera); although the interpretation of age has varied considerably. However, with the exception of the fossils from the Cacheuta basin, described by Cabrera (1944) and Rusconi (1947, 1948, 1951), and the therapsid fragments discovered in the Ischigualasto region (Cabrera, 1943) little vertebrate paleontological work was done

¹It seems quite possible that the unfossiliferous nature of these sediments is due to a lack of exploration by vertebrate paleontologists. There are unverified word-of-mouth reports of fossil vertebrates in the Roraima area.

in the area until 1958. In that year the highly fossiliferous nature of the deposits at Ischigualasto was recognized, and this in turn led to a vigorous and continuing interest in the region that has resulted in the discovery of a number of new fossil localities, Chañares, Puesto Viejo, Los Colorados, El Tranquilo, et cetera (see table 1).

TABLE 1

Triassic tetrapods of South America*

Santa Maria, Brazil

Santa Maria area

- Cynodontia: *Gomphodontosuchus*
 Thecodontia: *Hoplitosuchus*; *Rauisuchus*; *Rhadinosuchus*
 Saurischia: *Staurikosaurus*
 Rhynchocephalia: *Scaphonyx*

Chiniquá area

- Cynodontia: *Chiniquodon*; *Belesodon*; *Traversodon*
 Thecodontia: *Prestosuchus*; *Procerosuchus*
 Saurischia: *Spondylosoma*
 Dicynodontia: *Stahleckeria*; *Dinodontosaurus*

Candelaria area

- Procolophonia: *Candelaria*
 Thecodontia: *Cerritosaurus*
 Saurischia: gen. indet.
 Dicynodontia: *Dinodontosaurus*; *Barysoma*

Ischigualasto Basin, Argentina

Los Colorados Formation

- Dicynodontia: c.f. *Ischigualastia*
 Saurischia: *Riojasaurus*; *Strenusaurus*
 Thecodontia: *Neoaetosauroides*; *Riojasuchus*; *Pseudohesperosuchus*
 Crocodylia: *Hemiprotosuchus*
 Tritylodontoidea: c.f. *Tritylodon*

Ischigualasto Formation

- Capitosuroidea: *Promastodontosaurus*
 Cynodontia: *Chiniquodon*; *Exaeretodon*; *Proexaeretodon*; *Ischignathus*
 Dicynodontia: *Ischigualastia*
 Thecodontia: *Saurosuchus*; *Aetosauroides*; *Argentinosuchus*
 Saurischia: *Herrerasaurus*; *Triassoolestes*; *Ischisaurus*
 Crocodylia: *Proterochampsa*
 Ornithischia: *Pisanosaurus*
 Rhynchocephalia: *Scaphonyx*

Los Rastros Formation

- Ichneutes: *Rigalites*

Chañares Formation (? = Ischichuca)

- Cynodontia: *Probelesodon*; *Massetognathus*; 3 gen. indet.
 Dicynodontia: *Dinodontosaurus*; *Chanaria*
 Thecodontia: 6 gen. indet.

Tarjados Formation

- Dicynodontia: gen. indet.

Cacheuta Basin, Argentina

Cacheuta Formation

- Brachiopoda: *Pelorocephalus*
 Thecodontia: *Cuyosuchus*

Potrerillos Formation

- Cynodontia: *Colbertosaurus*

Las Cabras Formation

- Cynodontia: *Andescynodon*
 Dicynodontia: *Vinceria*

TABLE 1 (continued)

Other localities, Argentina

Puesto Viejo Formation

Cynodontia: *Cynognathus*; *Pascualgnathus*Dicynodontia: *Kannemeyeria*

Las Higueras Formation

Icnites: *Chirotherium*

El Tranquilo Formation

Saurischia: *Plateosaurus*

* Based on: Bortoluzzi and Barbarena (1967), Casamiquela (1967a, b, personal commun.), Cox (1965, 1968), Romer (1966, 1967, oral commun.), Bonaparte (1966, oral commun.), Colbert (oral commun.).


The geologic setting of the Argentine Trias is usually interpreted as a number of small intermontane basins located along the margins of the Pampean Massif, the transitional area, and even one or two within the geosynclinal zone (Stipanovic, 1967a; Groeber and Stipanovic, 1953; Harrington, 1962). Some of the areas were active from the Carboniferous through the Triassic while others came into existence only during the latter part of the Early Mesozoic. Geologic relationships were complicated by the breaking up of the massif and cordillera by Tertiary faulting, forming numerous mountain blocks differentially uplifted and downfaulted. This has made it difficult to determine the nature and extent of sedimentation within the basins. It is possible that there were originally one or two large sedimentary basins in the area rather than numbers of small ones. Stipanovic (1957, 1967b) lists eight different basins of deposition, containing twelve fossiliferous formations. Of these, the Cacheuta, Ischigualasto, Marayes, Barreal, and San Luis regions show distinct basin development consisting of a basal conglomerate-sandstone, an intermediate stage of shales, fine clays, and coal beds, followed by a later stage of typical red beds. Vertebrate fossils have been found only in the Ischigualasto and Cacheuta Basins, in which the following formations are recognized:

Cacheuta Basin

4. Rio Blanco — red claystones and sandstones, no fossils
3. Cacheuta — clays, coal seams, fossil plants, reptiles, amphibians, fish
2. Potrerillos — shales, tuffs, fossil plants, reptiles, fish
1. Las Cabras — red "fanglomerate", conglomerate, fossil plants, reptiles

Ischigualasto Basin

6. Los Colorados — red sandstone, fossil reptiles
5. Ischigualasto — white claystones, tuffs, fossil plants, reptiles, amphibians
4. Los Rastros — shales, sandstone, coal seams, fossil plants
3. Los Chañares — clays, tuffs, fossil reptiles
2. Tarjados — basal sandstone-conglomerate, shale, fossil plants, reptiles

- 
1. Talampaya — sandstones

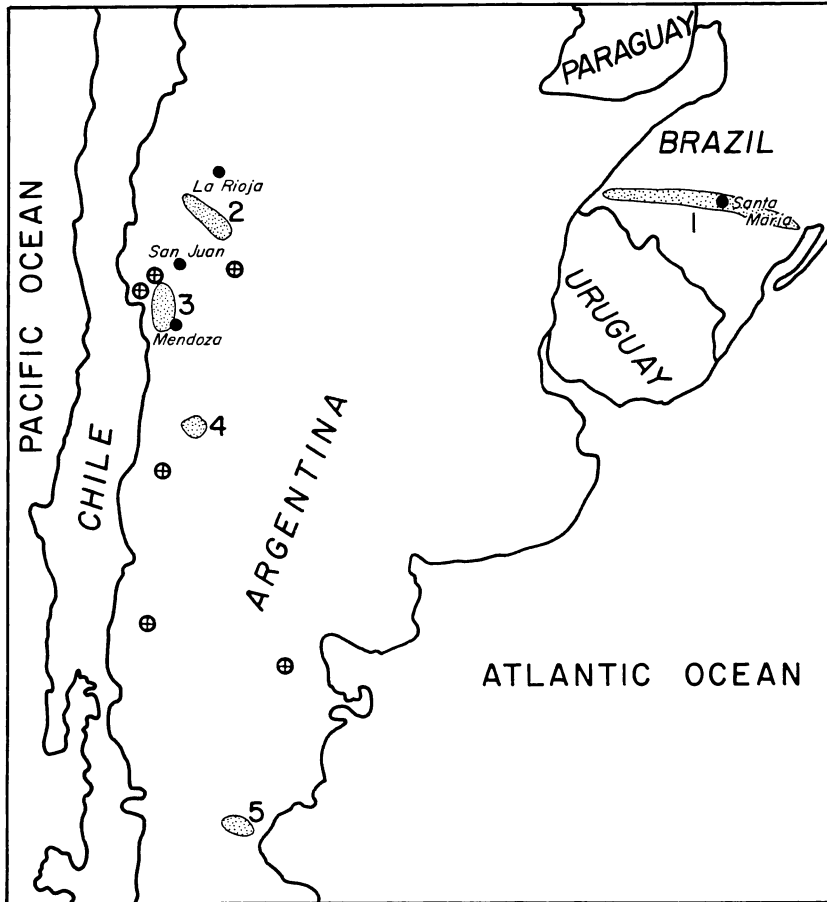


Fig. 1. Map showing Triassic tetrapod localities. 1. Santa Maria; 2. Ischigualasto; 3. Cacheuta; 4. Puesto Viejo; 5. El Tranquilo. Crossed circles represent additional localities where only fossil plants are found. (See Stipanovic, 1967b, for more details.)

Two other localities, not part of definable basins, have also produced vertebrate remains: the Puesto Viejo Formation south of the Cacheuta Basin and the El Tranquilo Formation in southwestern Patagonia. Fossil plants of the *Dicroidium* flora are known from six additional localities at which vertebrate fossils are not found (see fig. 1 and table 2).

CORRELATION OF THE SOUTH AMERICAN TRIASSIC

None of the South American vertebrate-bearing sediments are definitely synchronous. Different approaches to the relationships of these basins and formations to each other and to Triassic deposits in other parts of the world have, not unexpectedly, resulted in various interpretations regarding age and lateral equivalency. Current interpretation of the Argentine and Brazilian Triassic is summarized in figure 2.

TABLE 2

Triassic flora of South America
associated with vertebrate-bearing sediments*

Santa Maria, Brazil

Cycadophyta: *Dicroidium*; *Thinnfeldia*; *Pteruchus*; *Pachypteris*; *Sewardia*;
Samaropsis
Sphenopsida: *Schizoneura*; *Neocalamites*
Coniferophyta: *Baiera*; *Stenorhachis*

Ischigualasto Basin, Argentina

Ischigualasto Formation

Sphenopsida: *Neocalamites*
Coniferophyta: *Protomuniperoxylon*

Los Rastros Formation

Cycadophyta: *Dicroidium*; *Xylopteris*; *Yabeiella*; *Cycadocarpidium*;
Cardiopteridium
Coniferophyta: *Podozamites*
Sphenopsida: *Neocalamites*; *Phyllothea*
Pterophyta: *Cladophlebis*

Ischihuca Formation (? = Chañares)

Sphenopsida: *Neocalamites*
Cycadophyta: *Dicroidiopsis*

Cacheuta Basin, Argentina

Cacheuta Formation

Sphenopsida: *Neocalamites*
Cycadophyta: *Dicroidium*; *Dicroidiopsis*; *Xylopteris*; *Yabeiella*;
Cycadocarpidium
Coniferophyta: *Podozamites*; *Sphenobaiera*

Potrerillos Formation

Sphenopsida: *Neocalamites*; *Equisetites*; *Phyllothea*
Pterophyta: *Sphenopteridium*; *Cladophlebis*; *Desmiophyllum*
Cycadophyta: *Thinnfeldia*; *Xylopteris*; *Yabeiella*; *Dicroidium*; *Pteruchus*;
Fanerothea; *Feruglia*; *Cycadocarpidium*
Coniferophyta: *Podozamites*; *Czekanowskia*; *Baiera*; *Sphenobaiera*;
Phoenicopsis; *Ginkgoites*; *Stachyopitys*; *Desmiophyllum*;
Noeggerathiopsis; *Fraxinopsis*; *Callipteridium*
Caytoniales: *Sagenopteris*

Las Cabras Formation

Sphenopsida: *Neocalamites*
Pterophyta: *Cladophlebis*
Cycadophyta: *Dicroidium*; *Dicroidiopsis*; *Xylopteris*; *Taeniopteris*; *Nilssonia*

Other localities, Argentina

El Tranquilo Formation

Cycadophyta: *Dicroidium*; *Yabeiella*; *Linguifolium*

* Based on: Bortoluzzi and Barbarena (1967) Stipanovic (1957, 1967b, personal commun.), Jain and Delevoryas (1967).

Stipanovic (1957, 1967a, b; Groeber and Stipanovic, 1953) interpreted the Triassic sediments largely on the basis of cumulative field studies, stratigraphic relationships of igneous rocks, and paleobotanical evidence. He divided the Argentine Trias (fig. 3) into four groups: (1) a basal igneous complex dated radiometrically at 225 ± 20 m.y., (2) at another

		LOWER		MIDDLE		UPPER			
		SCYTHIAN		ANISIAN	LADINIAN	CARNIAN	NORIAN		
		"A" FAUNA		"B" FAUNA		"C" FAUNA		FAUNAL ZONES, ROMER	
		PUERTO-VIEJESE		CHAÑARENSE		ISCHI-GUALASTENSE	COLORADENSE	PROV. AGES, BONAPARTE	
* CHOIYOILITENSE IGNEOUS COMPLEX								STIPANICIC	EL-TRAN-QUIL-LO
								BONAPARTE	
								STIPANICIC	LOS-COLORADOS
								COX	
								ROMER	
								BONAPARTE	
								STIPANICIC	ISCHI-GUALASTO
								COX	
								ROMER	
								BONAPARTE	
								COX	LOS-RASTROS-SANTA-MARIA
								ROMER	
								STIPANICIC	CHAÑARES-CACHUETA
								COX	
								ROMER	
								BONAPARTE	
								STIPANICIC	POTRE-RILLOS
								ROMER	
								BONAPARTE	
								STIPANICIC	LAS-CABRAS
							ROMER		
							BONAPARTE		
							STIPANICIC	UPPER-PUERTO-VEJO	
							ROMER		
							BONAPARTE		

Fig. 2. Summary of current interpretation of the tetrapod-bearing sediments of South America, as discussed in text.

locality a nonfossiliferous series of sediments lying stratigraphically above the Permian and below the tetrapod and plant bearing sediments, followed (3) by a second igneous complex, the "Choiyoilitense", and (4) a second sedimentary complex characterized by tetrapod remains and plant fossils of the *Dicroidium* flora. The basal igneous complex is found south of the major basin areas in the province of Rio Negro lying unconformably between Early Permian granites and *Dicroidium*-bearing sediments. However, this complex cannot be definitely traced to the north or directly related to the vertebrate-bearing sedimentary basins there. The second complex is composed of the lower part of the Puerto Viejo Forma-

tion and the "Paganzo III"—Tarjados Formations of the Ischigualasto Basin. These lie stratigraphically below, sometimes unconformably, typical *Dicroidium*-bearing sediments and are unfossiliferous. To these Stipanovic assigned an Anisian age, based entirely on their stratigraphic

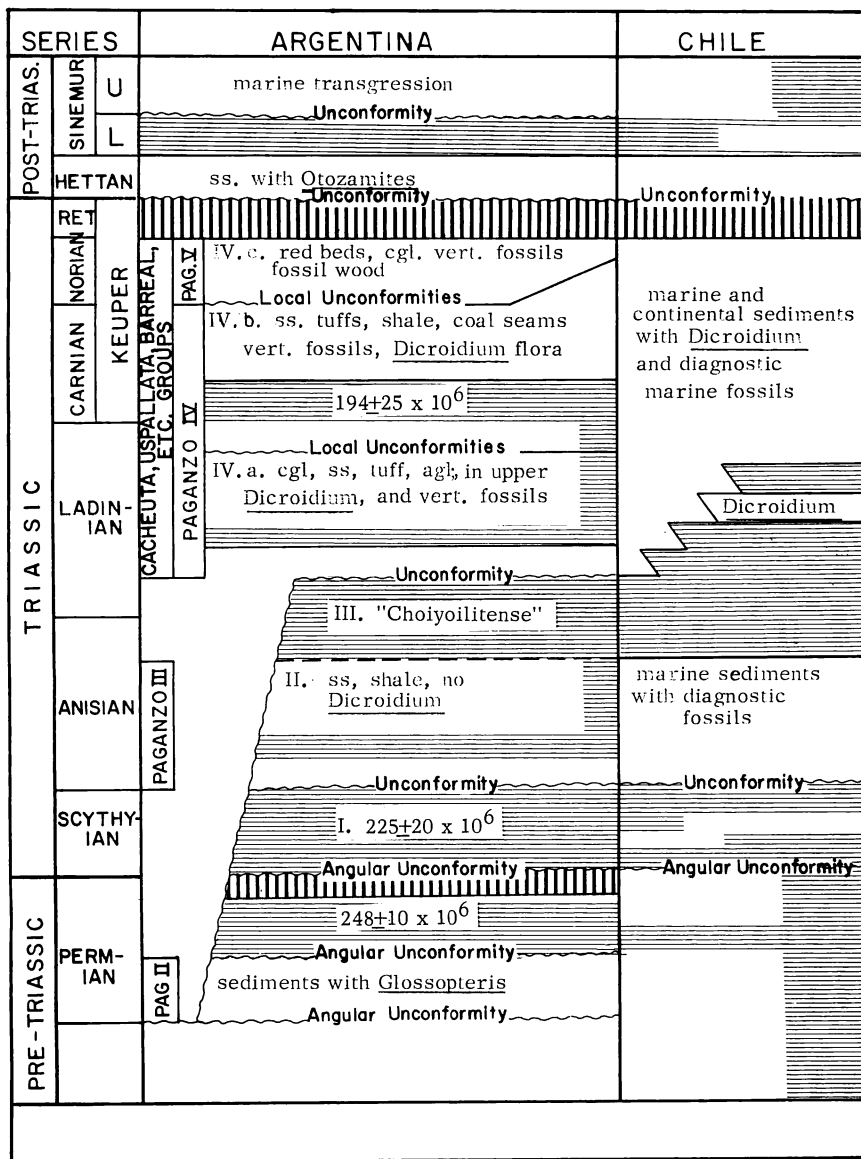


Fig. 3. Stipanovic's interpretation of the Triassic of Argentina and Chile. Horizontal lines represent igneous rocks. Text is condensed from the original (after Stipanovic, 1967b).

position below sediments he considered to be of Ladinian through Norian age. The igneous complex forming Stipanovic's third unit is part of the extrusive series called the Choiyolite or Upper Triassic Porphyritic Series (Groeber, 1918). This was originally considered one great igneous event that included all the extrusive rocks in the cordilleran region (Groeber, 1918). Later it was broken down into magmatic epochs corresponding to tectonic phases (Groeber, 1937, 1942; Groeber and Stipanovic, 1953) and ranging in age from the Middle Paleozoic to the Jurassic. This unit has been redefined over the years and is now limited to a series of porphyries and tuffs (Groeber, 1951, 1963) which, according to Stipanovic, lie stratigraphically below the Cacheuta sedimentary series and extend north into the province of San Juan. At the Chilean border the complex "practically interdigitates" (Stipanovic, 1967b, p. 3 and 7) with the Pastos Blancos igneous complex of Chile. The Pastos Blancos extends, somewhat sporadically, to the north where, at Alto del Carmen, it is found resting on marine shales containing a cephalopod and pelecypod fauna dated by Barthel (1958) and Zeil and Ichikawa (1958) as Late Anisian. The Pastos Blancos Formation and the "Choiyolite" (in the restricted sense) would then have to be at least Early Ladinian in age. According to Stipanovic, all known vertebrate-bearing Triassic sediments lie stratigraphically above this complex and either contain *Dicroidium* elements or can be correlated with other *Dicroidium*-bearing sediments. These include all the Triassic formations of the above mentioned basin areas and, in addition, the Rincon Blanco and Santa Clara Formations situated near the Barreal Basin, the Las Higueras Formation near the Cacheuta Basin, the Llantenes and upper Puesto Viejo Formations farther to the south, the unnamed *Dicroidium*-bearing sediments above the basal igneous complex in Rio Negro, and the El Tranquilo Formation of Patagonia. Of these, the upper "typical red-beds" are considered Norian on the basis of the dinosaur faunas from the Los Colorados and the El Tranquilo. The remaining formations are considered to be Carnian, possibly extending to the Middle Ladinian. Paleobotanic evidence is regarded as strongly supporting these age interpretations.

Romer (1960, 1962, 1966, 1967; Romer and Jensen, 1966) approached the correlation of the South American Triassic from a consideration of the world Triassic tetrapod fauna. He made three generalized groupings of the known faunas as follows: an early assemblage composed largely of carnivorous cynodonts, some herbivorous dicynodonts, primitive amphibians, and a few very primitive archosaurs, best represented by the faunas of the *Lystrosaurus* and *Cynognathus* zones of the South African Early Triassic, with additional representatives in China, Europe, and the Americas. At the other end of the Triassic, the last faunal stage consisted of advanced thecodonts, phytosaurs, and numerous and varied dinosaurs. This is the typical Keuper assemblage of Europe with equivalents in South Africa, China, and North America. Between these two Romer proposed a distinct "middle" faunal assemblage composed of herbivorous "gomphodont" cynodonts, abundant rhynchosaurs, and pro-

gressive thecodonts. This was in contrast to the previous concept (arrived at in the absence of a good fossil record) that the change from therapsid to archosaur faunas was gradational. Into this "middle" category he placed the Santa Maria, Ischigualasto, and Manda Formations of South America and East Africa respectively.

As transitional assemblages, he placed the Chañares fauna between the early and the middle, and the Maleri and Elgin faunas between the middle and the upper, groups.²

Like most of the vertebrate paleontologists working in the southern hemisphere, Romer believes that it is premature to try to match the Middle Triassic vertebrate sequence with the Alpine marine stages.

Cox (1968) examined the age relationships between the Chañares Formation of the Ischigualasto Basin, the Santa Maria of Brazil, and the Manda of East Africa. On the basis of similarities between dicynodonts from Chañares and Santa Maria he postulated that these two formations were of nearly the same age and considerably younger than the Manda Beds. This was in contrast to the stratigraphic position originally suggested by Romer, which placed the Chañares as older than or equivalent to the Manda, which in turn is considered older than the Santa Maria. While the major basis of Cox's argument is the close relationship between the dicynodonts, he also mentions the possibility that Manda "gomphodonts" are more primitive than those of Chañares and that the rhynchosaurs of the Manda Beds are apparently more primitive than those of Santa Maria. Rhynchosaurs are, however, not found in the Chañares Formation, and Cox explains this absence on ecological grounds noting that in Santa Maria sediments rhynchosaurs are not found associated with dicynodonts. The Chañares sediments would then correspond to the "Dicynodont environment", with the rhynchosaurs not significant as an age indicator. It should be noted, however, that rhynchosaurs and dicynodonts occur together in the Manda Beds, and according to Bonaparte (personal commun.) rhynchosaurs are present at all levels of the Ischigualasto Formation and thus not separated from dicynodonts. Cox also mentions the pseudosuchian thecodont *Mandasuchus* from the East African locality and its possible relationship to *Ticinosuchus* from the Alpine Anisian, considering this as a further indication of the older age of the Manda Beds. On this basis he maintains that the Triassic sediments of the Ischigualasto Basin, and their equivalents, must be younger than Anisian, with the stratigraphic range of the Chañares through Ischigualasto Formations representing uniform deposition over a relatively short period of time, probably parts of the Ladinian through Carnian. In this his conclusions are similar to those of Stipanovic, who would also limit the range of most Argentine Triassic sediments to the Ladinian and younger. Like Romer, Cox also suggests that it is inadvisable to use the European stage names to designate time units for the continental deposits of the southern hemisphere.

² Romer (oral commun.) has recently revised his concept of the Chañares fauna, bringing it more clearly into his "middle" assemblage.

Bonaparte (1966a, b, 1967) reviewed all the known tetrapod fossils from Argentina and formed them into four faunal age groups. His first group consisted of the faunas of the upper Puesto Viejo Formation and the strata of the Cacheuta Basin. Elements of these faunas (traversodontid cynodonts and kannemeyeriid dicynodonts) are quite closely related to similar forms from the *Cynognathus* Zones of South Africa and are considered to indicate late Lower or early Middle Triassic age. He also believes that the close similarity of the Argentine and African faunas, with one genus in common, is an indication of former land connections in the South Atlantic region. His second group is limited to the fauna of the Chañares Formation (a sedimentary unit he considers to be synonymous with the Ischichuca Formation of Frenguelli, 1944), characterized by numerous small "gomphodonts", small and medium-sized carnivorous cynodonts, and small thecodonts. He considers this assemblage clearly more modern than those of the Puesto Viejo and Cacheuta Basins and assigns it to the Middle Triassic. The third faunal assemblage is that of the Ischigualasto Formation, characterized by rhynchosaurs, large dicynodonts, advanced "gomphodonts," large thecodonts, and primitive dinosaurs. He considered this group to be generally comparable to the Santa Maria of Brazil, probably slightly younger on the basis of the dinosaurs and cynodonts, and both to be of early Upper Triassic age or uppermost Middle Triassic. The last faunal group is that of the Los Colorados and El Tranquilo Formations: typical Upper Triassic redbeds that contain essentially the same dinosaur fauna as occurs in similar sediments of this age in other parts of the world.

For purposes of correlation, Bonaparte introduces Provincial Age names based on the formations that contain these four faunal groups: Puestoviejense, Chañarensis, Ischigualastense, and Coloradense. This avoids the world-wide implications of the Alpine terminology and provides a more flexible standard for correlation of future discoveries within South America.

In sum, Stipanovic interprets the continental Triassic mainly on the basis of stratigraphic relationships derived from accumulated field studies covering all western Argentina. He considers the vertebrate remains to be of doubtful value for stratigraphic correlation, at least for the present. Romer on the other hand, correlates the Argentine Triassic almost exclusively on the basis of its vertebrate fossils, placing them in context with the known Triassic fauna of the world. Cox relies almost entirely on resemblances between a single group of animals, the dicynodonts, considering such a resemblance to indicate temporal proximity. The other faunal elements are viewed by him in the light of whether or not they contradict the interpretation of the dicynodonts. Bonaparte limits himself primarily to working out the faunal succession within South America. He places the South American Triassic vertebrates in a world wide context by making a rather loose extrapolation from the two good reference points: the Scythian *Cynognathus* zone therapsids and the Norian dinosaurs.

From the above discussion it can be seen that correlation of the South American Triassic is still rather unsettled. New discoveries have been made regularly during the past 5 years, and much of the fossil material from these discoveries has not yet been studied in detail. However, the time gap between the Scythian and the Norian is gradually being filled in. There is a consensus forming that the Santa Maria and Ischigualasto Formations probably represent the Late Ladinian or Early Carnian, the latter formation slightly younger than the former, and that the Santa Maria is probably equivalent to the Las Rastros Formation. All workers are agreed that the Los Colorados and El Tranquilo Formations are Late Carnian through Norian in age. The area of dispute has become focused in the Anisian and Ladinian time range, specifically as regards the age relationships of the Chañares, Puesto Viejo, and the five formations in the Cacheuta Basin. Here the lines of dissent are more clearly drawn and less flexible. The vertebrate fossils indicate an evolutionary stage apparently incompatible with a Ladinian or Keuper age, according to Romer and Bonaparte; while the field relationships and paleobotanical evidence seem to require such an assignment, according to Stipanovic.

This is of course the kind of dispute that will be settled by more field studies and the discovery of new material. However, an examination of areas of possible weakness in the present arguments might indicate where to look for the deciding evidence. Stipanovic's interpretation is based to a large extent on the field relationships of igneous rocks, particularly the redefined "Choiyolitense" extrusives, which he considers the eastern extension of a vast, synchronous magmatic event that preceded deposition of the tetrapod-bearing sediments. Some geologists, for example, Polanski (1966) and Fidalgo (1958), do not agree with this interpretation, stating that igneous activity and continental sedimentation occurred throughout the Triassic. Indeed, the interpretation of the "Choiyolitense" has been greatly modified during the last 30 years (see above). Recently Stipanovic (1967a) concluded that various magmatic events occurred in the region from the Carboniferous to the Triassic, with the "Choiyolitense" redefined to include only part of the igneous rocks present. It is possible that more work in the rocks of the Argentine-Chilean border area will result in further subdivision of igneous rocks that underlie the Cacheuta Basin and those that interfinger with Anisian marine shales in Chile. It is also possible that the presence of "*Cynognathus*-zone" fossils was due to geographic isolation, which allowed the groups to persist into later time periods, or that these fossils represent a sampling error (fossils are admittedly scarce in the disputed areas) and are not truly diagnostic of the faunal assemblage. In East Africa fossils very similar to those of Puesto Viejo are found not only in the *Cynognathus* zone but also in the later Molteno and Ntawere strata (Brink, 1963; Crompton, personal commun.), presumed to be of Anisian to Early Ladinian age.

Romer's subdivision of the Triassic fauna, whether intentional or not, gives the impression of corresponding to Early, Middle, and Late time periods within the Triassic. There is a possibility that his "middle" faunal assemblage may correspond to parts of the middle and the upper stages of the Triassic. There is also the possibility that there is more than one "middle" faunal stage between the Scythian-*Cynognathus* zone and the Norian-redbed deposits.

The conclusions reached by Cox are based almost exclusively on the relationships between two species of dicynodonts of the genus *Dinodontosaurus*, one common in the Chañares sediments, the other quite common in the Santa Maria beds. However, until similar comparisons are made between other groups, the meaning of such similarity cannot be fully ascertained. Study of the remaining faunal elements of the Chañares Formation is still in progress, and age evaluation on the basis of specific taxa should be deferred until more is known of the entire faunal community. Romer (1967) and Crompton (personal commun.) in their studies of the herbivorous traversodontid cynodonts of the Manda beds found them quite similar to those of the Chañares. Charig (personal commun.), working with the thecodonts of the Manda Formation considers one of them, *Mandasuchus*, to be rather closely related to *Prestosuchus* of the Santa Maria sediments, which in turn was considered by Krebs (1965) to be closely related to *Ticinosuchus* of definite Anisian age. Sill (in press), studying the rhynchosaurs, found those of Ischigualasto and Santa Maria to be congeneric and apparently more closely related to the Elgin rhynchosaur than to the one found in the Manda sediments. Colbert (1969) described a new saurischian dinosaur from Santa Maria and, after reviewing the problems involved in correlating vertebrate remains with the type area of the Middle Triassic, concluded that an Upper Triassic age was more appropriate for the Santa Maria and Ischigualasto Formations.

These add elements of both contrast and support to Cox's view based on dicynodonts and are an indication of more to come as other elements are studied in detail.

Out of this great influx of information about the South American continental Triassic and the healthy controversy that continues to surround the subject, some important contributions have emerged. It is recognized that a deficit exists in the amount of information available regarding emerging archosaur groups. In part, the deficit exists because biostratigraphic studies of pre-Norian Triassic faunas have been strongly oriented toward the declining groups of mammal-like reptiles. In general, the appearance of new forms provides a more refined assessment of time-stratigraphic relationships than does the persistence of old groups. Thus, as the thecodonts and dinosaurs of South America become better known, a more stable correlation can be expected. It is further recognized by most paleontologists and geologists that it is not yet practical to try to equate the so-called "Middle Triassic" continental deposits to the Anisian, Ladinian, and Carnian subdivisions based on marine se-

quences in the Alpine region of Europe.³ Emphasis is being placed more on working out the faunal succession within the southern continents, with the hope of then correlating between these continents. Only after this has been done should we attempt to match the continental sediments with the classic marine stages.

In this regard, Bonaparte's approach of establishing local faunal stages based on vertebrates is not unlike the "mammalian provincial ages" used to subdivide the Tertiary of the various continents and should become the standard working method for vertebrate paleontological work in Triassic sediments of the southern hemisphere.

The problem of how much time is represented by the strata, even where the stratigraphic succession is clear, is illustrated by the different interpretations of Cox and Romer for the same series of sediments. Do the strata of Ischigualasto through Chañares Formations represent a fairly short period of time—Late Ladinian to Early Carnian—as suggested by Cox (and Stipanovic), or a longer time span—Middle or Late Anisian to Early Carnian—as proposed by Romer (and Bonaparte)? Unfortunately, none of the other fossil-bearing strata in Argentina are definitely synchronous with those of the middle and lower Ischigualasto Basin, leaving the answer to this question dependent upon future discoveries.

ACKNOWLEDGMENTS

By its nature, this summary paper was dependent on the work of other people. I am particularly grateful to Dr. A. S. Romer, whose work in the Ischigualasto region triggered the "explosive evolution" of vertebrate paleontology in the Triassic of Argentina, for making available to me all his field notes and maps, in addition to spending his time discussing the matters with me. I am also especially grateful to Dr. Pedro Stipanovic and his wife, Dr. Maria Bonetti, for their hospitality during my visit to Argentina and for the time they spent reviewing with me all aspects of the Argentine Triassic. Also in Argentina, Sr. José Bonaparte showed me the collections of Triassic material made by the Miguel Lillo Institute and gave abundantly of his time and hospitality. In Brazil, Sr. Mario Barbarena and Sr. Carlos Bortoluzzi brought me up to date on the current status of the Santa Maria sediments. Dr. C. B. Cox also gave generously of his time. To all of these I express my sincere appreciation. Funds for the study, of which this was a part, were provided by NSF Grant GB 3167 and by a grant from the Society of Sigma Xi.

³This is not really a new idea. Huxley (1869) objected to the binding use of marine terminology for terrestrial faunas: "It does not appear to me that there is any necessary relation between the fauna of a given land and that of the seas of its shores. . . . I think it highly probable that sooner or later, the inhabitants of the land will be found to have a history of their own, mixed up with that of the sea, indeed, but independent of it . . .". He then proposed the term *Poikilitic* be applied to the period of duration of the Triassic land fauna. It was never accepted.

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