show a tendency for higher C_{soot}/C_{fine} ratios during the sampling periods dominated by biomass burning, in agreement with data from Townsville, Australia (*11, 28*), where I have observed values between 0.7 and 0.9 in aerosols which showed significant contributions from agricultural burning and brush fires.

Periods 4 and 11 were characterized by the virtual absence of C_{soot}, but not by extremely low total carbon concentrations, and consequently show the lowest C_{soot}/C_{fine} ratios (Fig. 2). At Cape Grim, Tasmania, I observed comparable amounts of organic carbon (140 to 310 ng/m^3) in marine air without a detectable soot component (< 20 ng/m^3) (*11*). In all these cases, there is almost no continental aerosol component detectable in the fine or large fractions. Total iron concentrations for periods 4 and 11 were 7.1 and 1.6 ng/m^3, respectively; at Cape Grim, iron was not detectable. It is not clear if this organic carbon represents truly marine organic matter, as has been suggested by Eichmann *et al.* (*29*), or the product of gas-to-particle conversion of long-lived vapor-phase organic precursors of continental origin, as has been suggested by Chesselet *et al.* (*27*).

MEINRAT O. ANDREAE
Department of Oceanography,
Florida State University,
Tallahassee 32306

References and Notes

1. G. T. Wolff and R. L. Klimisch, Eds., *Particulate Carbon: Atmospheric Life Cycle* (Plenum, New York, 1982).
2. M. O. Andreae, *WMO Spec. Environ. Rep. 14* (World Meteorological Organization Publication 549) (1980), p. 133.
3. M.-L. Yu and R. A. Hites, *Anal. Chem.* **53**, 951 (1981).
4. W. H. Benner, R. Brodzinsky, T. Novakov, *Atmos. Environ.* **16**, 1333 (1982).
5. B. Y. H. Liu and K. W. Lee, *Environ. Sci. Technol.* **10**, 345 (1976).
6. M. O. Andreae and W. R. Barnard, *Nucl. Instrum. Methods* **181**, 383 (1981).
7. E. S. Macias and L.-C. Chu, in (*1*), p. 131.
8. E. S. Macias, personal communication.
9. T. B. Johansson, R. E. Van Grieken, J. W. Nelson, J. W. Winchester, *Anal. Chem.* **47**, 855 (1975).
10. W. Seiler, personal communication.
11. M. O. Andreae, *J. Geophys. Res.* **87**, 8875 (1982).
12. A. C. D. Leslie, *Nucl. Instrum. Methods* **181**, 345 (1981).
13. J. A. Cooper, L. A. Currie, G. A. Klouda, *Environ. Sci. Technol.* **15**, 1045 (1981).
14. J. W. Winchester, M. Darzi, A. C. D. Leslie, M. Wang, L. Ren, W. Lü, in *Atmospheric Aerosol: Source/Air Quality Relationships*, E. S. Macias and P. K. Hopke, Eds. (Symposium Series 167, American Chemical Society, Washington, D.C., 1981), p. 287.
15. H. J. Annegarn, A. C. D. Leslie, J. W. Winchester, J. P. F. Sellschop, *Aerosol Sci. Technol.*, in press.
16. B. Mason, *Principles of Geochemistry* (Wiley, New York, ed. 3, 1966).
17. J. W. Winchester and G. D. Nifong, *Water Air Soil Pollut.* **1**, 50 (1971).
18. The samples were collected by L. C. Boueres, Florida State University, who also provided the potassium and calcium data.
19. D. G. Coles, R. C. Ragaini, J. M. Ondov, G. L. Fisher, D. Silberman, B. A. Prentice, *Environ. Sci. Technol.* **13**, 455 (1979).
20. L. E. Wangen, *ibid.* **15**, 1080 (1981).
21. W. Seiler and P. J. Crutzen, *Climatic Change* **2**, 225 (1980); V. Smil, *Bull. At. Sci.* **38**, 18 (1982).
22. G. S. Kowalczyk, G. E. Gordon, S. W. Rheingrover, *Environ. Sci. Technol.* **16**, 79 (1982).
23. R. K. Stevens, T. G. Dzubay, R. W. Shaw, Jr., W. A. McClenny, C. W. Lewis, W. E. Wilson, *ibid.* **14**, 1491 (1980).
24. R. K. Stevens, W. A. McClenny, T. G. Dzubay, M. A. Mason, W. J. Courtney, in (*1*), p. 111.
25. H. Rosen, T. Novakov, B. A. Bodhaine, *Atmos. Environ.* **15**, 1371 (1981).
26. P. K. Mueller, R. W. Mosley, L. B. Pierce, *J. Colloid Interface Sci.* **39**, 235 (1972).
27. R. Chesselet, M. Fontugne, P. Buat-Ménard, U. Ezat, C. E. Lambert, *Geophys. Res. Lett.* **8**, 345 (1981).
28. M. O. Andreae, unpublished data.
29. R. Eichmann, G. Ketsederis, G. Schebeske, R. Jaenicke, J. Hahn, P. Warneck, C. Junge, *Atmos. Environ.* **14**, 695 (1980).
30. V. Johannes, personal communication.
31. I thank W. Seiler for the invitation to participate in the *Meteor* cruise and the crew of the *Meteor* for their cooperation. I am grateful to S. Bauman, P. Houmere, R. Ferek, and L. C. Boueres for assistance with the PIXE and PESA analyses. I thank M. Dancy for help with the manuscript and figures. I thank J. W. Winchester for helpful discussions and a careful review of the manuscript. My travel was supported by NATO grant SA 9-6-02 (SRG20)83(81)CS.

5 November 1982; revised 5 January 1983

An Ictidosaur Fossil from North America

Abstract. *Teeth of a North American ictidosaur,* Pachygenelus milleri, *n. sp., found in the Upper Triassic Dockum Group of Texas, indicate that it is very similar to* Pachygenelus monus *of South Africa and* Chaliminia musteloides *of South America. The presence of a Gondwana element in the Northern Hemisphere attests to the ease of dispersal of the Late Triassic vertebrates through Pangea. Ictidosaurs are small, highly advanced, carnivorous cynodonts that display a mosaic of reptilian and mammalian features in the masticatory apparatus. They were contemporaneous with early mammals and probably closely related to them.*

The history of mammalian origins from cynodont reptiles toward the end of the Triassic is slowly unfolding. Recent mammals and reptiles are easily distinguished by the differences of anatomical, physiological, reproductive, and adaptive features, but in the reptile-mammal transition documented by the Late Triassic fossils, the distinction is not clear-cut. First, diagnostic mammalian features of soft anatomy are lacking from fossils; second, the fossil record of early mammals is very fragmentary—many taxa are known only from tiny teeth and jaws; third, many advanced cynodonts already possessed a large suite of mammalian features (such as secondary palate, enlarged dentary with coronoid process, reduced postdentary bones, complex cheek teeth with precise occlusion and limited replacement, and double occipital condyles) which make the class boundary more difficult. The presence of a squamosal-dentary articulation forming part or all of the joint between the skull and lower jaw is now used as the most practical diagnostic criterion for the class Mammalia (*1*).

This distinction in the jaw articulation was found to be inadequate, however. At least some cynodonts, such as ictidosaurs (*2*) and *Probainognathus* (*3*), have a dentary-squamosal contact, which makes them mammals by strict application of this criterion. Yet their complex lower jaws and single auditory ossicle in the middle ear are clearly still reptilian. Opinion has long been divided as to whether ictidosaurs are reptiles or mammals. Two features shared only by mammals and ictidosaurs among synapsids are prismatic enamel in the dentition (*4*) and overall small size. This is why the ictidosaurs are of special interests to evolutionists.

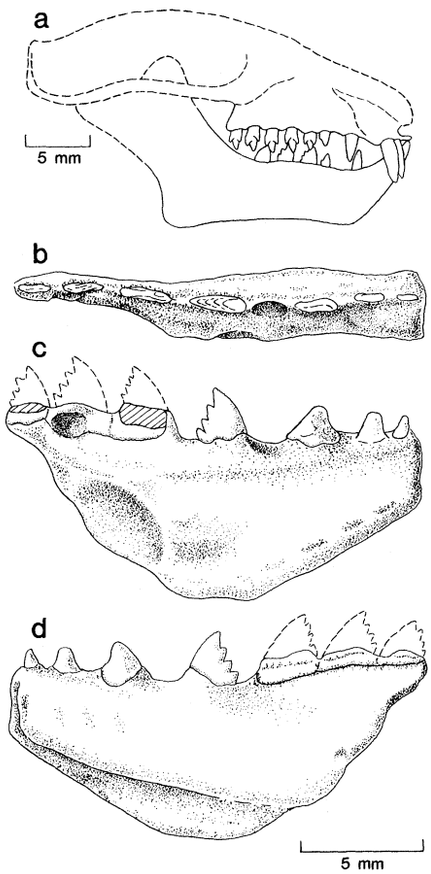

Fig. 1. (a) Right lateral view of the skull of *Pachygenelus monus* (*10*); (b) occlusal, (c) labial, and (d) lingual views of the right dentary of *Pachygenelus milleri*, n. sp. (TTU P 9020).

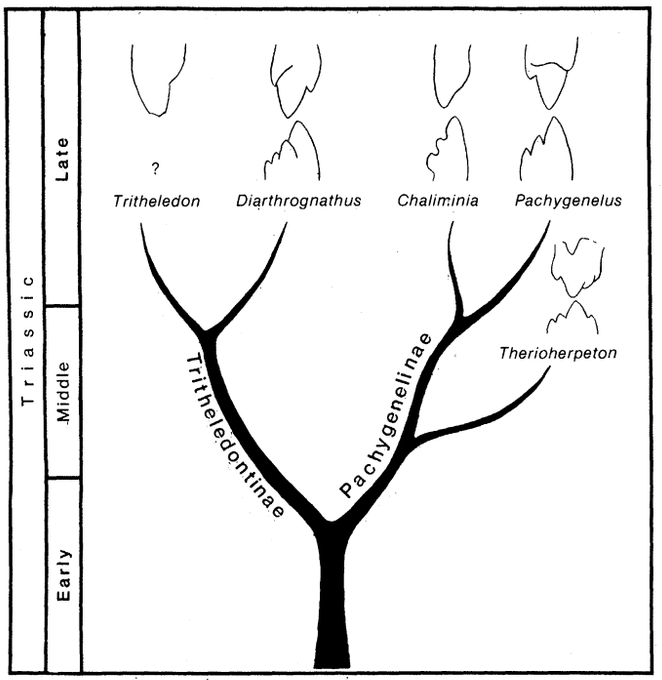

Fig. 2. Phylogenetic relationships of Ictidosauria. Labial views of opposing pairs of right postcanines are shown for each genus (*7*, *10*, *11*).

What is the relation of ictidosaurs to early mammals? Where we draw the line between reptile and mammal is a matter of convenience and personal preference (*5*, *6*). Ictidosaurs are reptilian in the structure of the pterygoid and interpterygoid vacuity, and in the retention of alternate tooth replacement, but mammalian in such features as prismatic enamel, jaw articulation, and overall small size. Recently Gow (*7*) has questioned the presence of dentary-squamosal joint in ictidosaurs. From ictidosaurs to mammals (*5*, *8*), further refinement in the dentition can be seen where the postcanines are differentiated into premolars (milk) and molars (permanent), with reduction of tooth replacement; there is a consistent triangular masticatory orbit forming during chewing. Accordingly, ictidosaurs are undoubtedly reptiles, though approaching mammalian condition.

From the Late Triassic to the Middle Jurassic, mammals took another evolutionary step which involved auditory apparatus, incorporating the malleus and incus as links between the stapes and tympanum. Malleus and incus are homologs, respectively, of the reptilian articular and quadrate bones, and if this difference is the criterion for defining mammals, all Triassic forms in which the otic region is known are excluded from the class Mammalia (*6*). Since the otic region is known in so few Triassic and Jurassic forms, the criterion of refined masticatory apparatus (*5*, *8*) is preferred here for defining mammals.

Two features debar ictidosaurs from immediate ancestry of Triassic mammals (*7*). First, they show reduction in the number of incisors. Second, they occur contemporaneously with early mammals. It seems at present that ictidosaurs are probably the sister group of mammals.

In the summer of 1982, while collecting a rich faunal assemblage from the continental Late Triassic Dockum Group of West Texas, I encountered a tiny isolated jaw of an ictidosaur; others have been found in South Africa and Argentina. Although the material is fragmentary, the postcanine teeth are diagnostic. The animal appears to be very similar to *Pachygenelus monus* of South Africa and *Chaliminia musteloides* of Argentina.

The ictidosaurian jaw was recovered from a red clay facies of the fluvial Dockum sediments, near Post, Garza County, West Texas. A quarry here has produced a varied tetrapod fauna, including new representatives of taxa hitherto unknown from the Triassic of North America. In addition to the ictidosaurian, there are half a dozen articulated skeletons of a bipedal thecodontian, the earliest land lizard, a microsaurid amphibian, and several problematic microvertebrates. These forms are quite different from the common Dockum tetrapod fauna collected earlier, which consists of parasuchids (phytosaurs), stagonolepipids (aetosaurs), metoposaurs, and trilophosaurs. The presence of numerous whole or partially articulated skeletons in a 1/2-m thick mudstone suggests a quick burial of a Dockum community in situ in consequence of a catastrophic event such as a flash flood.

Systematic paleontology. The new ictidosaur from Texas is formally named and characterized as follows:

Order	Therapsida
Infraorder	Cynodontia
Family	Tritheledontidae Broom, 1912
Genus	*Pachygenelus* Watson, 1913
Species	*Pachygenelus milleri*, n. sp.

Horizon: Dockum Group, Upper Triassic

Derivation of name: The specific name is given in recognition of R. C. Miller and his wife for their help and hospitality during my fieldwork.

Holotype: TTU P 9020, isolated right dentary of a juvenile individual, in the collection of Texas Tech University.

Locality: Near Post, Garza County, West Texas.

Generic diagnosis (*7*): Very advanced carnivorous cynodonts of small size (skull length, 2 to 10 cm) (Fig. 1a); dental formula, two incisors, one canine, and possibly seven postcanines; upper postcanines bulbous; central main cusp with small anterior and posterior accessory cusps connected by a labial cingulum; lingual side of the main cusp forming a vertical shear plane after wear. Lower postcanines laterally compressed and larger than the uppers; smoothly curved anterior main cusp and two lesser posterior cusps arranged longitudinally; cingulum on the lingual side; wear confined to tips and labial surfaces; tooth replacement alternate.

Specific diagnosis (based on characters of lower postcanines, as uppers have not been found): Differs from *Pachygenelus monus* in the additional development of an accessory posterior cusp.

Description. A fragment of the right dentary, about 17 mm long, is preserved. The bone is narrow in the front but deepens rapidly posteriorly, where a prominent masseteric fossa occupies the lateral surface. An internal groove passes forward to the symphysis for the reception of the splenial.

There are indications of two incisors, one canine, and five postcanine teeth in the preserved part. An empty alveolus occupies the position of first postcanine. The second postcanine is a newly erupting tooth that is complete and shows the anterior main cusp, followed by three posterior cusps. The anterior cusp is highly recurved in front with a sharp cutting edge. The third postcanine shows a strong wear facet on the labial side and a weak cingulum on the lingual surface. Weak cingulum may be attributed to youth of the individual at death (*7*). The fourth postcanine shows a pit at the base for the replacing tooth. The fifth one is damaged and difficult to interpret.

Distribution and relationships. The ictidosaurs are a poorly known group of Late Triassic to Early Jurassic carnivorous therapsids that are distinctive from all other cynodonts in their small size,

tooth morphology, and dentary-squamosal joint. Four genera are commonly included in the family Tritheledontidae. *Diarthrognathus*, *Tritheledon*, and *Pachygenelus* are known from the Red Beds and Cave Sandstone (Stormberg Group) of South Africa and Lesotho. There is a problem with the age of these formations, ranging from Late Triassic (*2*) to Early Jurassic (*9*). *Chaliminia* is recorded from the Los Colorados Formation of Argentina. *Pachygenelus* now appears in the Dockum Group of Texas.

Bonaparte (*10*) recognized two separate lineages, here considered as subfamilies among the ictidosaurs: Tritheledontinae (containing *Tritheledon* and *Diarthrognathus*), with transversely widened postcanines and a complex occlusion of the crowns; and Pachygenelinae (containing *Pachygenelus* and *Chaliminia*) with narrow postcanines and scissor-like occlusion.

Bonaparte and Barberena (*11*) described *Therioherpeton*, an interesting small cynodont of uncertain familial affinity, from the upper Middle or lower Upper Triassic Santa Maria Formation of Brazil. They identified such ictidosaurian cranial characters as a lack of postorbital bar, weak zygomatic arch, and wide braincase. The postcanines are four-cusped sectorial teeth with bifurcated root, otherwise similar to *Pachygenelus*. Since *Pachygenelus* tooth morphology was unknown at the time, they could not determine the systematic position of *Therioherpeton*. *Therioherpeton* is included here within Pachygenelinae, and its suggested relationship is shown in Fig. 2.

Although the continental drift theory has triumphed in recent years, many details are uncertain. There is a long-standing debate whether there were two unconnected supercontinents, Laurasia and Gondwana, or one supercontinent, Pangea, at the beginning of the Mesozoic. The discovery of an ictidosaur from Texas adds to the growing list of reptilian groups occurring in both North America and Gondwana in the Late Triassic and supports the concept of Pangea, which was probably still intact during the Late Triassic to Early Jurassic time. This is also reflected by the uniform fauna over most of the world such as rhynchosaurids, plateosaurids, morganucodontids, protosuchids, traversodontids, and tritylodontids. There may have been few impediments to tetrapod migration through Pangea.

SANKAR CHATTERJEE

The Museum,
Texas Tech University,
Lubbock 79409

References and Notes

1. K. A. Kermack and F. Mussett, *Proc. R. Soc. London Ser. B* **148**, 204 (1958).
2. A. W. Crompton, *Proc. Zool. Soc. London* **130**, 183 (1958).
3. A. S. Romer, *Science* **166**, 881 (1969).
4. F. E. Grine, and E. S. Vrba, *S. Afr. J. Sci.* **76**, 139 (1980).
5. A. W. Crompton and F. A. Jenkins, Jr., *Annu. Rev. Earth Planet. Sci.* **1**, 131 (1973).
6. K. A. Kermack, F. Mussett, H. W. Rigney, *Zool. J. Linn. Soc.* **71**, 1 (1981).
7. C. E. Gow, *Proc. R. Soc. London Ser. B* **208**, 461 (1980).
8. A. W. Crompton and F. A. Jenkins, Jr., in *Mesozoic Mammals: The First Two-Thirds of Mammalian History*, J. A. Lillegraven, Z. Kielan-Jaworowska, W. A. Clemans, Eds. (Univ. of California Press, Berkeley, 1979), p. 59.
9. P. E. Olsen and P. M. Galton, *Science* **197**, 983 (1977).
10. J. F. Bonaparte, in *Actas II Congreso Argentino de Paleontología y Bioestratigrafía y I Congreso Latinoamericano de Paleontología* (Buenos Aires, 1980), p. 123.
11. _____ and M. C. Barberena, *J. Paleontol.* **49**, 931 (1975).
12. I thank J. F. Bonaparte, J. A. Hopson, N. Hotton, A. W. Crompton, and M. W. Nickell for helpful discussions of the manuscript; D. Proctor, M. W. Nickell, and B. Small for field assistance; the R. C. Millers for allowing access to their property; M. W. Nickell for the illustrations; K. Hinson for photography; and S. Burgeson for typing. Supported by a series of grants from the National Geographic Society and Texas Tech University.

28 December 1982; revised 17 February 1983

Early Tertiary Age of Pitchstone in the Northern Black Hills, South Dakota

Abstract. *A block of pitchstone in the northern Black Hills, South Dakota, is Paleocene in age, according to potassium-argon dating of biotite and fission-track dating of zircon in the sample. These data invalidate published suggestions that the age is much younger. The pitchstone is not extrusive in its present position but instead is in a volcanic pipe with other fragments that came downward from as much as 1100 meters above the modern surface.*

An isolated small outcrop of pitchstone adjacent to the Tomahawk golf course, 10 km south-southeast of the city of Deadwood, has caused differences in interpreting the Cenozoic history of the northern Black Hills, South Dakota. Field evidence and numerous age determinations on intrusive rocks indicate an early Tertiary age for most or all of the igneous activity of the region, but a whole-rock potassium-argon age of 10.5×10^6 years for this pitchstone led Kirchner (*1*) to suggest that there was also a much younger period of volcanism. New potassium-argon age data on biotite and fission-track dating of zircon show the pitchstone to be 56×10^6 years old, which places it in early Tertiary time. This age is in accord with field relations indicating that the pitchstone and associated rocks are subsided material in a volcanic neck that originally penetrated approximately 1 km of cover.

The pitchstone (called obsidian by most earlier investigators) forms a single block, less than 10 m long, on a knoll underlain by bedded lithic tuffs and various volcanogenic clastic rocks. The volcanic assemblage extends over an elliptical area about 1600 by 800 m that is surrounded mostly by Precambrian schists but also is in contact with a tilted block of the Cambrian Deadwood Formation and with Tertiary rhyolite porphyry. Outcrops in the area are sparse.

The locality is near the southern edge of a belt of intrusions that crosses the northern Black Hills in a west-northwest direction. Compositions are mostly rhyolitic or monzonitic. Age determinations range from about 40×10^6 to 60×10^6 years (*1*).

After finding well-preserved biotite phenocrysts and sparse zircon in a small sample, we collected 70 kg of the pitchstone. In addition to glass, the rock contains gray, very fine-grained crystalline material in veinlets and layers that probably is highly altered obsidian but may be partly original. This material could be only partially excluded from the field sample. In thin sections of rock without megascopically visible alteration products, the glass is isotropic but has tiny anisotropic particles. Some of these particles are individual grains distributed through the glass, but most are in aggregates and veinlets that apparently represent devitrification. The rock also has phenocrysts of biotite with dimensions of as much as 0.4 by 0.7 mm and phenocrysts of plagioclase as much as 2 mm in diameter. A rim of devitrified glass surrounds some of the phenocrysts.

Biotite, glass, and zircon separates were prepared by standard methods. The glass was purified by use of both heavy liquids and an isodynamic magnetic separator to remove altered material. An analysis of the purified glass showed approximately 7.5 percent H_2O. Conventional age-determination techniques were used.

Potassium-argon age determinations ($\pm 2\sigma$) yielded $(55.8 \pm 1.4) \times 10^6$ years for the biotite and $(24.8 \pm 0.8) \times 10^6$ years for the glass. These ages are based