The
Petrified Forest
Through the Ages

A scene in Lithodendron Wash (Rio Seco) drawn by German artist Baldwin Möllhausen and published in 1858 in his book, *Diary of a Journey from the Mississippi to the Coasts of the Pacific with a United States Expedition.* Vol. II.

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The Petrified Forest Through the Ages

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Dedicated to
all the naturalists of Petrified Forest National Park,
especially the first Park naturalists,
Merl S. Walker and Phillip VanCleve,
both of whom discovered many significant fossils
in the park
and recognized their importance

Contents

Preface

The Director of the National Park Service, Russell Dickenson, recently stated, "The people of the United States have built the largest and most abundant system of National Parks in the world, an achievement benefiting the scope and grandeur of the nation's resources."

Petrified Forest National Park was first established as a National Monument by President Theodore Roosevelt on December 8, 1906. The national monument was established to preserve the mineralized remains of Mesozoic Forests commonly known as the "Petrified Forest," the natural environment, and cultural resources for public use and benefit. Full national park status for Petrified Forest National Monument was a long-cherished dream of many Arizonans and others throughout the United States. This cherished dream came true on December 8, 1962, when Petrified Forest did gain status as our country's thirty-first national park.

The park celebrated its seventy-fifth anniversary in 1981 with activities planned throughout the entire year to commemorate its establishment. The research symposium of November 6–7, 1981, was part of this commemoration. I am extremely pleased that such an outstanding representation of researchers presented their findings at the symposium and also completed written reports to be included in this volume of papers. My personal thanks to all researchers for taking time from their busy schedules to participate.

A special thanks to Dr. Roy Johnson of the National Park Service and Dr. Edwin Colbert of the Museum of Northern Arizona for the review and coordination of this publication. Also thanks to Diana Lubick of the Museum of Northern Arizona for her fine job in editing and to Eugenia M. Horstman, also of the Museum, for coordinating production.

The symposium's success, which is reflected in this publication, provides information that will enhance the public's interest and enjoyment of Petrified Forest National Park both now and in future generations.

Again, my personal thanks to everyone who made this special publication possible.

Roger K. Rector, Superintendent
Petrified Forest National Park

Contributors

Sidney Ash, professor of geology of Weber State College, has worked on the fossil plants preserved in the Petrified Forest for more than twenty years. He is the author of many papers on the plant life of the age of dinosaurs, including *Upper Triassic Floral Zones of North America* and *The Upper Triassic Chinle Flora of Petrified Forest National Park, Arizona.*

Karen L. Ballew is currently a graduate student in the Department of Paleontology, University of California, Berkeley. She has actively been involved with field work at Petrified Forest National Park and is investigating the phytosaurid thecodonts found in the park.

George H. Billingsley, geologist at the Museum of Northern Arizona, has conducted several geologic mapping projects in other national parks such as Grand Canyon National Park, Arizona, and Canyonlands National Park and Capitol Reef National Park, Utah.

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Robert A. Long, research associate at the Museum of Paleontology, University of California, Berkeley, has been involved with investigations of fossil vertebrates of the late Triassic Chinle Formation for a number of years. He has supervised four field parties at Petrified Forest National Park and vicinity between 1981 and 1984. His principal research involves early Mesozoic reptiles.

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Terah L. Smiley, professor emeritus, Department of Geosciences, The University of Arizona, Tucson, is editor, with others, of several publications: Terah L. Smiley, J. Dale Nations, Troy L. Péwé, and John P. Schafer, editors, *Landscapes of Arizona, The Geological Story* (University Press of America, 1984); Terah L. Smiley, editor, *The Geological Story of the World's Deserts* (Societas Upsaliensis Pro Geologia Quaternaria, 1982); Terah L. Smiley and James H. Zumberge, editors, *Polar Deserts and Modern Man* (The University of Arizona Press, 1971).

Michael E. Wright has published articles on wildlife diseases and wrote *Analysis of Habitats of Two Woodrats in Southern New Mexico.* He coauthored *Survival of House Sparrows and House Finches in Kern County, California.*

Introduction

by Edwin H. Colbert and R. Roy Johnson

The Petrified Forest of Arizona, known to the Indian inhabitants of the Southwest for many thousands of years, and discovered by American explorers and scientists in the middle of the nineteenth century, was quickly recognized and acclaimed as one of the most astounding concentrations of fossilized wood to be seen anywhere in the world. It was first brought to the attention of the literate world in the reports of several U. S. Army expeditions that explored the region during the 1850's, wherein there are not only descriptions of the area but also illustrations showing some of the immense fossil logs so typical of the Forest. By the end of the century the Petrified Forest had become widely known for the abundance and beauty of its fossil logs, preserved by the deposition of silica and certain colorful minerals such as iron and manganese in the cells of the ancient plants. The best known of the trees that are so prominently exposed throughout the Forest belong to three genera, *Araucarioxylon, Woodworthia,* and *Schilderia.* The fossilized trunks of these trees are commonly found intact or in fragments lying end to end where they originally settled as large logs. It is generally believed that most of the logs were transported from other areas by streams, losing their roots, limbs, and bark on the way before being entrapped in sediments. Other species of plants were covered with sediments which turned to stone, then later eroded away exposing these fossilized fragments as imprints, especially of leaves and stems. Some of the most spectacular finds have been of standing trunks of plants which were covered by sediments while remaining in an upright position.

Although the Petrified Forest is justly famous for the abundance of its plant fossils, it is also a repository where numerous animal fossils are found, particularly the shells of fresh-water molluscs, fresh-water fishes, and various amphibians and reptiles, including the remains of very early dinosaurs. All of the fossils, plants and animals, are of late Triassic age, and taken together provide a rich record of life on the North American continent when it was a tropical land, still an integral part of the great ancient supercontinent of Pangaea. This superb testimony of life as it existed almost 200 million years ago is deserving of the most careful protection and the most detailed study and interpretation that can be provided by the citizens of our country.

The importance of the Petrified Forest area as a scientific, cultural, and scenic resource was recognized early in the present century; consequently, Petrified Forest National Monument was established by a presidential proclamation from Theodore Roosevelt in 1906. In 1932, approximately 2500 acres of the Painted Desert were added to the Monument. The Petrified Forest with these attendant segments of the Painted Desert was designated Petrified Forest National Park by Act of Congress in 1962. In an attempt to further protect its natural resources, Congress designated more than 53% of the park as wilderness in 1970, including 43,020 acres in the Painted Desert and 7240 acres in the southern section of the park.

The Park consists of 93,492 acres located in northeastern Arizona in Navajo and Apache counties. Situated along old transcontinental U. S. Highway 66 (now Interstate 40), the Park receives more than 700,000 visitors annually, many of them foreigners who come to this region to see the Petrified Forest, the Painted Desert, and the Grand Canyon (approximately 185 highway miles to the northwest). Elevations range from 1615 m to 1900 m (5300 to 6235 ft) with most of the park at approximately 1767 m (5500 ft). Although located on the high Colorado Plateau, the Park is situated in the Puerco River Valley, a segment of the Little Colorado River drainage. Therefore, Park lands are at lower elevations than much of the rest of the Colorado Plateau. Despite the slight differences in elevation, a wide variety of rock and soil types have contributed to the development of a corresponding diversity in vegetation types. A mapping project completed by the Office of Arid Lands Studies, University of Arizona (1977) listed several basic ecological types. These included one category of barren land (natural areas with vegetation cover less than 5%), one category of land disturbed by human activity, 3 grassland types, 12 shrub types, and 3 riparian categories. The areas classified as barren land commonly occur in the Chinle Formation, containing rocks which decompose into clay, providing a substrate unsuitable for most plants. Thus the areas in which some of the finer examples of petrified wood are found are some of the poorest, vegetation-wise.

Grasses consist largely of types from short grass prairies, such as blue grama (*Bouteloua gracilis*) and semiarid (desert) grasslands such as galleta (*Hilaria jamesii*). Recent cultural activities such as grazing and fire suppression combined with natural phenomena such as drought have resulted in the invasion of much of the grasslands by shrub species and junipers.

Plants of the Park are generally adapted to arid and semiarid zones since annual precipitation averages only 8.69 inches (Sellers and Hill 1974). Approximately 50% of this occurs during the summer monsoons from July through

September. The driest months occur during spring and winter, when less than half the scant precipitation falls as snow. Extreme temperatures range from highs in excess of 100°F (37.8°C) to lows of below -20°F (-28.9°C). January daily mean maximum temperatures are 47.3°F (8.5°C) with daily mean minimum temperatures of 20.9°F (-6.2°C) for a monthly mean of 34.1°F (l.l°C). July means are: 92.0°F (33.3°C), 60.8°F (16°C) for a monthly mean of 76.4°F (24.7°C). Exceptions to the semiarid biota of the Park are found along some of the ephemeral watercourses and the single intermittent stream flowing through the Park, the Puerco River. The banks of the Puerco are lined by Fremont cottonwoods (*Populus fremontii*), saltcedar (*Tamarix chinensis*), and other mesophytes. Several species of birds and other animals and plants occur in higher concentrations, or exclusively, along the Puerco.

In addition to the physical and biological resources of the Petrified Forest and Painted Desert, outstanding cultural resources, including ruins and "rock art work" left by prehistoric inhabitants of the area, are discussed in one of the papers included in this symposium. Some of the better cultural remains are located near the Puerco, for prehistoric humans, like many other animals and species of plants, were attracted to and flourished near the most abundant sources of water.

The establishment of the Petrified Forest as a National Park was indeed a wise move. With increasing demands from the public for petrified wood, many areas outside the park are in danger of eventually having their supplies exhausted. Thus the Park remains as an inviolable preserve in a world of increasing pressures from all directions, where its ancient treasures will be protected for future generations.

And these treasures consist not only of the fossil plants but, as mentioned above, of rich deposits of fossil animal remains, not to mention the structures and artifacts left by the former human inhabitants of this land. For example, more than 200 species of fossil animals and plants have been catalogued from geologic formations within the Park or in those same formations not far outside the Park boundaries. Here is one of the most important localities, not only in North America but in the world, for the display and study of fossil plants and animals of late Triassic age. Thus the Petrified Forest reveals important aspects of ancient life as it existed in this particular region and, by extension, as it existed throughout the extent of a world that was in essence one world—the world of ancient Pangaea, where plants and animals were distributed across the vast expanses of a tropical supercontinent.

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General Stratigraphy
of the Petrified Forest National Park, Arizona

by George H. Billingsley

ABSTRACT

Two geologic rock formations are exposed in Petrified Forest National Park: the Triassic Chinle Formation and the Tertiary Bidahochi Formation. The prominent sandstone beds of the Chinle Formation in Petrified Forest National Park are excellent marker beds for local stratigraphic correlation; but because of erosion, structural downwarping, and abrupt pinchouts of some marker beds, it is difficult at best to correlate sandstone marker beds between the northern and southern portions of the Park. Remnants of the lower Bidahochi Formation are found in parts of the Painted Desert areas of the Park.

INTRODUCTION

The sedimentary rocks of the Petrified Forest National Park consist mainly of sandstones, shales, and conglomerates represented by the Triassic Chinle Formation. Volcanic rocks are interbedded with pale yellow to gray sandstones and shales of the Pliocene-Miocene Bidahochi Formation near the Painted Desert overlook and Pilot Rock (Fig. 1). Both the Chinle and Bidahochi Formations are covered in part by surficial deposits of alluvium, colluvium, and dune sand.

To help clarify stratigraphic position and correlation throughout the Petrified Forest National Park, this report is based on field mapping notes from 1977 through 1980 and from previous stratigraphic studies of Cooley (1957, 1958, and 1959), Roadifer (1966), and Sidney Ash (Personal communication, 1981, 1982, and 1983). Stratigraphic correlations of sediments throughout the park are made by a combination of lithology, color, stratigraphic position, unconformities, and stratigraphic continuity from aerial photo interpretations, as well as a few measured sections provided by Sidney Ash. The extensive surficial deposits throughout the central portion of the park (Puerco River), coupled with a structural downwarp or basin prevent direct lateral correlation of sandstone marker beds between the southern and northern areas of the park. For this reason, the sandstone marker beds of the northern Painted Desert area have different informal names from those in the southern portions of the park.

PREVIOUS WORK

There are several papers and reports concerning the stratigraphy of the Petrified Forest National Park and adjacent Painted Desert areas included in studies of Triassic rocks of the region. Only a few studies were conducted at or near the Petrified Forest National Park. The basic geologic framework of the region was outlined by Gregory

(1916, 1917), who published the first geologic map and made a hydrologic reconnaissance of the area. Many stratigraphic units Gregory originally described are accepted as standard.

Other reports that contributed substantially to the stratigraphic knowledge of this area were by Cooley, 1957, 1958, and 1959; Seff, 1965; Roadifer, 1966; and Repenning and others, 1969. A summary of work related to the study of the Chinle Formation is well documented by Breed, 1972.

Stratigraphy

Chinle Formation

The multi-colored shales and sandstones exposed in the Petrified Forest National Park represent a large section of the Chinle Formation. The one exception is the Bidahochi Formation consisting of yellowish-gray siltstones and black volcanic rocks that outcrop at Pilot Rock, the Painted Desert overlook, and a few places along Interstate 40 (Fig. 1).

The Chinle Formation was first defined by Gregory (1917) in the valley of Chinle Wash within the Navajo Reservation. Gregory (1950) also defined the Petrified Forest Member of the Chinle Formation within and near the Petrified Forest National Park. The Chinle has been further subdivided into several members in northeastern Arizona (Repenning and others, 1969). Two of the members, the Petrified Forest and Owl Rock, are represented within the Petrified Forest National Park.

The Petrified Forest Member is the lowermost and most widespread rock unit in the park and has been locally subdivided into three subunits; the upper and lower Petrified Forest Member separated by the Sonsela Sandstone (Akers and others, 1958). Unfortunately for correlating purposes, the Sonsela is not widespread throughout the park because of its lenticular and discontinuous nature.

Rocks of the lower Petrified Forest Member crop out in and around the vicinity of Rainbow Forest, from the Crystal Forest northward to the Puerco River, and again along Lithodendron Wash just north of Interstate 40. These sediments are composed mainly of grayish-blue mudstones, siltstones, and gray-white sandstones, which have a total thickness of nearly 300 ft. (91.4 m) (Cooley, 1959). Several sandstone marker beds in the lower Petrified Forest Member lense out or, in some cases, change lithology rather abruptly and become poor representative marker beds for extensive correlation purposes. They do, however, serve as useful marker beds for local correlation in specific areas.
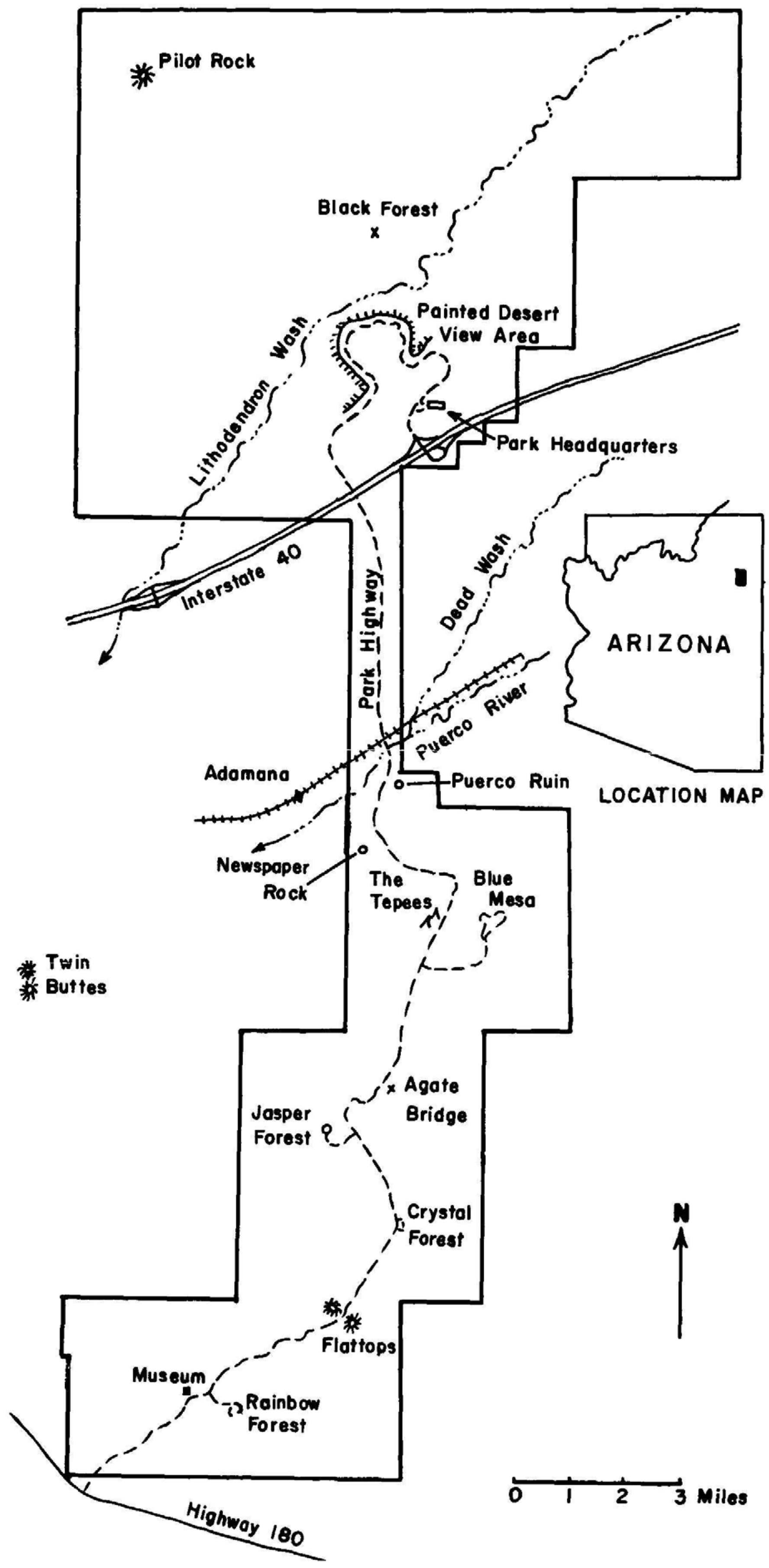
Figure 1. Map of Petrified Forest National Park showing principal geographic locations

Newspaper Sandstone

The lowest mappable sandstone unit exposed in the central portion of the Petrified Forest National Park is the newspaper rock sandstone (Stagher, 1941, *in* Daugherty, 1941), herein referred to as the newspaper sandstone (Fig. 2). The newspaper sandstone is present on a small mesa that is traversed by the park highway between the Puerco River and Blue Mesa (Fig. 1). The newspaper consists mainly of a light brown cliff-forming, medium to coarse-grained sandstone which lenses out or has abrupt facies changes to reddish and gray mudstones. The thickness of the newspaper varies from 0 to 35 feet (10.7 m). The contact with the underlying bluish-gray mudstones is an erosional unconformity with relief up to 15 or 20 feet (4.5 to 6.1 m).

The contact with the overlying blue shales and siltstone is generally gradational but somewhat abrupt in a few places. Erosion has removed the overlying mudstones in all but the Blue Mesa area.

The most distinctive feature of the newspaper is the micro-gross-laminations that characterize the bedding (Roadifer 1966). The newspaper is structurally dipping to the northeast towards the Puerco River about 3 to 4 degrees. West of the Puerco Indian Ruins and south of the Puerco River the newspaper is a thin discontinuous brown sandstone that caps ridges of shale that gently dip northward towards the Puerco River. Thus, the newspaper sandstone is very local and mainly restricted to the central vicinity of the park and adjacent areas westward along the Puerco River valley.

Rainbow Sandstone

The lowest mappable sandstone unit exposed in the southern Petrified Forest National Park is the rainbow sandstone defined by Cooley (1957), who places the bed stratigraphically between the newspaper sandstone and the Sonsela Sandstone. Roadifer (1966) states that the rainbow sandstone bed probably correlates with rock units above the Sonsela Sandstone and suggests the term rainbow sandstone be dropped (Fig. 2). However, based on recent geologic mapping, aerial reconnaissance, and personal communication with Sidney Ash (1983), the rainbow sandstone appears to occupy a stratigraphic position about 60 feet (18 m) below the Sonsela Sandstone; therefore the term rainbow sandstone is herein retained as an informal rock unit placed stratigraphically below the Sonsela Sandstone and above the newspaper sandstone as Cooley (1957) originally stated (Fig. 2).

The rainbow sandstone varies in thickness but averages about 20 feet (6.1 m), and is locally tilted approximately three degrees to the north along old Highway 180 west of Rainbow Forest. Elsewhere, the rainbow is nearly flat lying or dipping about one degree northeast. Beneath the rainbow sandstone are a series of blue mudstones and siltstones, gray-white sandstones, and conglomerates. Colorful petrified logs characterize the rainbow sandstone. These petrified logs are stratigraphically the oldest logs in the park. A series of blue siltstones and lenses of white sandstone, approximately 50 feet (15.2 m) in thickness, gradationally overlies the rainbow sandstone.

Brown Sandstone

The lowest mappable sandstone unit in the northern portion of the Petrified Forest National Park is a prominent, brown, coarse-grained cliff-forming sandstone along the banks of Lithodendron Wash between Interstate 40 and the park boundary. This sandstone unit is herein informally referred to as the brown sandstone (Fig. 3). The sandstone occupies a stratigraphic position similar to the newspaper sandstone near Blue Mesa, but its texture and weathering characteristics are distinctly different. It is possible that this brown sandstone is a facies change or a lateral equivalent of the newspaper sandstone, but it is probably a separate sandstone that lenses out southward and eastward and herein is treated as such.

The brown sandstone overlies a series of interbedded blue siltstones and thin bedded sandstone that generally form a slope with ledges in the lower Petrified Forest Member. Approximately 35 feet (10.5 m) above the brown sandstone lies another prominent sandstone bed that forms
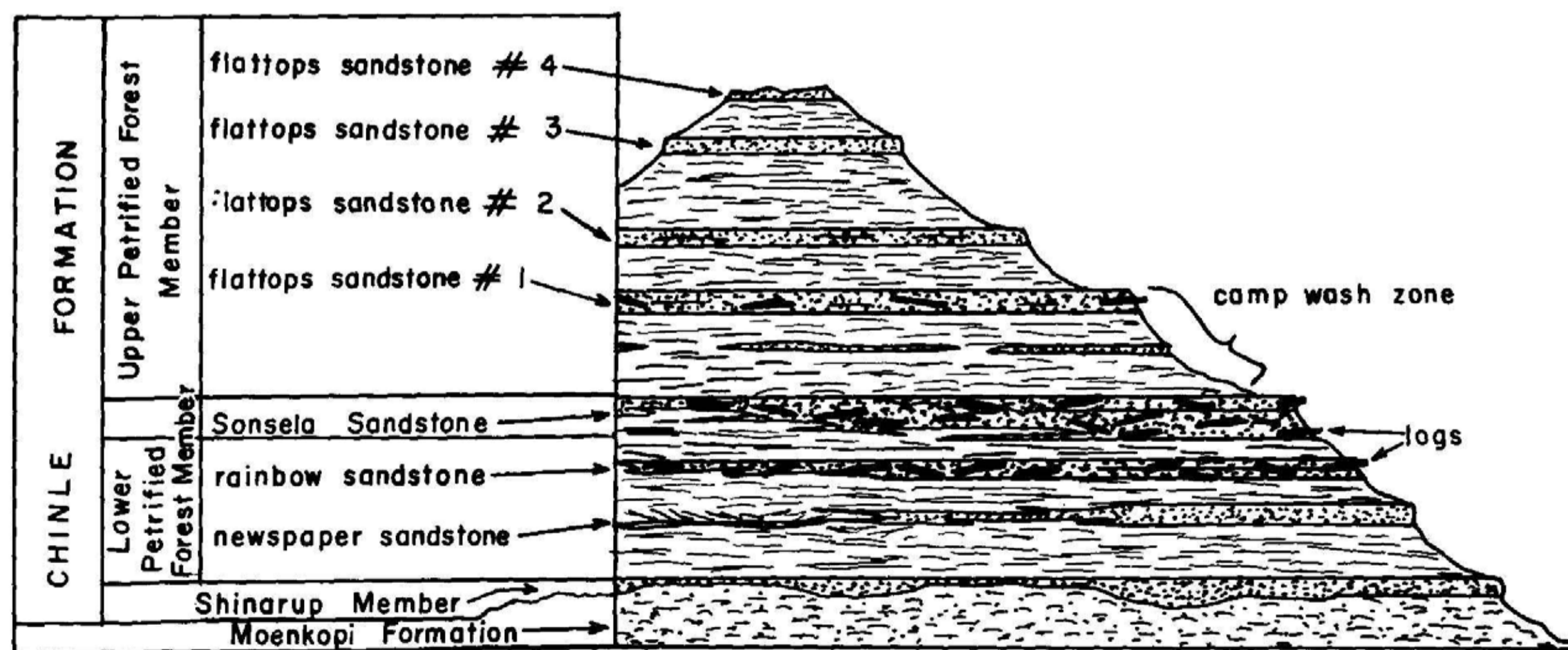

Figure 2. Stratigraphic section (not to scale) of the southern portion of Petrified Forest National Park and vicinity

the small mesa surface on the west side of Lithodendron Wash near I-40. The brown sandstone forms a ledge within the slope beneath that mesa. This local sandstone bed nearly lenses out on the east side of the wash and forms a weak ledge in the blue shale series up to the Sonsela Sandstone (Fig. 3).

Sonsela Sandstone

The Sonsela Sandstone bed unconformably overlies the blue mudstones and siltstones and occurs over a large area northeast of the Petrified Forest National Park. It has been described by Akers and others, 1958, and is generally considered to separate the upper and lower Petrified Forest Member. The Sonsela Sandstone has been identified in the park by Cooley (1957) and used by Roadifer (1966).

The Sonsela Sandstone as described by Cooley (1957) includes all of the grayish-white cliff and slope—forming very fine to very coarse-grained sandstone and conglomerate beds between the upper and lower Petrified Forest Members. Mudstone and siltstone layers as well as a few interbedded thin beds of limestone conglomerates containing Unio (?) shells, occur as thin discontinuous lenses within the Sonsela. The Sonsela has an intertongueing relationship with the underlying and overlying shale units. Many of the chert pebbles in the Sonsela contain fossil bryozoa, brachiopods, pelecypods, and fusulinids originating from the Permian Kaibab Formation (McKee, 1936).

Roadifer (1966) introduces the term "camp wash zone," which includes the upper part of the Sonsela Sandstone bed as its lower part (Fig. 2). The term camp wash zone is confusing in this respect and is stratigraphically the same horizon of the flattops sandstone number one used later in this report. The term camp wash is herein dropped from further use and is replaced with flattops sandstone number one, which does not include parts of the Sonsela Sandstone.

The Sonsela Sandstone forms the cliffed mesas at Jasper Forest, Agate Bridge, Blue Mesa, and the ridge east of Crystal Forest. It thins and changes facies to a soft slope forming sandstone and shale before reaching the plateaus of the flattops area. Red petrified logs are found in the Sonsela Sandstone everywhere it is exposed and is the second major stratigraphic layer in the Park. The majority of Sonsela petrified logs are found at Blue Mesa, Jasper Forest, and the Crystal Forest. These logs are commonly red or "jasperized" and roll down-slope to mix with the bluish multicolored logs of the lower Sonsela bed. The red logs are present, but in fewer amounts, wherever the Sonsela bed outcrops in the central sections of the Park, including lower Lithodendron Wash just north of Interstate 40. Petrified stumps of trees that grew in the lower Sonsela Sandstone swamps and streams are commonly found near Blue Mesa and Jasper Forest.

At Lithodendron Wash between the park boundary and Interstate 40 are outcrops of gray-white sandstones and conglomerates with interbedded blue siltstones (Fig. 3). These occur approximately 85 feet (26 m) above the stream bed of Lithodendron Wash and are very similar to those at Blue Mesa approximately eight miles to the southeast. The flattops sandstone number one (camp wash zone of Roadifer, 1966) also has similar lithologic characteristics to those units with a few petrified logs and could possibly be confused as equivalent; however, the flattops sandstone number one is at a higher stratigraphic position. In this report, this sandstone and blue shale series is believed to represent the Sonsela Sandstone horizon for the following reasons: (1) the lithology is strikingly similar; (2) the sandstones and conglomerates are of a similar channeling and lenticular nature; (3) similar stratigraphic thickness and position; (4) scattered jasperized petrified logs in the upper parts; and (5) overlying red siltstones and mudstones are typical of the upper Petrified Forest Member. Direct correlation to Blue Mesa or other areas to the south is speculative at best, even with measured sections.

Upper Petrified Forest Member

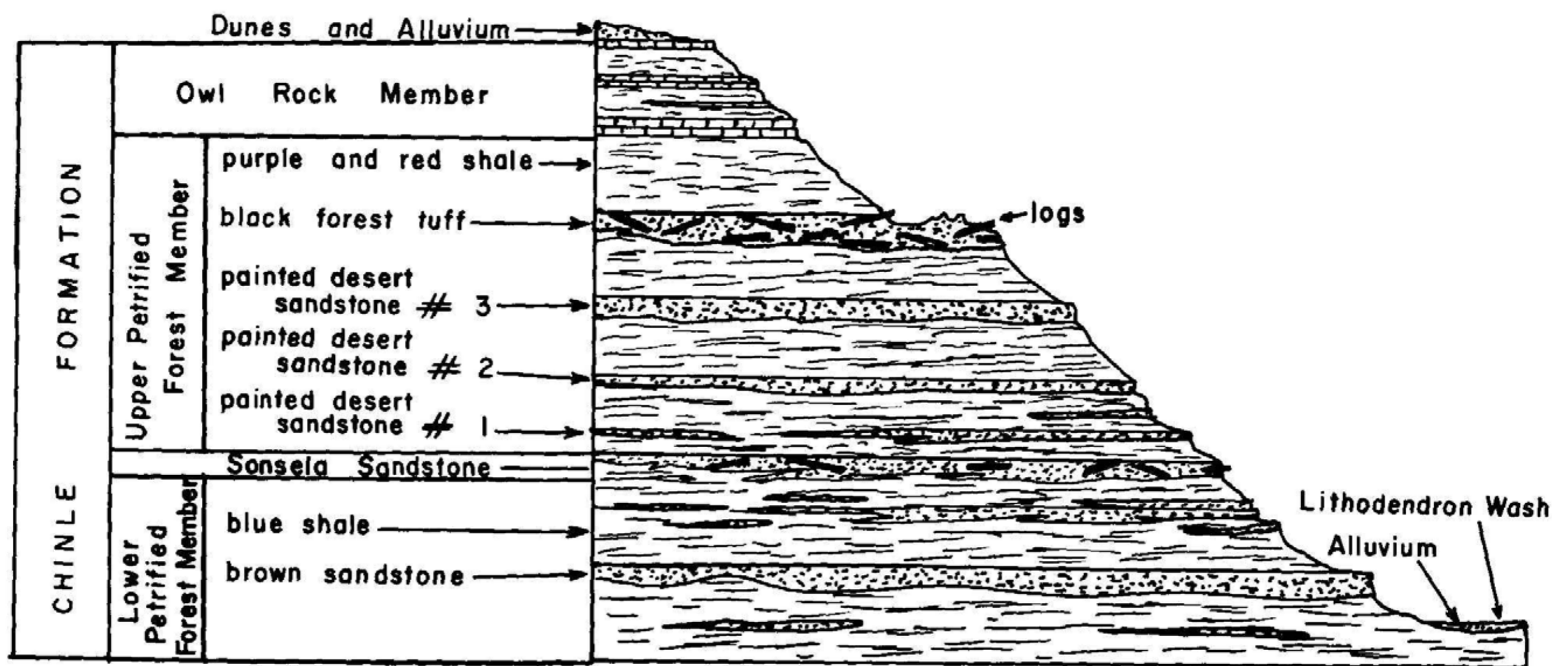Overlying the Sonsela Sandstone are banded grayish-red,

Figure 3. Stratigraphic section (not to scale) of the northern portion of Petrified Forest National Park and vicinity

pale reddish-brown, and pale red-purple lenticular mudstones and siltstones with a few interbedded pale red to grayish ledge forming sandstone beds of the upper Petrified Forest Member (Cooley, 1957). The upper Petrified Forest is nearly 800 ft (243.8 m) thick in Petrified Forest National Park (Cooley, 1957). These beds are exposed in the mesas and plateaus of the flattops area and most of the Painted Desert Wilderness area.

Flattops Sandstones

Several ledge forming sandstone beds occur in the upper Petrified Forest Member in the flattops area. Some of the most prominent sandstone beds are suitable for mapping and correlation purposes because of their extensive lateral continuity, topographic expression, and lithology. Roadifer (1966) recognizes four sandstone beds in this sequence and has informally named them the camp wash zone, flattops number one, two, and three sandstones (Fig. 2). Roadifer also recognizes flattops sandstone one, two, and three in the Lithodendron Wash area although no map was provided to indicate which sandstone was one, two, or three. Measured sections by Roadifer do provide a possible correlation between these two areas; however, the measured sections are several miles apart and provide only a weak basis for correlation because many of the sandstone beds are presently eroded away and were probably discontinuous over large distances. The lithologies of each sandstone are very similar to one another and do not provide much of a basis for distinguishing individual units. The thicknesses of shale beds between these sandstone beds vary considerably from one place to another in short lateral distances and provide a poor basis for correlation. The lower contacts of each sandstone are generally sharp and unconformable with the underlying red-gray mudstones. The upper contacts are gradational into overlying reddish mudstones and siltstones.

Flattops sandstone number one

Flattops sandstone number one (camp wash zone of Roadifer, 1966) is separated from the Sonsela Sandstone by an interval of slope-forming pale reddish mudstone and siltstone approximately 40 feet (9 m) thick. This interval also contains a few interbedded grayish-white sandstone beds that lense in and out laterally, forming a crumbly ledge. One of these sandstones forms a small, elevated bench that is crossed by the park highway about a mile and a quarter south of Crystal Forest. The next prominent sandstone bench caps several small, isolated mesas west of the park road (west of Crystal Forest) which is also the horizon of the flattops sandstone number one. This sandstone also forms the most prominent cliff in the plateau west of the park and is best seen from Jasper Forest.

The flattops sandstone number one contains numerous pelecypod shells in a matrix of sandstone and small chert pebbles cemented with calcite (Roadifer, 1966). A few petrified logs do occur in this sandstone over scattered distances (also reported by Roadifer, 1966). The mesa north of the Rainbow Forest and west of Camp Wash is capped by the flattops sandstone number one, which is approximately 35 feet (10.7 m) thick in this location. The sandstone does not reach the old Highway 180 because of recent erosion.

Flattops sandstone number two

Flattops sandstone number two is widespread from the flattops area westward and forms a caprock on a few isolated mesas superimposed on the prominent plateau west of Jasper and Crystal Forests. Both flattops sandstone number one and two are readily traceable on aerial photos owing to their topographic expression and lateral continuity.

Flattops sandstone number three

Flattops sandstone number three is mainly restricted to the flattops area. This sandstone is characterized by alternating sets of very thinly cross-bedded to cross-laminated light-gray and reddish shaly sandstone beds (Roadifer, 1966). The sandstone weathers to a brownish ledge a few feet thick.

Flattops sandstone number four

Flattops sandstone number four forms the highest sandstone of the flattops area, forming a protective caprock approximately 5 to 10 feet (1.5 to 3 m) thick. Erosion has removed this sandstone from all other areas in the southern portion of the park. A limestone-pebble conglomerate occurs locally at the base of each sandstone in the flattops series (Roadifer, 1966).

Painted Desert Sandstones

The prominent sandstone beds in the northern portion of the park (Painted Desert Wilderness area) are informally referred to as the painted desert sandstones, one, two, three, and the black forest tuff (number one being the lowest unit) (Fig. 3). Roadifer (1966) correlates these sandstone beds (except the black forest tuff) to the flattops sandstones on the basis of measured sections. Cooley (1957) does not correlate these sandstones with any of the sandstones in the flattops area and does not name them. A fence diagram by Cooley (1957) suggests that one of the painted desert sandstones may be equivalent to his chambers sandstone further east. The sandstones at Lithodendron Wash in the upper Petrified Forest Member are treated in this report as separate sandstone units for mapping purposes, and are not correlated to the sandstones of the flattops area.

Painted desert sandstone number one

Painted desert sandstone number one is found only along Lithodendron Wash one mile downstream from Zuni Well. This sandstone forms a mappable prominent ledge in this area and is very local in extent. The basal contact is sharp and unconformable with underlying pale-reddish siltstones as is the case with all painted desert sandstones. The upper contact of each sandstone is gradational with the overlying reddish siltstones and mudstones of the upper Petrified Forest Member.

Painted desert sandstone number two

Painted desert sandstone number two is a mixture of fine to medium-grained sandstone and limestone conglomerate. Low angle and trough cross-bedding are common, and the unit forms a crumbly ledge and weathers into blocks. This unit is mainly restricted to a small area one mile south of Zuni Well and east of Lithodendron Wash and again along the western banks of Dead Wash two miles south of the park headquarters. Elsewhere at this stratigraphic horizon is a very discontinuous small lense of sandstone that fills occasional erosional channels cut into the siltstones.

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Painted desert sandstone number three

Painted desert sandstone number three is the most prominent and widespread sandstone bed in the Painted Desert area. This ledge-forming sandstone is composed of grayish-red, fine-grained, calcareous, cross-bedded sandstone and contains lenses of limestone conglomerate in the lower part. The most distinctive feature of this unit is the curving beds of cross-bedded sandstone exposed on eroded surfaces. The curving beds formed as distinctive point bar deposits of a meandering stream pattern clearly seen with aerial photos.

Black Forest Tuff

The Black Forest tuff is located in the central area of the Painted Desert Wilderness area represented by a distinctive pinkish-gray tuff and sandstone bed. The petrified logs associated with this unit are generally black with little variation in color and are stratigraphically higher and younger than the petrified logs exposed in the southern half of the park. The pinkish-gray tuff is not correlated with any of the flattops sandstones but probably occurs at a stratigraphic position between the flattops sandstone numbers three and four. The Black Forest bed is an excellent marker horizon in the sedimentary sequence of the upper Petrified Forest Member, and contains interbedded lenses of Unio (?) limestone that are very local in extent.

Thick deposits of reddish-brown and gray-purple mudstones and siltstones of the upper Petrified Forest Member gradationally overlie the Black Forest tuff forming vast areas of scenic badlands northward to Pilot Rock and Chinde Mesa.

Owl Rock Member

The Owl Rock Member of the Chinle Formation is exposed at Chinde Mesa along the northern boundary of the Petrified Forest National Park. The Member is primarily a pale-red calcareous siltstone with alternating beds of light greenish-gray limestone and nodular limestone, forming a steep slope 120 ft (36.6 m) thick. The boundary between the Petrified Forest and the Owl Rock is gradational and arbitrarily placed at the first limestone bed in the sequence. The upper part of the Owl Rock at Chinde Mesa has been removed by erosion and is now covered by a thick mantle of surficial sand and alluvium.

Bidahochi Formation

The Bidahochi Formation crops out in isolated places in the northern portion of the Petrified Forest National Park. Only the lowermost sediments of the formation are exposed. The Bidahochi is found around the park headquarters area, Pilot Rock area, along the plateau ridge northeast of the park headquarters, and in erosional scarps of Dead Wash south of the park headquarters. The Bidahochi sediments were deposited in a fresh water lake environment as a pale yellow, silty mudstone and siltstone that once covered much of the park area approximately three to six million years ago. Erosion has since removed much of the Bidahochi from the park area. Monchiquite lava flows erupted into and onto the lake sediments of the lower Bidahochi Formation and formed landmark features such as Pilot Rock and the Painted Desert view point area.

Surficial deposits of windblown sand and alluvium are very extensive deposits that mantle the mesas, plateaus, and valleys of the park. These deposits represent the most recent deposits of the area and are largely stabilized with vegetation, mainly grasses. Parabolic sand dunes are common along the Lithodendron valley north of the Painted Desert view point.

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The Geology and Climate of the Indigenous Forest, Petrified Forest National Park, Arizona

by Terah L. Smiley

ABSTRACT

Fossil remains of flora and fauna of Triassic age are being eroded from rocks comprising the Petrified Forest Member of the Chinle Formation. The fossils and the rock matrix indicate an original physical environment considerably different than that now present in the Petrified Forest National Park.

In the Triassic, this area was on the northwest leading edge of the northward moving Pangaea supercontinent. The northern half of the Arizona area was then equatorially located and part of a broad but low-lying hummocky coastal plain, and the southern half was part of a high volcanic mountain area in which rivers rose to meander north and west across the plain before emptying into the nearby Triassic ocean. Catastrophic events such as a nuee ardente or laharic activity on or near mountain flanks, or explosive volcanos with excessive ash could have quickly destroyed and buried vegetation and animals living in the area. Tectonism continued and the Arizona land was submerged beneath ocean waters several times and each time it received a heavy blanket of marine sediments. With the northward movement of the continent and the rise of the Colorado Plateau, the Park area is quite different than when the trees were a living forest. Erosion is today stripping away the overlying rocks and the fossil flora and fauna are being exposed.

INTRODUCTION

The Petrified Forest National Park in northeastern Arizona was created in 1906 primarily to preserve the results of a long series of geologic, climatic, and botanic processes operating over the last 200,000,000 or so years. These various processes originally were responsible for the formation of forests of tall araucaria, woodworthia, and schilderia trees as well as for their quick destruction, burial, petrification, and eventual exposure. This spectacular collection of silicified "logs" is now eroding from colorful variegated bentonitic claystone, clayey sandstone, and conglomerate rocks.

Today, the area is a high steppe type located at approximately 35° North Latitude, 110° West Longitude, and is roughly at 1,650 meters (5,400 feet) in elevation. Surrounded by higher lands, it is dry and relatively mild in temperature with an average rainfall of 190 millimeters (7.5 inches) and a mean annual temperature of 12.7° Celsius (54.8° Fahrenheit). What we see and experience here today is not, however, the same as that which we would have seen and experienced if we had been here when these petrified remains were living trees; there have been changes.

The crust of the Earth is, in general, constantly moving.

Continental land masses, called "plates," drift over the Earth's surface. Land areas rise and fall. Earthquakes and volcanos are but two catastrophic manifestations of several of these changes. Erosion by water and wind moves high elevation land materials to low areas, even to ocean bottoms. Arizona, as part of the North American plate, is no exception to such changes. It is, however, only when viewed through geological time that these changes become evident.

Recent advances in several areas of research allow a reconstruction of past conditions that was not possible even as late as ten years ago. Studies in the geology, the climate, and the botany of the area at the time of the indigenous forest now allow us to make what we believe to be a reasonable but sketchy reconstruction of the environment at the time the petrified logs were living trees.

THE GEOLOGY

The present-day steppe area in which the park is located, has moved some over the face of the Earth since the time the petrified logs were living trees. It has also been drowned beneath ocean waters, covered with a thick blanket of sediments, raised again above sea-level, scoured by wind, washed and eroded by rain, baked by the sun, and blistered by volcanos—to name several of the natural processes that have altered that ancient land into what we see today.

Approximately 250 million years ago during the Permian Period, most of the present-day continental areas were loosely united into a large, predominately southern supercontinent we now refer to as Pangaea (Figure 1). The southern portion of Pangaea that is now Antarctica and Australia was extensively glaciated, but since the large supercontinent was moving north, the glaciation gradually disappeared. The Arizona territory was at that time part of the northwestern continental shelf and was covered by relatively shallow oceanic waters with several large islands projecting above the surface (Figure 2).

Tectonic forces were not only moving Pangaea northward, but they were also changing surface elevations, and by 200 or so million years ago, the Arizona area was elevated above sea level. The supercontinent was also being latitudinally rifted into two major areas: Gondwana to the south and Laurasia to the north. The Arizona area was on or near the geographical equator and was part of the leading edge of the rotating North American portion of the Laurasian land mass (Figure 3). The tectonic forces exerted by pressure and compression of these moving land masses caused the development of a high, volcanic mountainous area, the Mogollon Highlands in southern Arizona, and a broad but
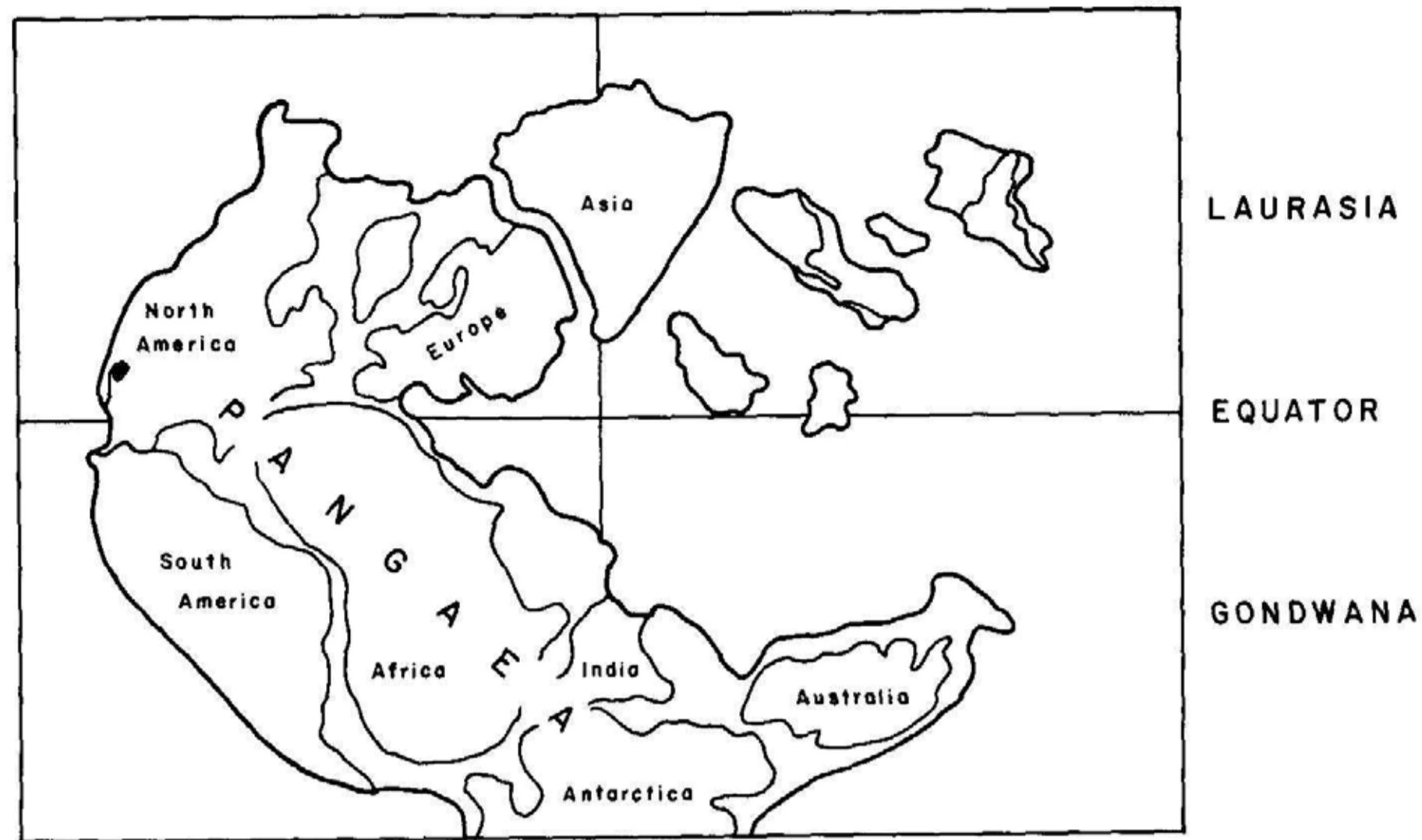
Figure 1. A reconstruction of the supercontinent of Pangaea of approximately 250 million years ago based on recently completed paleomagnetic studies. Many large islands had not yet coalesced to form the Asiatic mainland. Redrawn from *Science 81* (John C. Holden - 2), December 1981, p. 7.
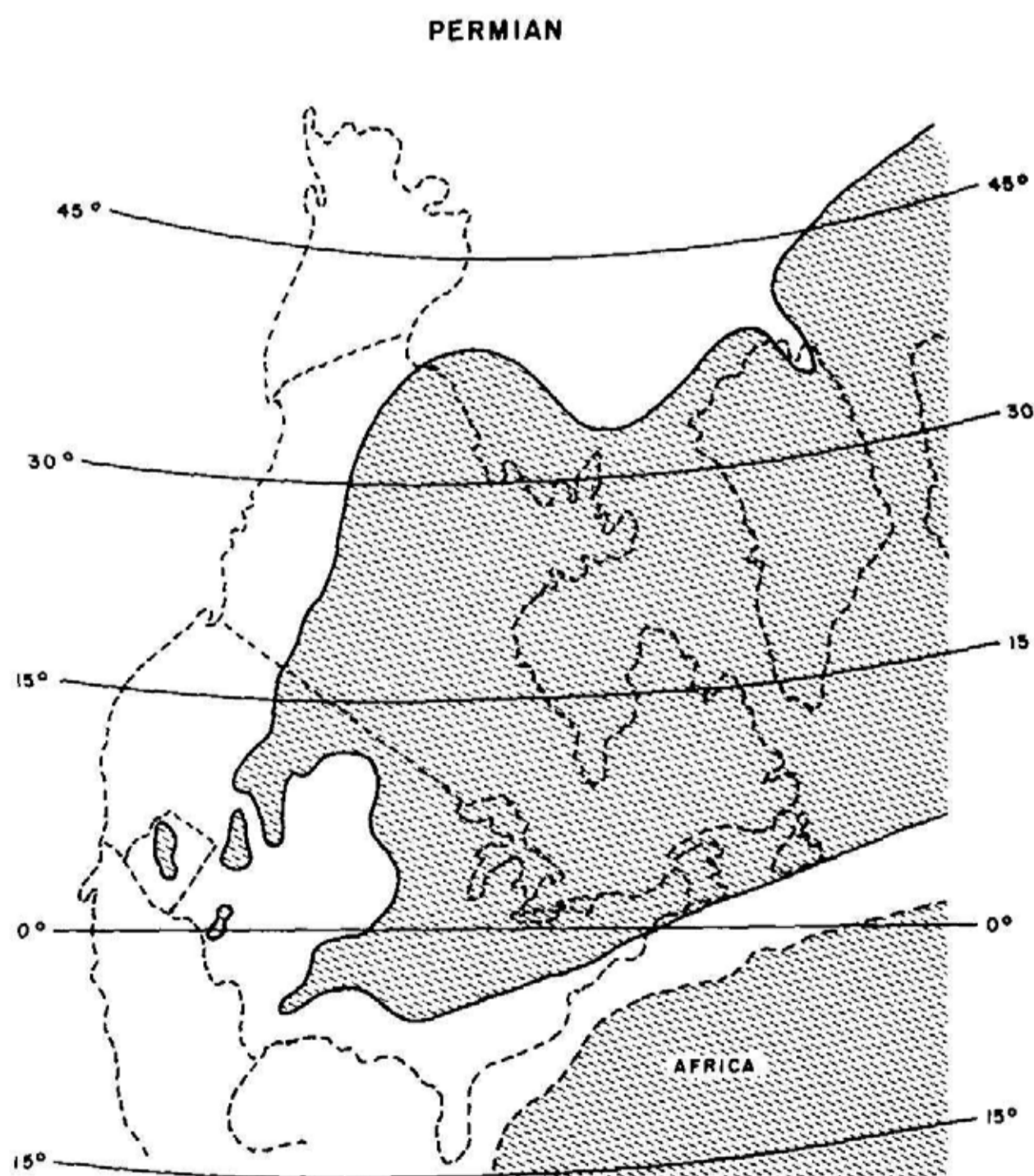

Figure 2. The extent and position of the North American land mass during Permian, or Pangaean, times approximately 250 million years ago. Permian seas covered a large portion of what is now western and southern North America. A large island extended diagonally across the Arizona area. (After Seyfert and Sirkin, 1979.)
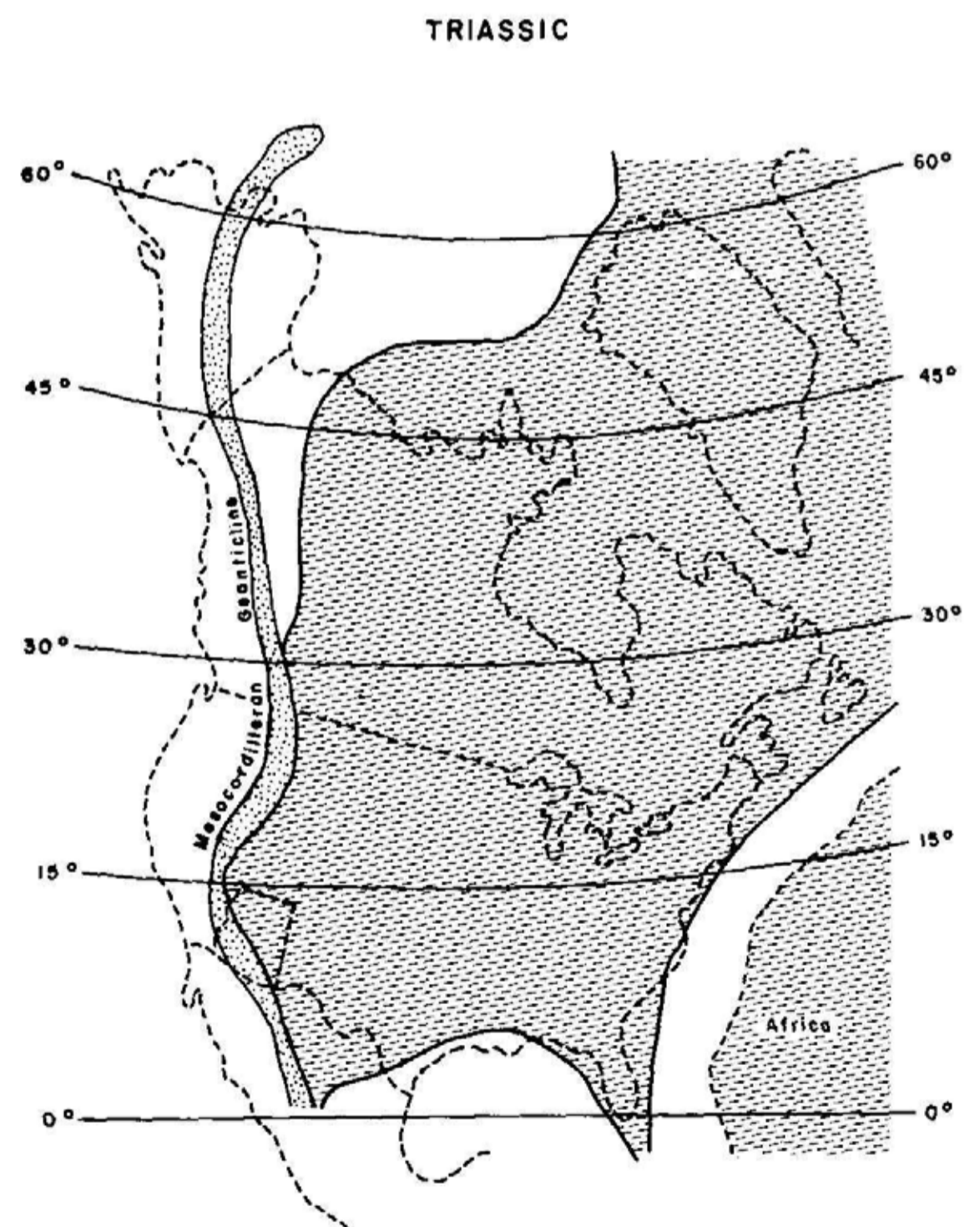
Figure 3. The extent and position of the North American land mass (shaded) during the Triassic, or late Pangaean, times approximately 200 million years ago. The land mass was rotating and moving northward, and the Arizona area had emerged from the Permian seas. (After Seyfert and Sirkin, 1979.)

low-lying hummocky coastal plain in the northern portion of this area (Figure 4). Adjacent to the northeast corner of the state was another elevated region of intense volcanic activity, the Uncompahgre Highlands. Rivers with headwaters in these highland areas meandered north and west across this coastal plain to empty into the nearby Triassic Sea. The wide stream-valley flood plains contained numerous lakes, marshes, and swampy areas.

The enormous quantities of material ejected by the volcanic activity in the highlands were carried away by winds and by the streams. Thick deposits were accumulated over the southern part of the coastal plain nearest the Mogollon Highlands, thinning to the north and west; many of these thick deposits could have been a result of laharic activity on or near the flanks of the mountains. These deposits later were to be turned into horizontally stratified claystone, clayey siltstone, cross-stratified clayey sandstone, and conglomerates containing chert pebbles of Permian age. The deposits also contained quantities of volcanic glass and other small volcanic particles that were quickly altered to
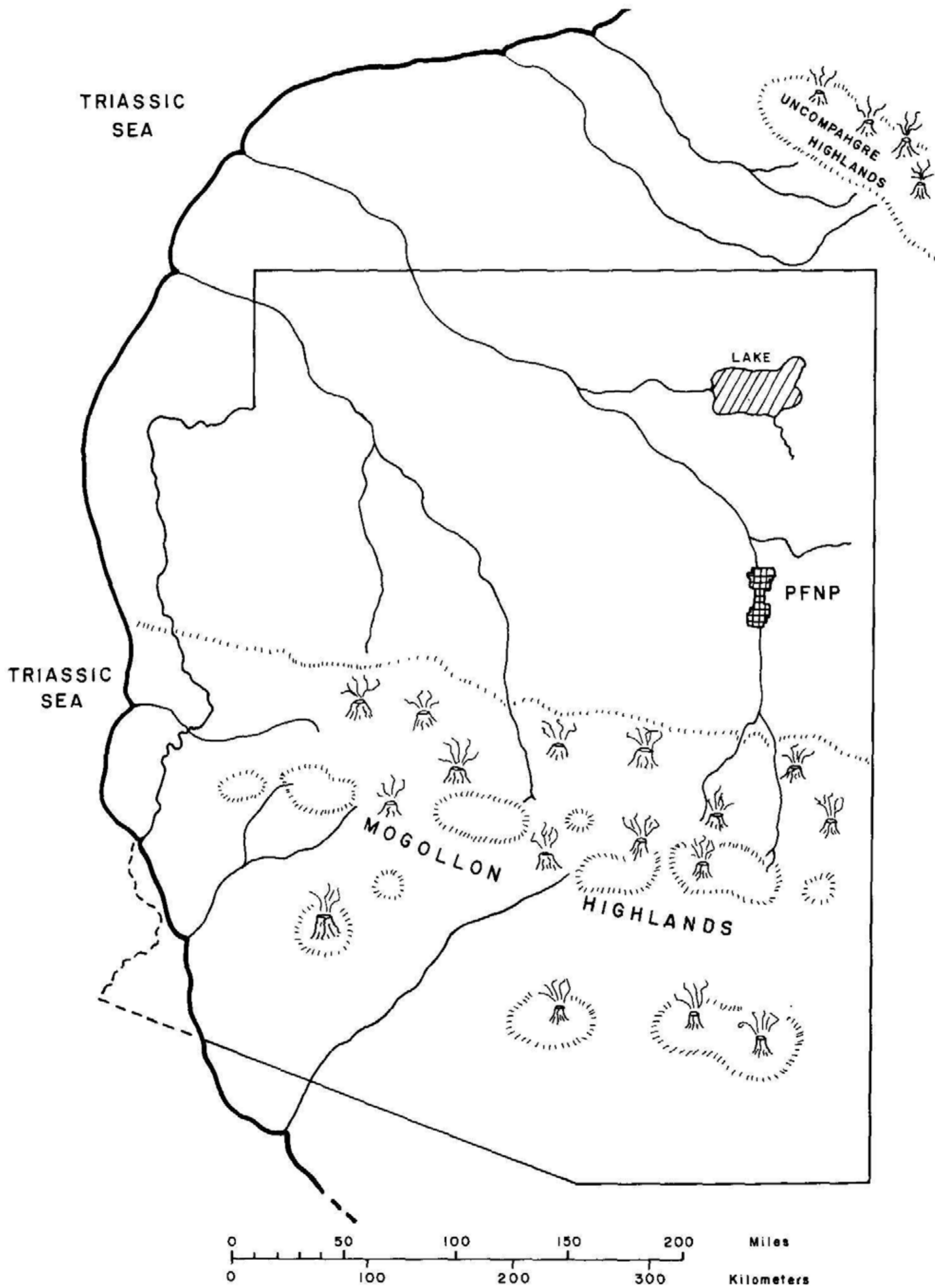

Figure 4. The Arizona area during Triassic times approximately 200 million years ago—when the petrified logs were an indigenous forest. A broad coastal plain extended from the highlands areas west and north to the Triassic Sea. The Petrified Forest area, marked as PFNP, was on the coastal plain but near the Mogollon Highlands.

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montmorillonitic clay. The environment of rapid deposition was excellent for the burial, preservation, and fossilization of any plant or animal remains trapped in a still-water locality. The water was rich in dissolved silicates, and as it soaked into the buried remains, it deposited the silica and other minerals in the petrification process.

Several areas immediately around the *in situ* tree stumps contain what could be considered to be ancient soil clumps. Other than in these limited occurrences, no widespread fossil soil horizons have as yet been found anywhere in the Chinle Formation unless the Mottled Strata, found in the very beginning, or bottom, of the Chinle depositional period proves to be of such an origin. The lack of any fossil soil horizons possibly indicates that there was fairly constant deposition, and no ground surface remained stable for a long enough period for soil to form.

The surface of this coastal plain continued to change as additional sediments accumulated. Streams changed courses and lakes were formed and destroyed—as were swamp areas. The highlands were gradually eroded as volcanism in those areas lessened. Approximately 100 million years ago, during Cretaceous times, oceanic waters again covered this area, and ocean bottom sediments accumulated on top of the earlier continental materials. Later, the area once again rose from the Cretaceous waters, and erosion started stripping away the thick deposits of accumulated sedimentary rocks. The process was slow, however, since the area remained at low elevation.

Thirty-five million years ago, tectonic forces began uplifting and forming the Colorado plateaus. The plateau area uplift has been widespread and uniform, and the stratified rocks have remained essentially horizontal with only minor changes. Approximately six million years ago, this area was once again covered with water—only this time, it was the fresh water of Lake Bidahochi. The lake did not last long in geological time, and following its drainage at least 5 million years ago, erosion again began stripping away the thick sediments. This process has, in places, removed all the overlying materials until, once again, the original sedimentary layers containing the petrified logs are being exposed.

THE FOREST

The dominant botanical features seen in the park today are the petrified remains of what was once a Triassic "forest." Nearly all of the petrified logs were formerly tall *Araucarioxylon, Woodworthia,* and *Schilderia* trees. Numerous other plant types are represented by the fossil remains of woody stems, branches, twigs, leaves, and fruits as well as by microscopic pollen and spores (see the report by Ash, in this report).

Large, somewhat scattered petrified stumps with spread root systems have been found in several localities within the park area. The root molds today are generally filled with limonite, a mixture of crypto-crystalline minerals common to regions containing iron-bearing minerals that have been subjected to oxidation. The stumps are rather widely spaced;
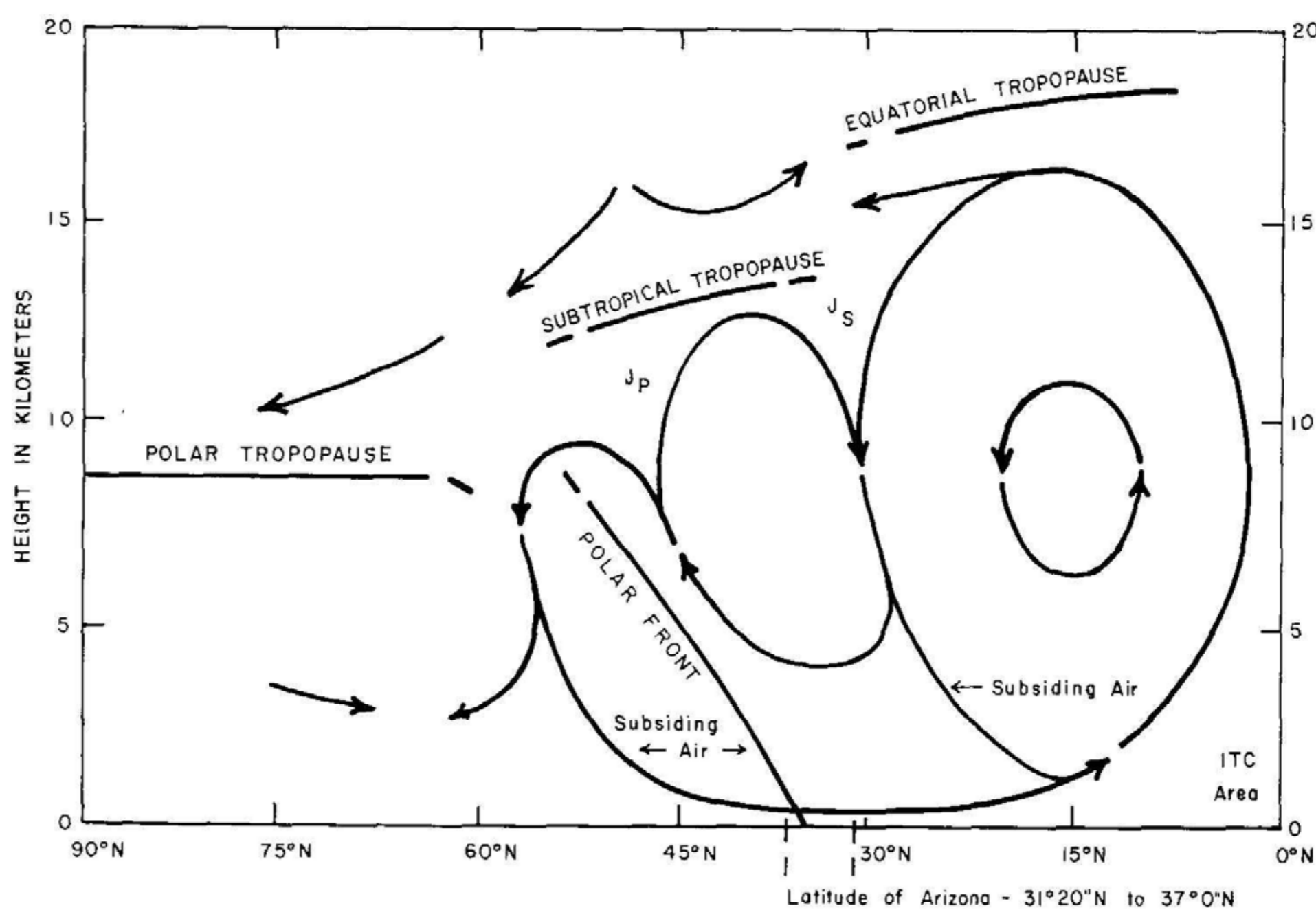

Figure 5. A highly generalized diagram of air circulation seen in cross-section along a meridian reaching from the Equator to either pole (the North Pole in this diagram). *Jp* marks the location of the Polar jet stream, and *Js* marks that of the Subtropical jet stream; both blow toward the east. Note the latitudinal position of Arizona as related to this circulation model. Its position is directly in the path of the greatest atmospheric subsidence, and the Polar front also reaches southward into the state. The Southern hemisphere has essentially a mirror image of this circulation, and the equatorial area where the two circulation systems meet is called the Intertropical Convergence Zone, or the ITC. (After Lamb, 1966.)

thus, unless differential burial and preservation took place, the forest was, at least in this hummocky area, more of an open woodland type. The preservation of the stumps *in situ* could indicate that heavy, reasonably catastrophic deposition took place on the hummocky areas as well as on the flood plains.

It is impossible at this time to determine the full extent of the "forest" over the entire coastal plain. Petrified wood has been found in most areas where the Petrified Forest Member of the Chinle Formation outcrops. It is equally impossible to determine whether the logs came from nearby stump areas or if they were washed far downstream from higher areas to the south and settled in quiet ponded waters along the river courses. In either case, they had to have been quickly covered by sediments in an anaerobic environment that would have slowed decay until such time as silicates in solution could gradually replace the wood materials.

The cause of death and fast burial of the logs can only be speculated upon. Volcanic phenomena such as a *nueé ardente*, or an ash flow, or a Krakatoa-like eruption could cause widespread devastation and fast burial under ash. Certainly the Mount St. Helens explosion of 18 May 1980 demonstrated the effect such a volcanic explosion can have on a forest. It also resulted in the burial of logs and other debris by flood waters nearby as well as many kilometers downstream from the volcano. Many logs in the Blue Forest area are encrusted with charcoal as though they had been burned by fire. Although forest fires could have been responsible for the burning, a *nueé ardente* or an ash flow would have the same effect as at the St. Helens eruption where charring by the extremely high temperatures of the explosive gases extended for many kilometers from the mountain.

Other botanical materials, as described by Ash elsewhere in this report, fit into the equatorial, humid, forest-like environment. The animals inhabiting the area, as described by Colbert (this report), indicate a climate for the indigenous forest that was warm and moist with mild, if any, temperature change between seasons.

CLIMATE

The climate within the park area at the time of the indigenous forest was considerably different from the present one. It is necessary to explain the physical aspects of modern climates before an understanding of the local Triassic climate can be had.

The climate of any specific area results from the interaction of many atmospheric and geologic conditions and processes such as solar radiation, atmospheric properties and
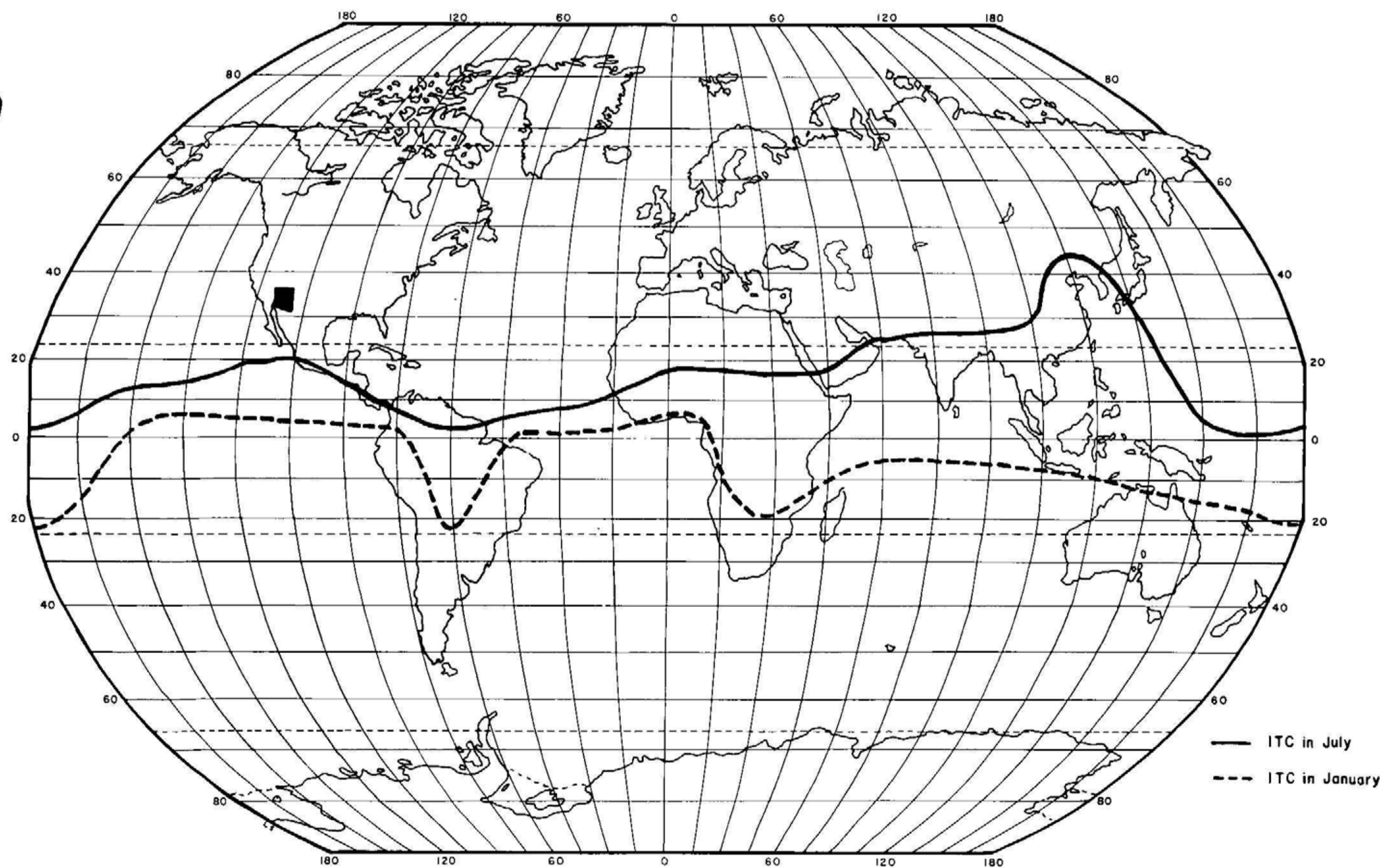

Figure 6. The July and January positions of the Intertropical Convergence Zone (ITC) that marks the location of the heat balance equator between the Northern and Southern Hemispheres. The equatorial area is, in actuality, a broad band moving back and forth with the seasons and local conditions. (After Lamb, 1966, p. 42.)

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circulation, configuration of continents and oceans, geographic location on the Earth, land roughness, and elevation.

The equatorial area of the Earth receives approximately 2.5 times as much incoming solar radiation as do the polar areas. This excessive heating causes an imbalance in heating the Earth's surface and the atmosphere. Thus, the hotter, less dense air must move toward colder and denser air. H. H. Lamb published in 1966 a model of the circulation patterns the atmosphere takes as it heats and moves from the equator toward the poles (Figure 5). As the atmosphere in the equatorial area heats, it expands, and because it is light, it rises to its buoyancy level, or tropopause. The air in the opposite hemisphere undergoes the same process. Thus, where the two meet, they form the Intertropical Convergence Zone. As the air rises toward the tropopause, it moves horizontally and cools. Because of its density, the air begins to descend. Other circulatory rises and descents take place before the air reaches the polar areas. These circulatory movements, called Hadley Cells, transport the excessive equatorial heat toward the poles.

Actual atmospheric circulation is different, however, from this model, since numerous physical conditions cause considerable distortion. For example, the rotation of the Earth causes a drag effect, mountain ranges act as circulation barriers, land roughness interferes with surface winds, land elevations exercise limiting controls over temperature, and water and land surfaces absorb and give off heat at different rates.

Today, seventy percent of the Earth's land areas are in the northern hemisphere and seventy percent of the Earth's ocean areas are in the southern hemisphere. Because of the land-water hemisphere unbalance, plus the prior listed modifiers, the "heat-balance" equator, or the Intertropical Convergence Zone (ITC), is well to the north of the geographic equator in July and somewhat south of it in January. The "heat-balance" equator (ITC) is, climatically speaking, a broad zone with several irregularities caused by

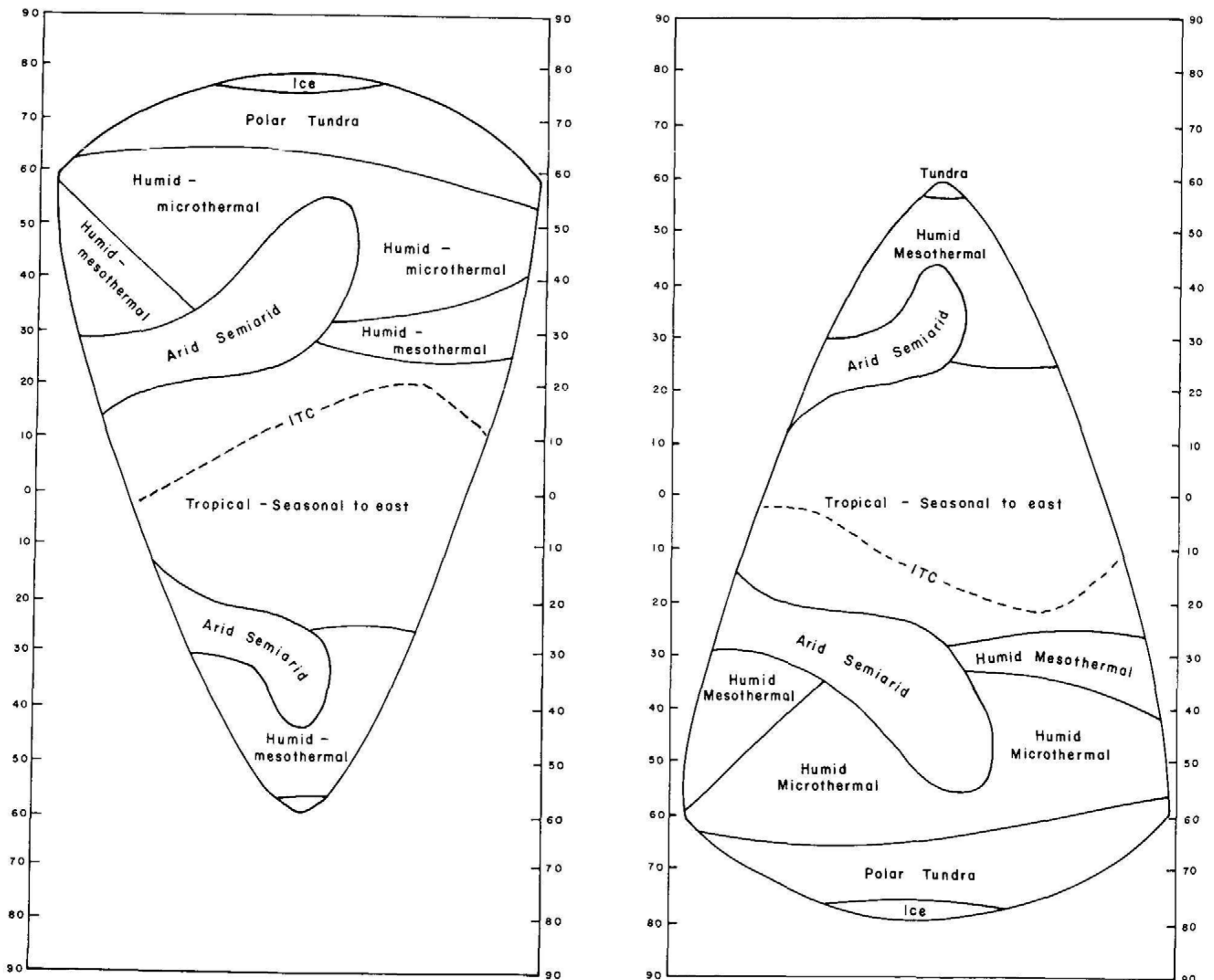Figure 7. The types of climate possible on hypothetical supercontinents based on Trewartha's boundary conditions. *Left*, A modified version of Trewartha's arrangement of the principal climatic types on a hypothetical supercontinent of low relief and uniform elevation. *Right*, A reversed map of the one at left, which is not too different from the map of Pangaea shown in Figure 1. (After Trewartha, 1954.)

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the position of the continents and the oceans, as shown in Figure 6. The temperate and polar climatic zones do not have as much seasonal variations in their positions as does the tropical zone and are not as clearly defined.

A model of a hypothetical supercontinent with low and uniform land elevations was published by G. T. Trewartha in 1954. He superimposed on it climatic types according to various boundary conditions. Because of the disproportion of land and water in the two hemispheres, the climatic zones are moved northward much as they are today (as shown in Figure 7A). Figure 7B shows this same diagram reversed, with the bulk of the land mass in the southern hemisphere much like it was in Pangaea times as shown in Figure 1 when the south polar area was being glaciated. The presence of mountain ranges or other land elevations would cause many proportionate distortions.

Approximately 200 million years ago, the Arizona territory had a high mountain range during the time of the indigenous forest when the Mogollon Highlands covered the southern portion of the state. This highland area would have acted as a barrier to the normal flow of meridianal atmospheric circulation, and the Trade Winds moving toward the Intertropical Convergence area would have had to rise—creating a heavy rainfall on the mountains. A heavy rainfall would have given ample headwaters for streams moving out and across the northern coastal plain in a manner somewhat similar to the way the present-day Blue Nile comes out of high areas in Ethiopia. Certainly, the higher land elevations had sufficient rainfall to support a forest or a "savanna-like" forest with its understory vegetation.

The climate near the seashore on the northwestern edge of the broad coastal plain was probably dry, but there was increasing precipitation inland toward the Mogollon and Uncompahgre Highlands. Local rainfall in the park area probably was seasonal and moderately light; otherwise, many of the iron oxides and other heavy minerals present would have been leached from the soils. Fossil lateritic soil horizons have not been discovered in the park area although the mottled strata at the base of the Chinle Formation might be indicative of a soil zone.

The climate of the area at the time of the "indigenous forest" was warm equatorial, probably with pronounced wet-dry seasons in the highlands.

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A Short Thick Cycad Stem From the Upper Triassic of Petrified Forest National Park, Arizona, and Vicinity

by Sidney Ash

ABSTRACT

Charmorgia dijolii gen. et sp. n. is a short thick stem with an armor of closely spaced, rhombic, persistent leaf and cataphyll bases. The stem agrees with certain members of the Cycadales in many features including medullary vascular bundles, possible girdling leaf traces, and cyclocytic stomata. Unlike the living Cycadales, however, the vascular bundles in the leaf bases of *Charmorgia* contain a large amount of centrifugal metaxylem as in the Cycadeoids. *C. dijolii* gen. et sp. n. occurs in the Upper Triassic Chinle Formation of Arizona and is the first short thick cycad stem to be described from rocks older than Paleocene.

INTRODUCTION

Fossil cycad stems are very rare in the geologic record. Only eight genera based on fossil stem material that have been described in the past can be attributed with reasonable assurance to the family, and most of them are based on just a single specimen. In this paper, a ninth genus is described from the Upper Triassic Chinle Formation in Petrified Forest National Park, Arizona, and vicinity. It is based on three specimens and is referred to *Chamorgia dijolii* gen. et sp. n.

MATERIAL AND METHODS

The stems on which the new genus is based are petrified and were studied mainly by the thin section technique. Acetate film impressions of the epidermis on the leaf and cataphyll bases were also used. The peel technique was tried but it was not very successful. A few fragments of the stems were dissolved in hydrofluoric acid, a technique which yielded broken hairs, tracheids, and isolated cells. The holotype of the new genus and the slides made from it are in the collections of the Museum of Northern Arizona (MNA), Geology Series, G7.257. The paratypes and the slides made from them are in the collections of Petrified Forest National Park (PFNP), catalogue numbers 1352 and 2471.

SOURCE

The holotype (MNA G7.257) was found weathering out of the Petrified Forest Member of the Chinle Formation at locality 1 on Figure 1 about 7 km north of the Cholla Electrical Generating plant between Holbrook and Joseph City, Arizona, by Mr. Charles Morgan of Flagstaff, Arizona. In 1967, I visited the locality with Mr. Morgan and collected additional fragments of the fossil from the formation. The fragments were concentrated within an area of about one square meter. The paratypes were found weathering out of the Petrified Forest Member of the Chinle Formation in the southern part of Petrified Forest National Park, 50 km east

of the locality that contained the holotype as shown on Figure 1. Paratype PFNP 2471 was collected from locality 3 (see Figure 1) in 1964 by P. F. Van Cleave, who was then the Chief Naturalist of the park and paratype PFNP 1352 was collected in 1958 from locality 2 (Figure 1) by H. N. Heward, an employee of the park. The paratype (PFNP 2471) collected by Van Cleave was nearly complete when found, but most of it has since been lost. All three fossils occurred at about the same horizon in the lower part of the Petrified Forest Member and were associated with fragments of colorful petrified wood typical of the Chinle Formation.

Although these fossils were not extracted from the Chinle Formation by the collectors, I am satisfied that they came from that formation. Their mode of preservation is very similar to that of other petrifications in the Chinle and is unlike that of the cycadeoid trunks reportedly found in the Cretaceous of New Mexico. In addition, the present fossils are so fragile that it does not seem possible that they could have been transported to where they were found by early rivers or other agencies from any other formation. In fact, they probably had been exposed for only a fairly short time (geologically speaking) before they were collected. There are few other possible sources for these fossils in the vicinity of the cycad localities. Except for Quaternary alluvium, the only younger formation exposed within about thirty km of the localities is the late Teritary Bidahochi Formation (see Figure 1). That formation is represented by small discontinuous exposures in the vicinity of the localities and is not known to contain petrified wood. Cretaceous strata are present thirty km or more from the localities yielding the fossils described here. Although cycadeoid trunks were reportedly obtained from Cretaceous strata seventy-five km. or more east of the Petrified Forest by Wieland (1930), it is difficult to believe that such fragile fossils could have been transported from that area by streams to where they were found. The Early-Middle Triassic Moenkopi Formation and Early Permian Kaibab Limestone are widely exposed in areas adjacent to the localities, but they are not known to contain petrified wood.

Several other genera based on wood collected in the Petrified Forest and vicinity were found under similar circumstances as *Charmorgia*—i.e., apparently weathering out of the Chinle Formation. These fossils include *Chinlea* Daugherty (1941), *Lyssoxylon* Daugherty (1941), and *Itopsidema* Daugherty (1960). They are generally attributed to the Chinle Formation without hesitation by other authors, although the attribution of *Lyssoxylon* to the Chinle For-
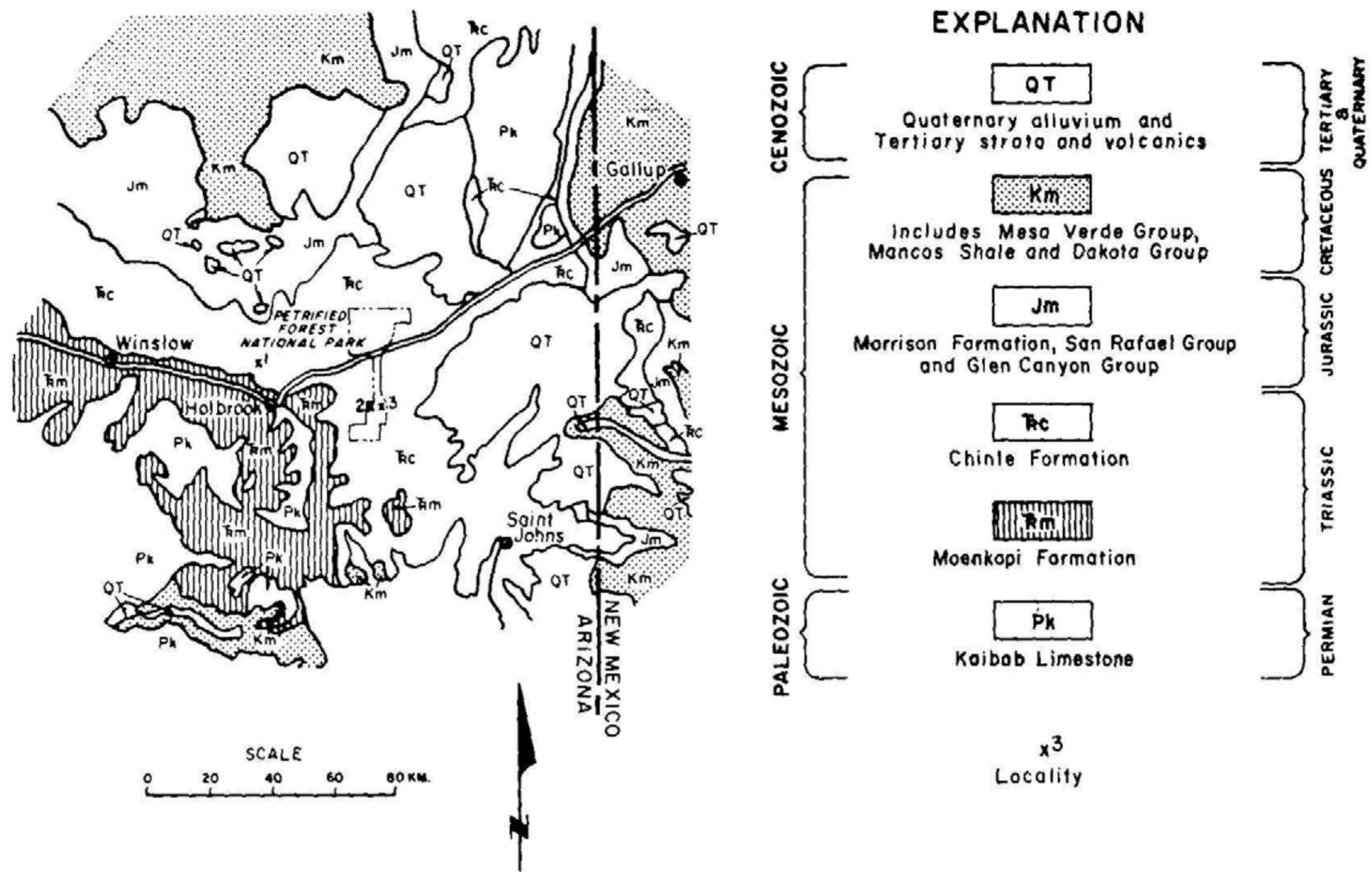
Figure 1. Geologic map of part of east-central Arizona and adjacent areas in New Mexico showing the localities where the remains of *Charmorgia dijolii* gen. et sp. n. were collected. Wieland (1930) obtained cycadeoid trunks from Indians living north of Gallup, New Mexico, on the right side of the map. He presumed that the fossils came from the Mesa Verde Group of Late Cretaceous age in that area, but this has never been confirmed. Adapted from the geologic maps of Arizona (Wilson and Moore, 1969) and New Mexico (Dane and Bachman, 1965).

mation is rather tenuous. The holotype of that taxon was collected from an island in the Rio Puerco near the western boundary of the Park where it could have been carried from the Cretaceous or Jurassic rocks to the east much more easily than the three specimens of *Charmorgia* described here. Furthermore, the paratypes of *Lyssoxylon* came from a locality in western New Mexico which is only 6–8 km from extensive deposits of Jurassic and Cretaceous age that could have been their actual source.

The Chinle Formation is of Late Triassic age and is roughly equivalent to the Keuper Stage of Germany (Stewart and others, 1972). It appears that the fossils described here occur in the *Dinophyton* floral zone of Ash (1980), which is thought to be middle to late Carnian in age.

PREVIOUS INVESTIGATIONS

The holotype of *Charmorgia dijolii* gen. et sp. n. was first reported by Breed and Ash (1969), and the larger paratype (PFNP 1352) was first mentioned by Ash (1972). In both reports, the fossils were attributed to the Cycadeoidales because of their superficial resemblance to previously described cycadeoid stems. The fossils were later mentioned by Delevoryas (1976, 1982), who also attributed them to the Cycadeoidales. Recently, however, after detailed anatomical studies of the fossils were made, they were placed in the Cycadales (Ash, 1979).

DESCRIPTION

The original height of the holotype is unknown because the upper and lower ends are missing. However, the arrangement of the persistent leaf bases indicates that the stem was probably originally short (Pl. 1, Figs. *e-h*). In cross-section, it is round, has a diameter of about 24 cm, and is now about 10 cm tall. The stem does not appear to have been compressed very much, if at all, but the pith has collapsed—forming a conspicuous broad cavity on the base (Pl. 1, Figs. *g, h*). Preservation varies considerably in the fossil. The pith and cortex are generally poorly preserved, having been replaced almost entirely by translucent chalcedony typically showing only faint traces of ducts and vascular strands. Some pith and cortical cells, however, are preserved in a few places near the vascular cylinder. The secondary xylem and phloem of the stem are reasonably well preserved in places, but the cambium and primary tissues have not been identified. The leaf and the cataphyll bases are the best preserved parts of the stem as many have been permineralized and show most types of cells, some even with cellular contents. A mat of hairs occurs in a thin discrete layer of mineral matter between the bases (Pl. 3, Figs. *b, g, h*).

Paratype PFNP 1352 is nearly complete and clearly demonstrates the short, thick form of the stem (Pl. 1, Figs. *a-c*). It is more or less oval in cross section and is 22 × 30 cm in diameter and about 10 cm high. The base of the fossil shows a small oval and more or less flat area that is the scar where the tap root was attached (Pl. 1, Figs. *c, d*). The fossil has been obliquely and much more strongly compressed than the holotype. Consequently, the persistent leaf bases are now tightly compressed and somewhat distorted (Pl. 1, Figs. *a-d*). It has been permineralized to totally replaced by an iron rich silicate mineral similar to jasper. Cellular detail is generally lacking in the fossil or is strongly distorted by compression. Paratype PFNP 2471 is represented only

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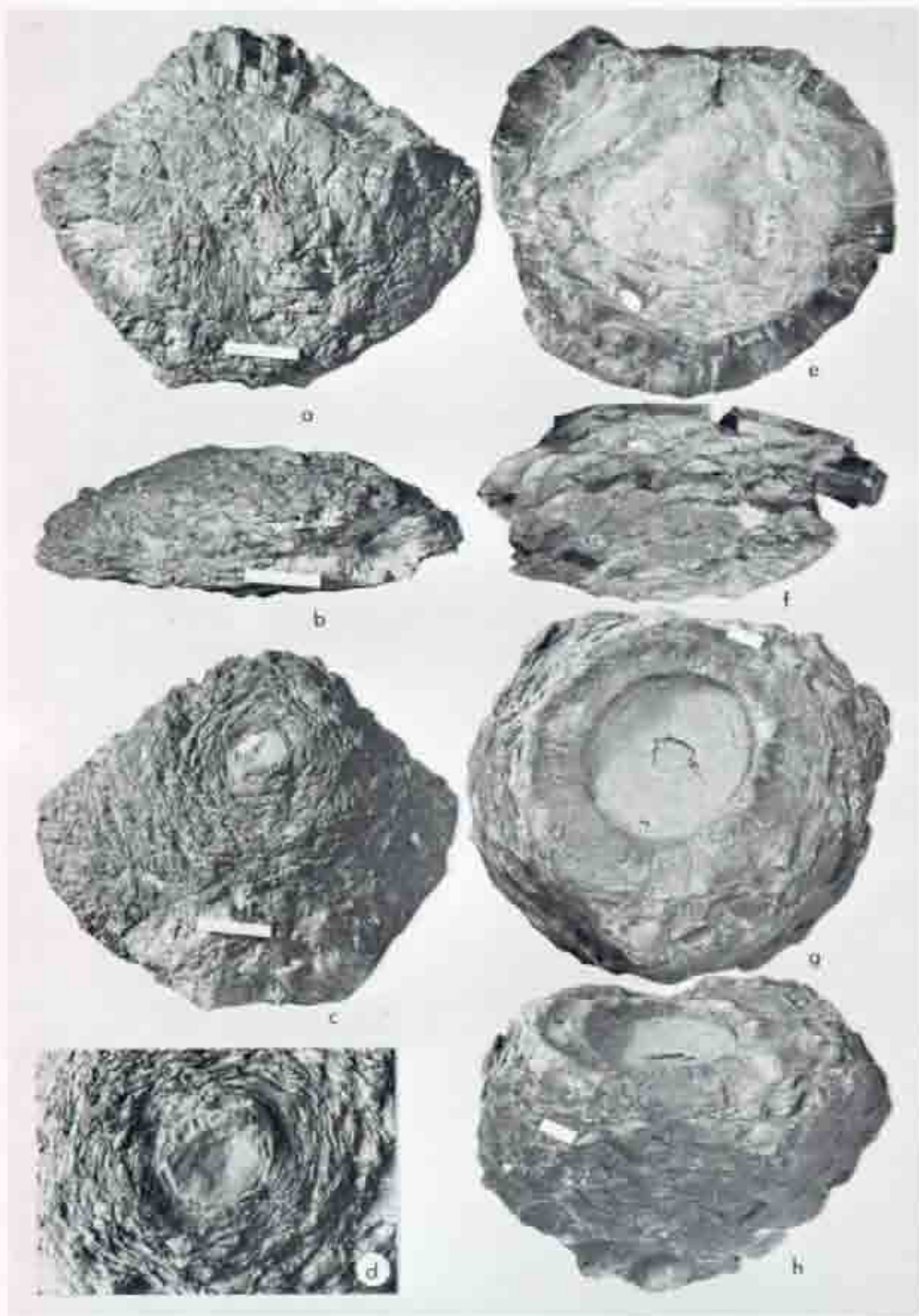
Plate 1. *Charmorgia dijoli* gen. et sp. n. *a*. Apex of paratype from above. PFNP 1352 × ⅓. *b*. Side view of paratype. PFNP 1352 × ⅓. *c*. Base of paratype showing tap root scar from below. PFNP 1352 × ⅓. *d*. Tap root scar on paratype. PFNP 1352 × ⅓. *e*. Apex of holotype from above. MNA G7.257. × ⅓. *f*. Side view of holotype. × ⅓. *g*. Base of holotype from below showing the conspicuous depressed pith area. × ⅓. *h*. Oblique view of holotype showing the depressed pith area. × ⅓.

by fragments of wood and one fairly complete leaf base (Pl. 3, Fig. 3c). These fragments are preserved in the same manner as the other paratype, and little cellular detail can be observed in them.

The general arrangement of the tissues in the stem is illustrated in Figure 2d. As shown in the figure, the center of the stem is occupied by a broad pith containing scattered ducts and meandering medullary bundles. A narrow vascular cylinder consisting of very diffuse wood surrounds the pith. Beyond the vascular cylinder is a relatively broad cortex containing what are presumably girdling leaf traces. The exterior of the stem has an armor of elliptical to rhombic, persistent leaf and cataphyll bases.

Stele

The pith is about 8 cm in diameter in the holotype. The ground tissue of the pith consists principally of thin (1-3 μm) walled, more or less isodiametric to elongate polygonal or oval cells about 90-400 μm in diameter. Many of these cells contain a single small, round, dark body which is about 4-6 μm in diameter and several larger light-colored to nearly transparent globular bodies ranging from about 4 to 14 μm (most are about 12 μm) in diameter. The medullary bundles are concentrated in a zone about 2 cm broad along the periphery of the pith. The tracheids in the bundles are longitudinally elongated and range from 18 to 26 μm in diameter. The tracheid walls are 5-8 μm thick and often show biseriate, contiguous, alternate bordered pits that have elliptical apertures. Between the tracheids are uni- to multiseriate rays up to 30 cells high consisting of thin walled, round to polygonal cells 20-50 μm in diameter (Figures 2 l, m; Pl. 2, Fig. j).

The vascular cylinder contains a single zone of xylem, which does not show any obvious growth rings. The xylem zone is about 0.8-1.3 cm wide and is interrupted by narrow rays and large multiseriate ones containing a leaf trace (Pl. 2, Fig. a). The primary xylem of the vascular cylinder consists of small, thick-walled cells. They are round in cross section, about 10 μm in diameter, and have walls about 2 μm thick. The lumens are about 6 μm across. The cells have not been observed in longitudinal section, and nothing is known of their secondary wall thickenings. The secondary xylem of the vascular cylinder consists of tracheids that are round to oval in cross section, with rounded lumina (Pl. 2, Fig. b). They are about 24-35 μm in diameter and up to one mm or more in length. The ends are wedge shaped. The walls are about 4 μm thick and show bordered pits mainly, but a few tracheids exhibit scalariform pits. The bordered pits are uni or biseriate, contiguous, alternate, and have elliptical apertures (Pl. 2, Figs. e, f). They are about 12 μm in diameter with borders about 2 μm wide.

The narrow rays in the xylem are 1-28 cells high; usually they are uni-seriate, sometimes bi-seriate, rarely tri-seriate. Typically, they consist of thin (1-2 μm) walled, round to polygonal, isodiametric cells 24-60 μm in diameter (Fig. 2j; Pl. 2, Fig. d). The large multiseriate rays range from 11 to 28 cells in width and consist principally of thin-walled cells similar to those of the narrow rays. Each large ray contains several primary xylem strands and a mucilage duct (Pl. 2, Fig. d).

The phloem of the vascular cylinder is about 6 mm wide.

It is rather poorly preserved and has been definitely recognized at only a few places (Pl. 2, Fig. a). At these places, the phloem is represented by only secondary type consisting of about equal proportions of narrow, thick-walled cells (fibers?) and larger, thin-walled cells (parenchyma?). Although no sieve plates were observed, it is possible that some of the large, thin-walled cells are actually sieve tubes. The fibers are arranged in files 1-4 cells wide, but they usually occur in files that are 2 cells wide (Pl. 2, Fig. a). They are square to rectangular in cross section (22-34 μm in diameter) with square to rounded lumina. The fibers are long (at least 1 mm) and have wedge-shaped ends. Their walls are 6-12 μm thick and do not show pitting. The thin-walled cells are square, rectangular, oval, and are about 20-80 μm in diameter. The walls of these cells are about 3-6 μm thick and do not show any pitting.

The cortex generally is not well preserved, but it seems to be about 1-1.5 cm wide. The ground tissue of the cortex is similar to that of the pith as described above.

Leaf and Cataphyll Traces

The origin of the leaf and cataphyll traces is unclear. However, it is evident that they pass through the large multiseriate rays into the cortex (Pl. 2, Fig. d). During this process, the trace is connected to the secondary xylem by irregular, upward-curving tracheids at the base of the rays. Upon entering the cortex from the ray, the leaf traces turn upward abruptly (Pl. 2, Fig. k). Ultimately, the leaf traces bend over and presumably run more or less horizontally around the stem, coalescing with other strands to form a complex girdling meshwork outside of the vertical traces (Pl. 2, Figs. i-k). In transverse section, the vertical and horizontal traces are triangular to fan-shaped with the wider portion towards the outside of the stem (Pl. 2, Figs. i, j). One or more leaf traces enters each of the leaf and cataphyll bases from the girdling meshwork. The exact number could not be determined because of the poor preservation of this part of the fossils.

The leaf traces are not very well preserved in the large multiseriate rays. They consist of a few rows of narrow tracheids showing annular secondary thickenings adaxial to many rows of wider tracheids showing spiral to scalariform thickenings. The tracheids of the traces in the rays range from 12-30 μm in diameter. Those tracheids joining the leaf traces in the rays are about 10-20 μm in diameter and show spiral to scalariform thickenings. In the cortex, the tracheids in the leaf traces have cells arranged in radiating files often separated by narrow rays 1-2 cells wide composed of thin-walled cells (Pl. 2, Fig. i). The tracheids are round to polygonal in cross section. They range from about 16-34 μm in diameter with the narrow cells near the periphery and grade to the largest cells in the middle. The secondary thickening also shows a gradation from annular in the narrow cells to helical and scalariform in the larger (Pl. 2, Fig. c). It is assumed that the smaller cells are protoxylem and larger cells are metaxylem (centrifugal xylem). Ray cells are thin-walled, cubic to polygonal and 22-48 μm in diameter, and 22-63 μm long. The phloem is abaxial to the xylem and consists mainly of long cells similar to the fiber cells of the vascular cylinder phloem. They do not show any pitting. The traces are surrounded by a sheath
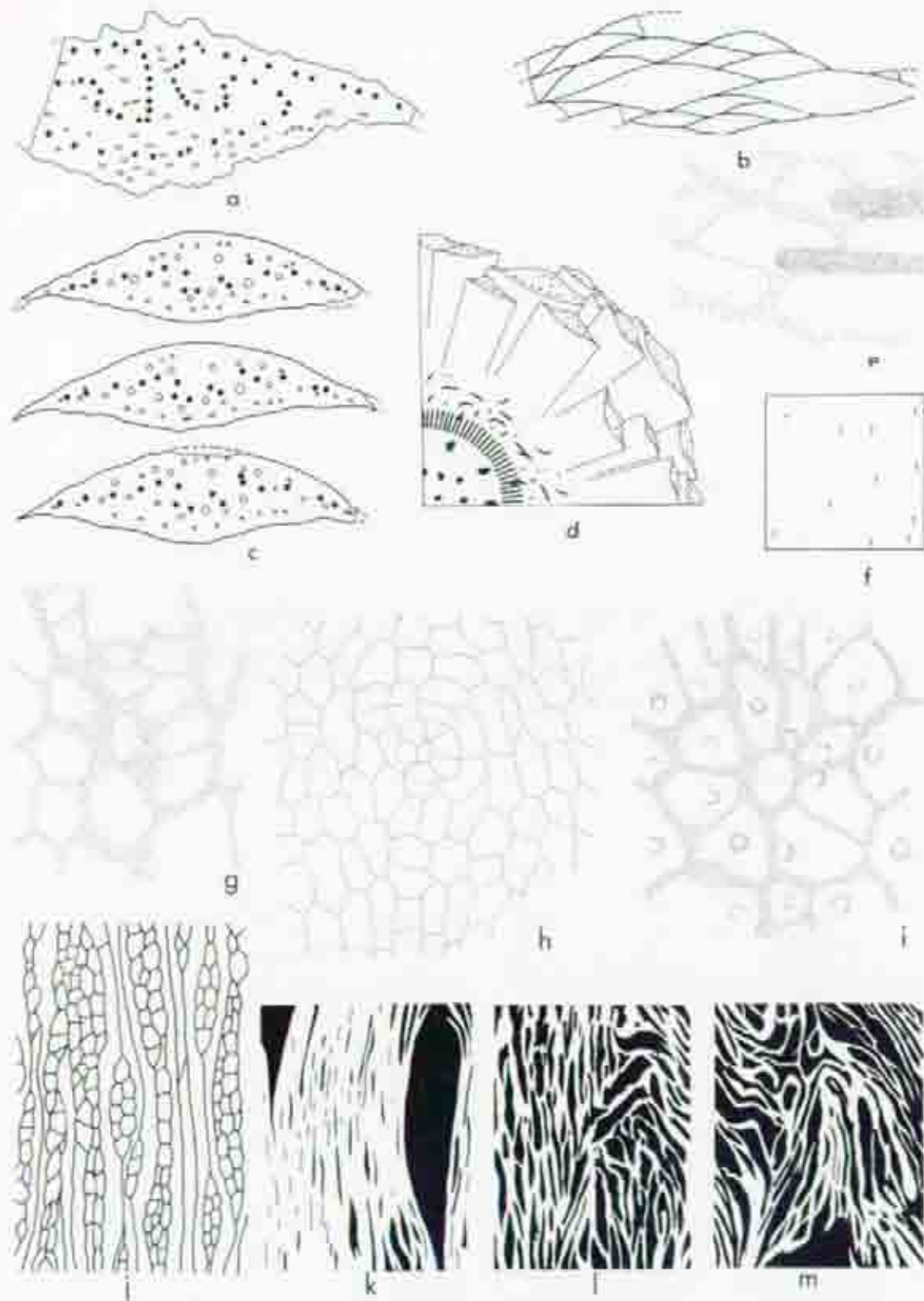
Figure 2. *Charmorgia diffolii* gen. et sp. n. a. Cross section of a leaf base in which the omega bundle pattern is evident. Vascular strands are represented by black dots, and the ducts are represented by open ovals. PFNP 1552, × 4. b. Tangential section of the armor about 3 cm from the vascular cylinder of the holotype showing the closely packed leaf and cataphyll bases. MNA G7.257a, × ½. c. A series of cross sections of a cataphyll base showing a weakly developed omega pattern formed from the vascular strands. The sections were cut about 1 mm from each other. The upper cross section is the furthest from the pith, the lower is the closest. MNA G7.257b, c, d, × 2. d. Generalized cross section of a portion of the stem. The medullary bundles and leaf traces are shown in black. The vascular cylinder is represented by radiating lines, and the ducts are represented by small dots. The vascular strands in the leaf bases are indicated by large dots. About × ½. e. Two hairs attached to the upper epidermis of a cataphyll base. Slide preparation MNA G7.257z, × 100. f. Distribution and orientation of stomata (short lines) on 1 square mm of the lower epidermis of a leaf base. Slide preparation MNA G7.257y, × 25. g. Cyclocytic stomatal apparatus in which the periclinal epidermal cell walls are smooth. Slide preparation MNA G7.257bb, × 200. h. Amphicyclocytic stomatal apparatus. Slide preparation MNA G7.257y, × 100. i. Cyclocytic stomatal apparatus in which the periclinal epidermal wall of nearly every epidermal cell shows a trichome (hair) base. Slide preparation MNA G7.257aa, × 200. j. Tangential section of the xylem in the vascular cylinder showing variation in the rays. Drawn on a photograph. MNA G7.257z, × 30. k. Tangential sections of the regular rays in the xylem of the vascular cylinder. A large ray is right of center in the figure. Drawn on a photograph. Compare with the tangential sections of the medullary bundles in Figures l, m. MNA G7.257h, × 1. l, m. Tangential sections near the outside of the pith showing the irregularly wandering bundles (black) separated by medullary parenchyma (white). Compare with Figure k. Drawn on photographs. MNA G7.257f, g, × 10.
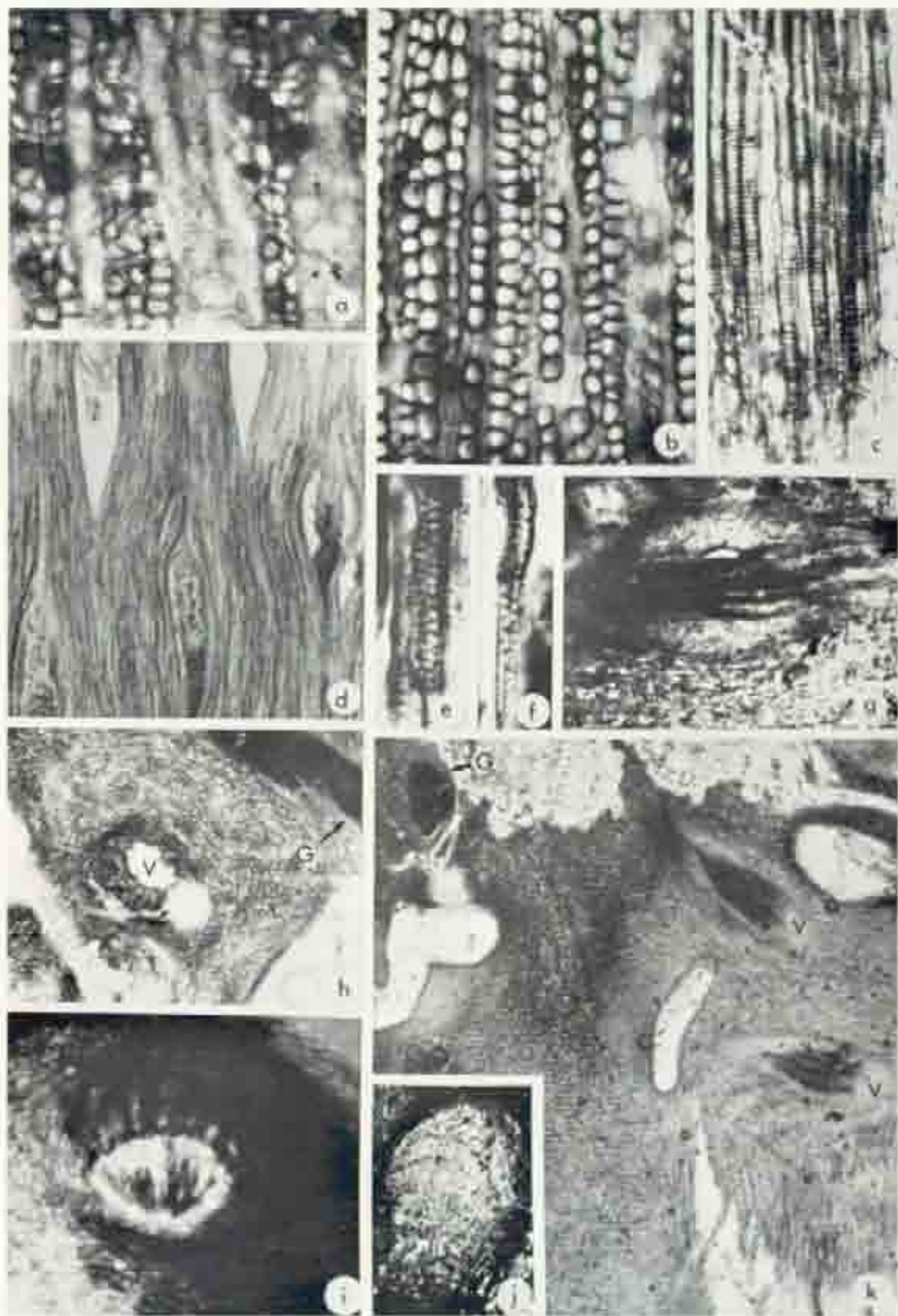
Plate 2. *Charmorgia dijolii* gen. et sp. n. *a.* Transverse section of the phloem. MNA G7.257i, × 100. *b.* Transverse section of the secondary xylem. MNA G7.257j, × 100. *c.* Longitudinal section of a leaf trace in the cortex. Note the scalariform thickenings. MNA G7.257k, × 100. *d.* Tangential section of the secondary xylem. The large multicellular rays are apparent in this view. MNA G7.257h, × 10. *e, f.* Bordered pitting on the radial walls of the tracheids in the secondary xylem of the vascular cylinder. MNA G7.257l, × 100. *g.* Oblique longitudinal section of a leaf trace in the cortex. The xylem is to the right in this view. MNA G7.257l, × 10. *h.* Transverse section of the cortex showing a vertical leaf trace (*V*) and a girdling leaf trace (*G*). MNA G7.257m, × 10. *i.* Transverse section of a vertical leaf trace in the cortex. MNA G7.257i, × 10. *j.* Cross section of a medullary bundle. PFNP 1352, × 10. *k.* Radial section of the phloem (to the right), the cortex, two vertical leaf traces (*V*) and a girdling leaf trace (*G*). MNA G7.257n, × 10.
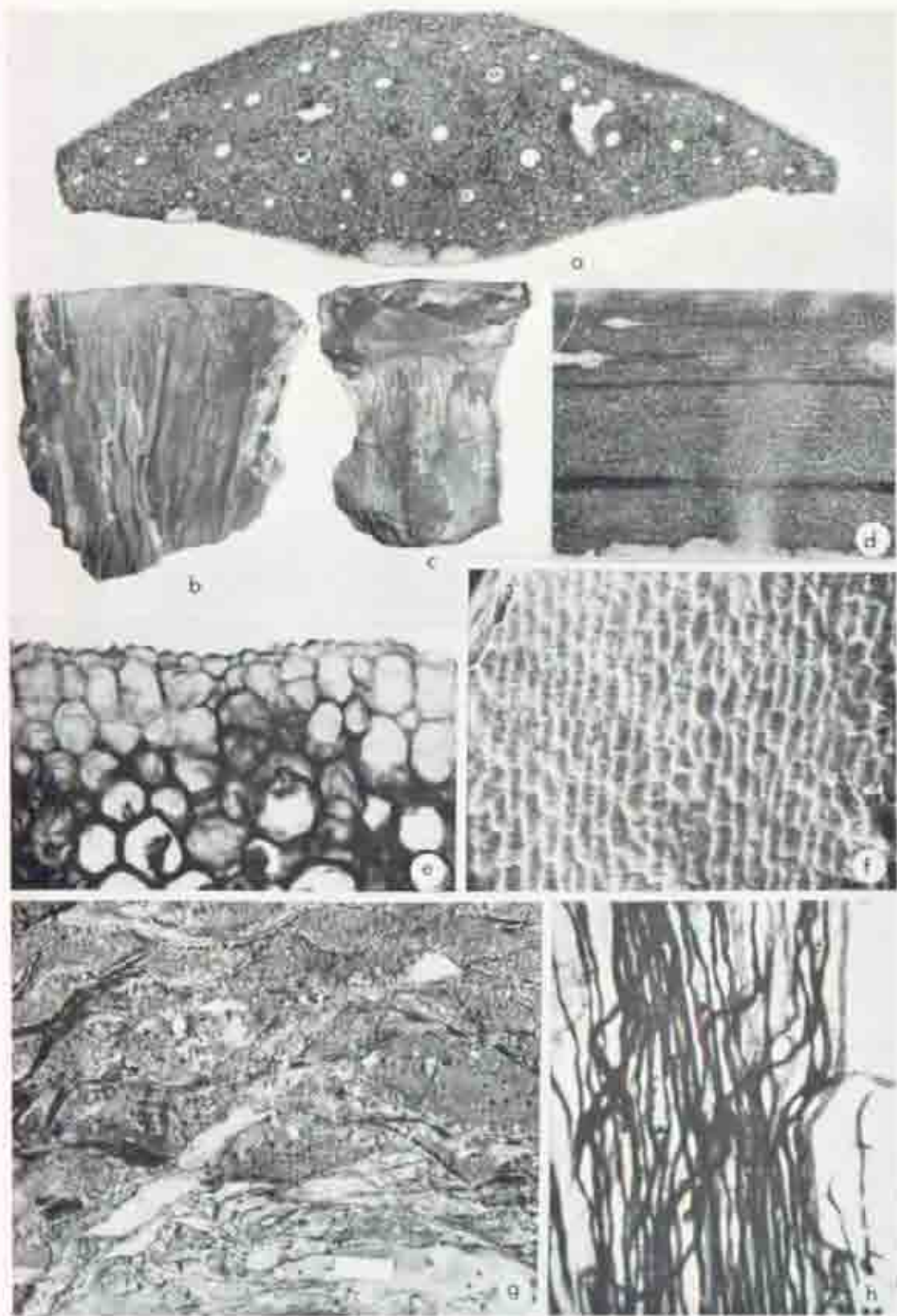
Plate 3. *Charmorgia dejolli* gen. et. sp. n. *a.* Cross section of one of the cataphyll bases. The mucilage ducts are white, and the vascular bundles are black. The cavity to the right is probably due to decay. MNA G7.257o, × 5. *b, c.* Wrinkles on outer surface of leaf bases and the layer of mineral matter containing the long hairs. Fig. *b* is an enlargement of a portion of this layer. MNA G7.257p (on the left) and PFNP 2471a (on the right), × 1. *d.* Longitudinal section of a cataphyll base showing two vascular bundles (dark lines) and parts of two ducts. MNA G7.257g, × 3. *e.* Cross section of the epidermis and the larger adjacent cells of a cataphyll base. Note the convex outer wall of the epidermal cells. The cuticle cannot be differentiated from the epidermal cells in this section. MNA G7.257h, × 100. *f.* Surface view of the epidermis. SEM micrograph. MNA G7.257r, × 100. *g.* Leaf and cataphyll bases on the holotype. MNA G7.257, × 100. *h.* Hairs embedded in a layer of mineral matter from between two bases. MNA G7.257s, × 100.

of 1–3 layers of small oval thin-walled cells which are about 10–30 μm in diameter (Pl. 2, Figs. g–k).

Leaf and Cataphyll Bases

The persistent leaf bases on all the specimens of this fossil are of two distinct sizes with the smaller being most abundant (Figs. 2 a–c, 3a, b; Pl. 1, Figs. a–h; Pl. 3, Fig. g). As shown below, the larger bases on the present fossils (Fig. 3a) compare with the foliage leaf bases of *Cycas* (Fig. 4a), and the smaller (Fig. 3b) compare with the cataphyll bases on *Cycas* (Fig. 4b). Therefore, in this report, I will refer to the larger bases as leaf bases and the smaller as cataphyll bases.

The leaf and cataphyll bases are elliptical to rhombic in cross section with broad, thin, lateral flanges (Figures 2a–d, 3a, b; Pl. 3, Figs. a–c, g). They overlap each other and are closely arranged in a low helix (Pl. 3, Fig. g). The leaf bases are scattered amongst the cataphyll bases and do not appear to occur in obvious zones (Pl. 1, Figs. b, c, f, h), although in places there is the hint of such a zone (Fig. 2b). In the holotype, the leaf bases typically range from 5.8–8.2 cm in width and from 1.2–2.8 cm in thickness, whereas the cataphyll bases generally range from 2.3–3.6 cm in width and 0.7–0.9 cm in thickness (see Fig. 6). Both the leaf and cataphyll bases have a maximum length of about 6 cm. In the paratype that is nearly complete (PFNP 1352), the leaf bases usually range from 1.9–2.4 cm. in width and from 0.7–1.0 cm in thickness, and the cataphyll bases range from 1.2–1.7 cm in width and from 0.2–0.6 cm in thickness (see Fig. 6). They have a maximum length of 5 cm on the paratype. The leaf base of paratype PFNP 2471 is 4.7 cm long, 3.8 cm wide, and about 1.1 cm thick.

The upper and lower surfaces of the leaf and cataphyll bases on all specimens show narrow, irregular, longitudinal wrinkles 0.5–1.0 mm broad (Pl. 3, Figs. b, c). The ends of many of the bases on paratype PFNP 1352 are rounded irregularly (Pl. 1, Figs. b–d) and look somewhat like the shriveled ends of the bases on living cycads.

Each base contains 10–40 vascular bundles and 30–50 ducts (Figs. 2a, c; 3a, b; Pl. 3, Fig. a). The bundles and ducts follow more or less straight courses through the bases (Pl. 3, Fig. d). In the leaf bases, the bundles are arranged to form a well-developed omega pattern as seen in cross section (Figs. 2a, 3a), whereas in the cataphyll bases they form a generally poorly developed omega pattern (Figs. 2c, 3b; Pl. 3, Fig. a). The bundles are round to oval in cross section and range from 0.5–1.5 mm in diameter (Fig. 3e; Pl. 4, Figs. g–i). The ducts are randomly scattered in the bases and are typically round to oval in cross section (Pl. 3, Fig. a; Pl. 4, Fig. a). Both types of bases often show irregular cavities (Pl. 3, Fig. a) that are probably due to decay and are not true intercellular spaces.

The ground tissue of the leaf and cataphyll bases consists of compactly arranged, thin-walled (5–9 μm) cells and scattered thick-walled (10–14 μm) cells (Pl. 3, Figs. a, d, e). Most cells of the ground tissue are round to polygonal and range from 50 to 200 μm in diameter (Pl. 3, Fig. e). They often contain a single, small, round body about 4-6 μm in diameter (Pl. 4, Figs. k–n) that are similar to those in the ground tissue of the pith and cortex. However, the bodies occur in more cells in the leaf bases than in the pith and cortex. In some bases, there are several layers of thick-walled cells present below the epidermis, particularly the upper. These thick-walled cells (fibers?) are longitudinally

Abbreviations: px, protoxylem; cf, centrifugal xylem; cp, centripetal xylem; p, phloem.
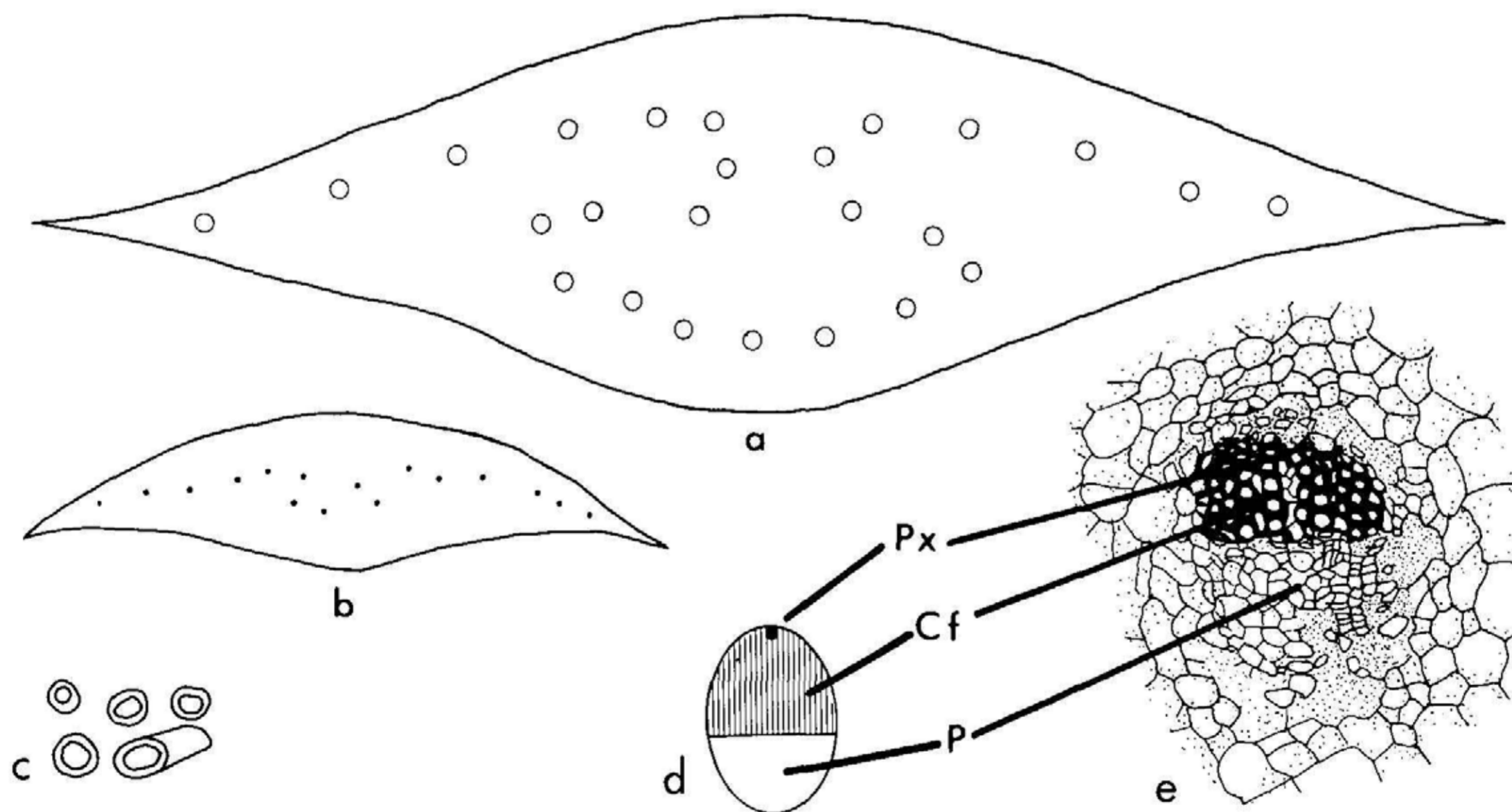
Figure 3. *Charmorgia dijolii* **gen. et sp. n.** *a.* Transverse section of a leaf base showing the well-developed omega pattern of vascular bundles. × 2. *b.* Transverse section of a cataphyll base showing the poorly developed omega pattern of the vascular bundles. × 2. *c.* Cross sections of hairs in the ramentum. × 100. *d.* Diagrammatic drawing of a leaf base bundle. × 30. *e.* Transverse section of a leaf base showing a well-developed omega pattern of vascular bundles. × 40. Figures 3a–3c, 3e adapted from slides of the holotype.
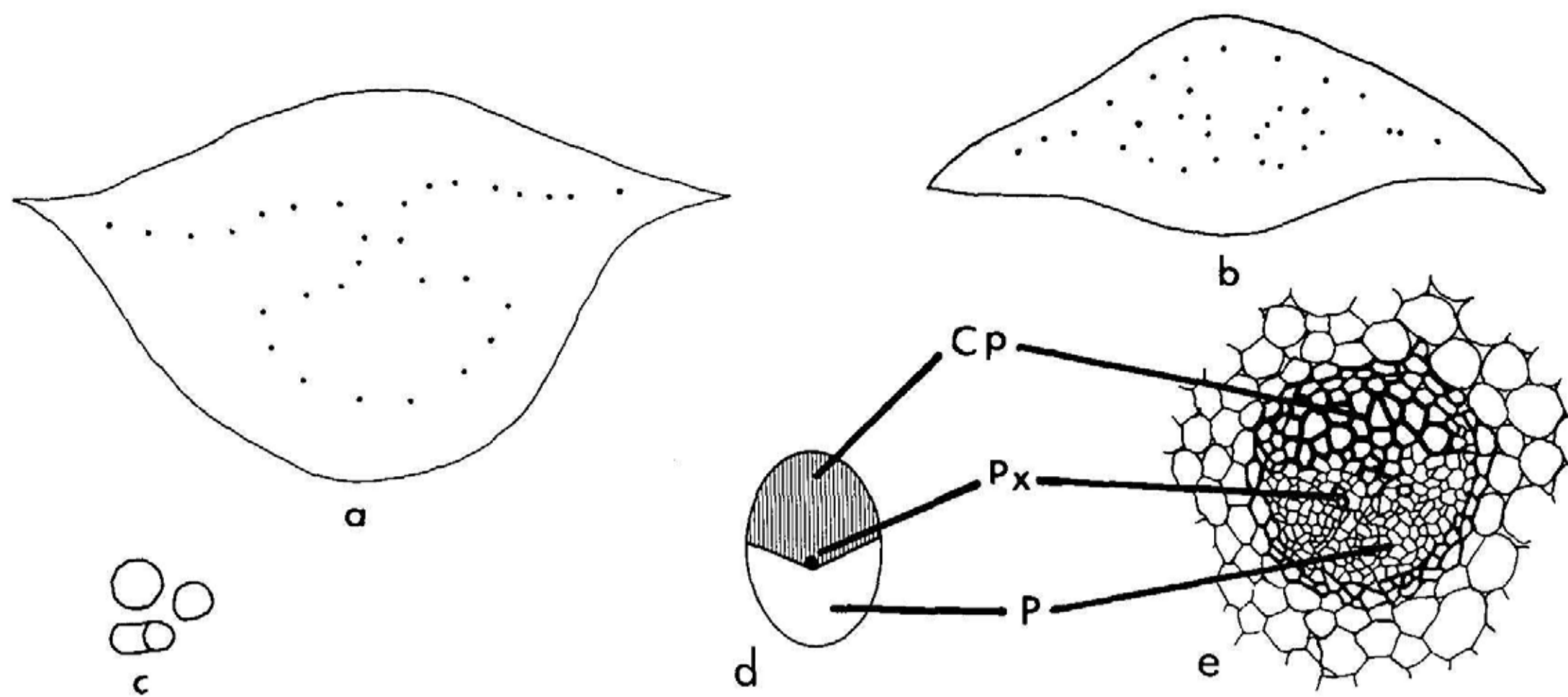
Figure 4. *Cycas* **sp.** *a.* Transverse section of a leaf base showing a well developed omega pattern of vascular bundles. × 2. *b.* Transverse section of a cataphyll base showing a poorly developed omega pattern of the vascular bundles. × 2. *c.* Cross sections of several hairs in the ramentum. × 100. *d.* Diagrammatic drawing of a leaf-base bundle. × 100. *e.* Transverse section of a leaf-base bundle. × 40. Figures 4a–4c, 4e adapted from slides furnished by Dr. D. W. Stevenson.
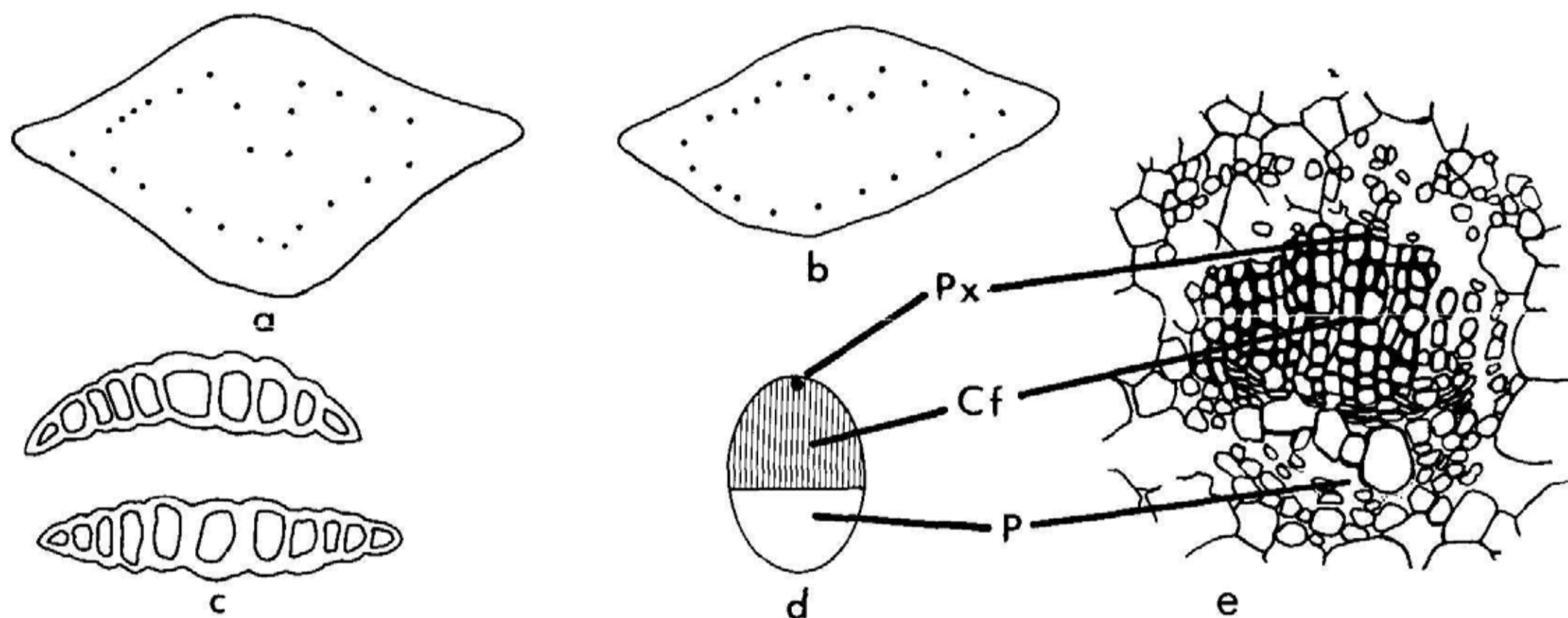
Figure 5. *Cycadeoidea dacotensis* **Wieland.** *a, b.* Transverse sections of two leaf bases showing a C arrangment of vascular bundles. × 2. *c.* Cross sections of two scales in the ramentum. × 100. *d.* Diagrammatic drawing of a leaf base bundle. × 30. *e.* Transverse section of a leaf-base bundle. × 40. Figures 5a–5c adapted from Peabody Museum of Natural History slides 5063, 5068. Figure 5e adapted from Wieland, 1906, Fig. 98b.
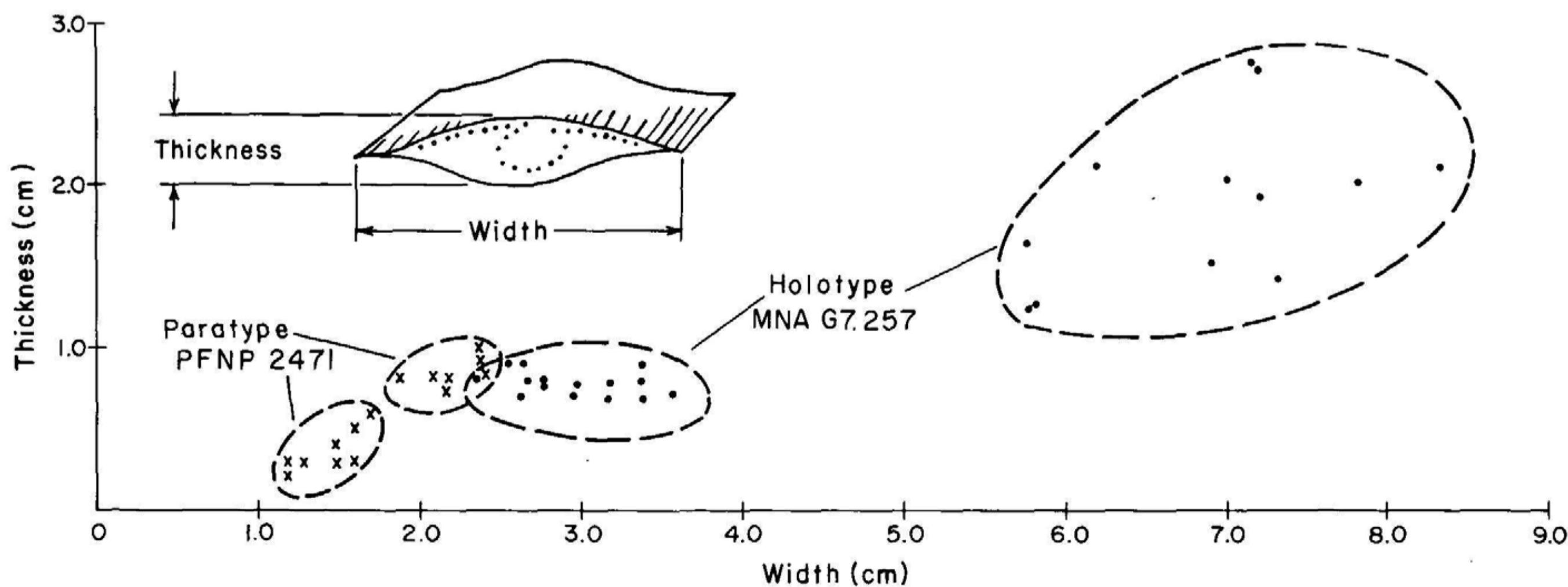
Figure 6. Graph showing variation in the width and thickness of the leaf bases (to the right) and the cataphyll bases (to the left) in the holotype (MNA G7.257) and the nearly complete paratype (PFNP 1352). Measurements were made at about the same place in each specimen. Note that the base sizes fall into two groups on each specimen.

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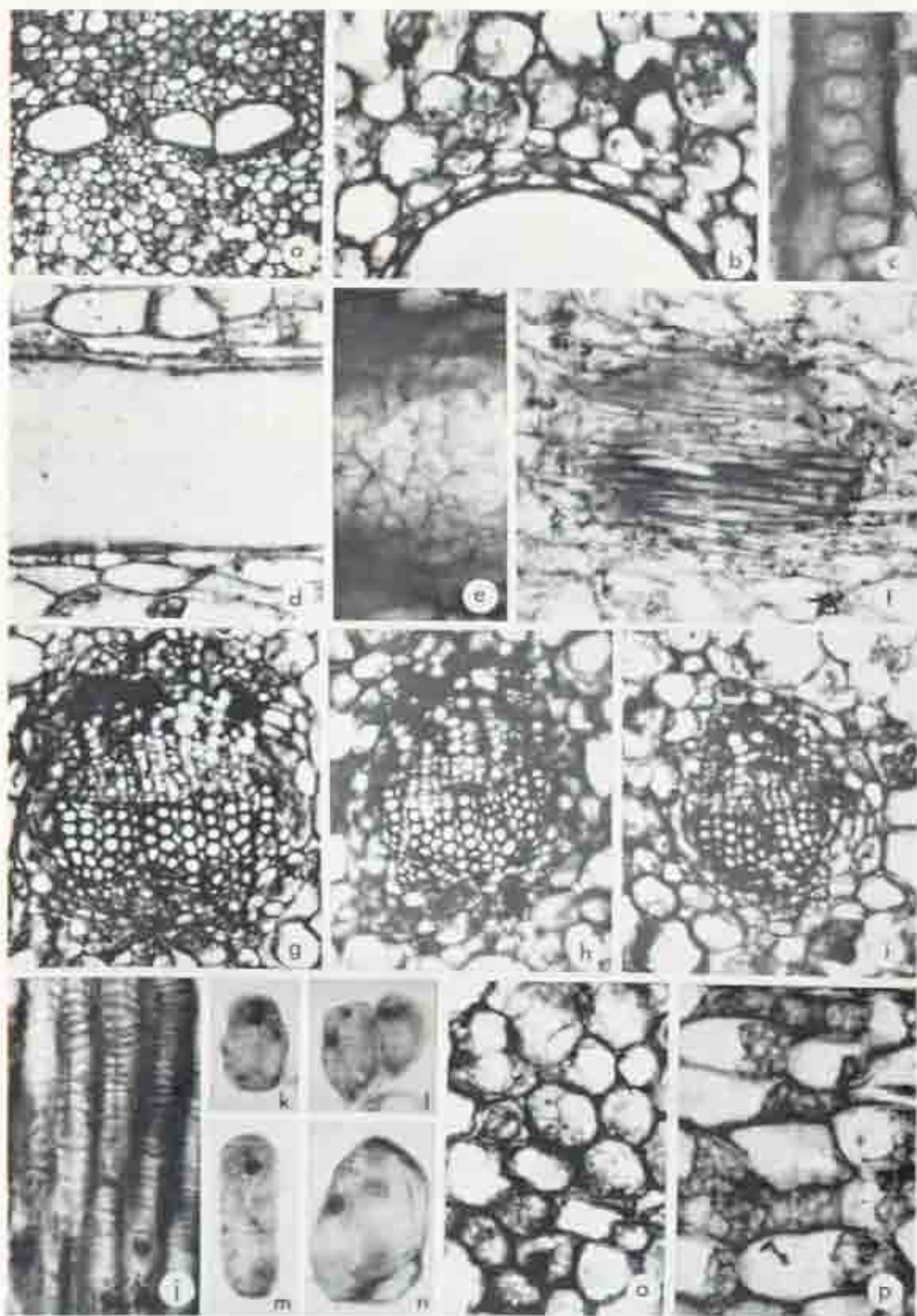
Plate 4. *Charmorgia djalii* gen. et sp. n. *a.* Transverse section of three ducts in a cataphyll base. MNA G7.257t, × 30. *b.* Transverse section of a duct in a cataphyll base showing the flattened cells lining the duct and the sheath of small cells which surrounds the duct. Some of the larger cells adjacent to the sheath contain small globular bodies which may be starch grains. MNA G7.257r, × 100. *c.* Bordered pitting on the wall of a tracheid in the xylem of a vascular bundle in a leaf base. MNA G7.257u, × 250. *d.* Longitudinal section of a duct showing the flattened cells and the adjacent cells of the sheath and ground tissue. MNA G7.257c, × 100. *e.* Longitudinal section of a duct showing the epithelial cells in surface view. MNA G7.257x, × 100. *f.* Oblique section of a vascular bundle in a cataphyll base. MNA G7.257x, × 100. *g–i.* Transverse sections of the vascular bundles in a leaf base. MNA G7.257t, d, d, × 100. *j.* Longitudinal section of the tracheids in a cataphyll base bundle showing the scalariform thickening. MNA G7.257y, × 200. *k–n.* Isolated cells obtained from the ground tissue of a cataphyll base. Each of the cells shows a single dark globular body and several light coloured globular bodies. MNA G7.257u. *k–m,* × 250. *n,* × 500. *o.* Transverse section of the ground tissue in a cataphyll base. MNA G7.257d, × 100. *p.* Longitudinal section of the ground tissue in a leaf base showing the small globular bodies which occur in these cells. MNA G7.257w, × 100.

elongated and range from 34 to 52 μm in diameter and 150 to 300 μm in length. The walls of these cells are as much as 10 μm thick.

The sheath surrounding the vascular bundles in the leaf and cataphyll bases is 1-3 cells thick (Fig. 3e; Pl. 4, Figs. g-i). These cells are round to polyhedral and range from 12-30 μm in diameter, and their side walls are 2-4 μm thick. The tracheids in the bundles are thick-walled (6-10 μm) and aligned in files 1-3 cells wide. These cells range from 4-6 μm in diameter near the periphery on the adaxial side of the bundles to about 18-38 μm in diameter near the middle. The secondary thickenings in the tracheids also vary. Near the periphery they are annular, and they grade to helical and scalariform at the middle. A few show circular bordered pits (Pl. 4, Fig. c). In cross section, the tracheids are square to rectangular with oval to round lumens (Fig. 3e; Pl. 4, Figs. g-i). They are elongated longitudinally (up to 240 μm long). Typically the end walls are oblique, but some are transverse to the side walls. It is presumed that the small cells with annular secondary thickenings are protoxylem and the larger are centrifugal metaxylem. There may be some secondary xylem present also as the xylem is typically separated from the phloem by a layer of flattened, thin-walled cells which may represent the cambium and the tracheids occur in files (Fig. 3e; Pl. 4, Figs. g-i). The presence of circular bordered pits on some of the tracheids also suggests this. The phloem occurs on the abaxial side of the xylem strands and consists mostly of short, thick-walled (3-6 μm) cells that are square to rectangular in cross section and longitudinally elongated (Pl. 4, Figs. g-i). The phloem cells are generally arranged in files. Typically they are 12-32 μm in diameter and up to 40 μm long. The walls do not show any pitting or pores. Scattered among the thick-walled cells are thin-walled (1-3 μm) cells.

The epidermis on the bases consists of a single layer of generally small, thin-walled cells that are mostly rectangular to polygonal in surface view and equidimensional to longitudinally elongated (Figs. 2e, g-h; Pl. 3, Fig. f). These cells range from 80-120 μm in length, 24-50 μm in width, and 16-48 μm in thickness. The side and end (periclinal) walls are straight to slightly curving and are about 3-6 μm thick. The outer (anticlinal) wall is convex outward (Pl. 3, Fig. e). The cuticle cannot be differentiated from the outer wall of the epidermal cells in cross section, and the cuticle and outer wall have a combined thickenss of about 5-12 μm.

Trichome (hair) bases and stomata occur on both the upper and lower surfaces of the leaf and cataphyll bases. The trichome bases consist of a small crescent or ring (about 20-70 μm in diameter) on the surface of the epidermal cells (Fig. 2i). Hairs have been observed attached to a few of these cells (Fig. 2e). Stomata are uncommon (8-13 per square mm) and occur in poorly defined longitudinally files (see Fig. 2f). They are monocyclic (cyclocytic) with 2 polar and 4-7 lateral subsidiary cells forming a ring around the stomatal pit (Figs. 2 g, i). A few stomata are amphicyclocytic with a ring of small encircling cells surrounding the ring of subsidiary cells (Fig. 2h). The subsidiary and encircling cells range from 25-50 μm in diameter and are smooth and unthickened. The stomatal pit is shallow, oval to round, and has a diameter of about 20-70 μm. The guard cells are unknown, but the orientation of the oval stomatal pits suggests that they are generally longitudinally elongated.

Ramentum

The hairs of the ramentum are unbranched, and although a complete hair has not been observed, the fragments that have been studied in section and in insoluble residues suggest that they are one cm or more in length. The fragments are 20-80 μm wide (as compressed). The hairs do not show cross walls, and the apices are acute (Pl. 3, Fig. h). They arise from the surfaces of the leaf and cataphyll bases (Fig. 2e; Pl. 3, Fig. f) and possibly from the stem epidermis. Only a few have been observed which apparently are attached to the epidermis of a cataphyll base (Fig. 2e).

Ducts

The ducts that occur in all parts of the fossils are 70-800 μm in diameter. They consist of a broad central cavity lined with a single layer of small, flattened cells that is enclosed, in turn, by a sheath of small, oval cells (Pl. 4, Figs. a, b, d). The flattened cells are polygonal in surface view (Pl. 4, Fig. e) and range from 20-70 μm in diameter and 20-40 μm in thickness. The wall of the cavity (the outer wall of the flattened cells) is smooth and is about 4-9 μm thick. The other walls of the flattened cells are usually thinner (2-5 μm). The sheath surrounding the ducts consists of one to three layers of small, oval, thin-walled cells about 36 to 60 μm high, 44 to 120 μm wide, and 120-250 μm long (Pl. 4, Figs. b, d). A brownish substance sometimes fills or lines the central cavity.

Taproot Scar

The taproot scar is an oval, nearly smooth structure on the base of paratype PFNP 1352. It is about 3.2 × 2.8 cm in diameter (Pl. 1, Figs. c, d) and shows several low concentric ridges and grooves and a slightly depressed central portion about 1 × 1.2 cm in diameter. As shown in the figures, the leaf and cataphyll bases are concentrically arranged around the scar.

SYSTEMATIC POSITION

The stems described here resemble some of the Jurassic and Cretaceous cycadeoid stems that have been described from North America (Wieland, 1906, 1916), England (Buckland, 1828, Carruthers, 1870), and elsewhere. In fact the holotype with the broad cavity on the base looks surprisingly like one of the Jurassic cycadeoid trunks called "fossil crow's nests" or "fossil bird's nests" by British quarrymen on the Isle of Portland during the last century (cf. Pl. 1, Figs. g, h, with Buckland 1828, Plate 47, Figures 3, 4). The trunk of *Charmorgia* gen. n., however, is in close agreement with that of the Cycadales in general as described by Greguss (1968), and a comparison (Table 1) of certain features of the present fossils shows that they are more like the stems of the Cycadales than the Cycadeoidaceae.

In the absence of any reproductive structures in the *Charmorgia* specimens, we must rely on its vegetative features for evidence of its systematic relationships. Although none of the vegetative features recognized in *Charmorgia* gen. n. (except possibly the stomata) can by themselves unequivocally indicate the relationships of the fossil, the combination of them seems to be good evidence that the fossil is Cycadalean. In Table 1, certain of the features of *Charmorgia* are compared with those of the Cycadales and the Cycadeoidaceae. Additional comments about each of the characters in the table follows:

Table 1. Comparison of certain generally typical characters of the Cycadales and Cycadeoidacea with those of *Charmorgia* gen. n.

	Cycadales	*Charmorgia* gen. n.	Cycadeoidaceae
1. Medullary vascular bundles	Present	Present	Absent
2. Position of cones	Apex of stem	?Apex of stem	Axil of leaves
3. Course of leaf traces in cortex	Girdling	?Girdling	Direct
4. Shape of leaf traces in cortex	Round to fan shaped throughout cortex	Round to fan shaped throughout cortex	Round to fan shaped near pith but abruptly become "C" shaped
5. Arrangement of leaf traces in cortex	Scattered	Scattered	In large "C" shaped bundles
6. Origin of vascular bundles in leaf and cataphyll bases	From several distinct leaf traces (multilacunar)	From several distinct leaf traces (multilacunar)	From a single leaf trace (unilacunar)
7. Composition of armor	Sparse leaf bases and abundant cataphyll bases	Sparse large (?leaf) bases and abundant small (?cataphyll) bases	Large and small leaf bases
8. Arrangement of vascular bundles in leaf and cataphyll bases	Omega shaped	More or less omega shaped	"C" shaped
9. Composition of ramentum	Short to long branched or unbranched hairs	Long unbranched hairs	Broad multicellular scales
10. Pitting of secondary xylem	Alternate, multiseriate bordered pits (scalariform in two genera)	Dominately alternate, multiseriate bordered pits	Typically scalariform (bordered pits in two species)
11. Form of side walls of epidermal cells	Straight	Straight	Wavy to sinuous
12. Stomatal type	Cyclocytic and amphicyclocytic (haplocheilic)	Cyclocytic and amphicyclocytic (haplocheilic)	Paracytic (syndetocheilic)

1. Medullary vascular bundles such as those found in *Charmorgia* gen. n. (see Figs. 2*l, m*; Pl. 2, Fig. *j*) seem to be characteristic of the Cycadales (Greguss, 1968, p. 25) but not of the Cycadeoidaceae (Chamberlain, 1935, p. 46).

2. The absence of cones in *Charmorgia* gen. n. is not conclusive evidence that the fossil is Cycadalean because many cycadeoid stems also do not have cones. This is usually thought to be an indication of either the age of the stems or season when they were fossilized (Crepet, written communication, 1981). However, the presence of medullary vascular bundles in *Charmorgia* gen. n. suggests that an apical cone was present because such bundles would not be expected in stems with axillary cones as in the cycadeoids (Chamberlain, 1935, p. 46).

3. It has not been possible to trace an individual leaf trace bundle for any great distance by use of serial sections, because of the incomplete preservation of the fossils. Thus my statement that the stems have girdling leaf traces is inferred from the portions of the leaf traces which are visible at places in the cortex. For example, ascending or vertical traces are visible together with horizontal traces at many places in both radial (Pl. 2, Fig. *k*) and transverse (Pl. 2, Figs. *h, i*) sections of the stem.

4. Leaf traces are round to fan shaped near the periphery of the pith in the Cycadales, *Charmorgia* gen. n. and the Cycadeoidaceae, but in the cycadeoids they abruptly become "C" shaped as they move outward towards the periphery of the stem (Wieland, 1906, 1916). However, they remain round to fan-shaped throughout the cortex in both the Cycadales (Greguss, 1968) and in *Charmorgia* gen. n., as shown in Plate 2, Figs. *h, i*.

5. In both the Cycadales and *Charmorgia* gen. n. the leaf traces are irregularly scattered throughout the cortex whereas they are grouped into large "C" or horseshoe-shaped bundles in the cycadeoids (Sporne, 1974, p. 94).

6. Although it has not been possible to trace any individual leaf trace bundle any great distance by using serial sections it appears that vascular bundles in the leaf bases form from several leaf traces because I have observed the joining of two leaf traces in the cortex at several places in the holotype.

7. Some cycadeoid stems do show both large and small leaf bases as in *Charmorgia* (see Wieland, 1906, 1916). However, the well developed omega bundle pattern in the large (leaf) bases of *Charmorgia* (Figs. 2*a*, 3*a*) can be matched with the pattern in the leaf bases in certain Cycadales as shown in Figure 4*a* (also see Wieland, 1906, Figure 32). Furthermore, the irregular omega bundle pattern in the small (cataphyll) bases in *Charmorgia* (Figs. 2*c*, 3*b*; Pl. 3, Fig. *a*) can be matched with those in the cataphyll bases in certain Cycadales according to Stevenson (written communication, 1981).

8. As shown in Figures 3*a, b*, the bundle patterns in the large (leaf) and small (cataphyll) bases of *Charmorgia* seem to be generally characteristic of some Cycadales (cf. Figs. 4*a*, 4*b*) whereas a "C" bundle pattern (see Figs. 5*a*, 5*b*) is characteristic of both the large and small leaf bases in the cycadeoids (Wieland, 1906, p. 62-63).

9. A ramentum composed of unbranched hairs as in *Charmorgia* (see Fig. 3*c*; Pl. 3, Fig. *h*) is accepted (Stevenson, 1981, Wieland, 1906, p. 51-54) as being characteristic of the Cycadales (Fig. 4*c*) whereas the ramentum in the cycadeoids consists of multicellular scales as shown in Figure 5*c* and by Wieland (1906, p. 52).

10. The dominance of bordered pits in *Charmorgia* (Pl.

4, Fig. c) suggests a closer relationship with the Cycadales as the tracheids in most living cycads have multiseriate bordered pits and in only *Zamia* and *Stangeria* are the tracheids scalariform (Sporne, 1974, p. 108). On the other hand, in most species of the Cycadeoidaceae the tracheids are scalariform, and in only two species are there bordered pits (Chamberlain, 1935, p. 47).

11. It is generally accepted that the side walls of the epidermal cells of the Cycadales are usually straight as in *Charmorgia* (see Figs. 2*e*, *g–i*) not wavy to sinuous as in the cycadeoids (Taylor, 1981, p. 398).

12. Stomata which are surrounded by one or more rings of subsidiary and encircling cells (cyclocytic and amphicyclocytic pattern or haplocheilic pattern) as in *Charmorgia* (Figs. 2*g–i*) are characteristic of the Cycadales, whereas stomata that have a single subsidiary cell next to each guard cell is a consistent characteristic of the cycadeoids (Taylor, 1981, p. 398).

SYSTEMATIC DESCRIPTIONS

Division Cycadophyta
Order Cycadales

Genus *Charmorgia* Ash gen. n.

Diagnosis. Stem short, thick, having armor of closely spaced, elliptical to rhombic, persistent leaf and cataphyll bases. Pith broad, heterogeneous, containing ducts, and anastomosing vascular bundles. Vascular cylinder with a single zone of endarch xylem and phloem. Cortex containing ducts and leaf traces. Leaf traces presumably forming complex girdling meshwork outside of vertical traces. Leaf bases sparse, large, scattered among abundant, smaller cataphyll bases. Both types of bases containing many vascular bundles and ducts. Vascular bundles arranged in a broad, well developed omega pattern in leaf bases, and in a poorly developed omega pattern in cataphyll bases. Stomata cyclocytic and amphicyclocytic. Ramentum of long unbranched hairs present between leaf and cataphyll bases.

Etymology. The name honors Charles Morgan who collected the holotype.

Generitype. *Charmorgia dijolii* Ash sp. n.

Charmorgia dijolii Ash sp. n.
1969 Cycad: Breed and Ash, Fig. 2, p. 36.
1972 Bennettitalean stem: Ash, Plate 1, Figure 7, p. 38-39.
Figures 2, 3, Pl. 1-4

Diagnosis. Stem 30–40 cm tall, 20–30 cm in diameter, covered with armor of closely spaced, elliptical to rhombic persistent leaf and cataphyll bases. Pith 15–20 cm in diameter, containing ducts and anastomosing vascular bundles. Vascular cylinder narrow with single zone of endarch xylem, containing narrow medullary rays and multiseriate rays containing a leaf trace. Tracheids of secondary xylem showing bordered pits on radial walls. Phloem composed of thick-walled and thin-walled cells. Cortex containing ducts and leaf traces. Leaf traces presumably forming a girdling network outside vertical traces before entering leaf and cataphyll bases. Leaf bases large, about 1.9–8.2 cm wide, sparse, cataphyll bases small, about 1.2–3.1 cm wide, abundant. Each leaf and cataphyll base containing up to 40 vascular bundles and 50 ducts. Vascular bundles arranged to form a broad, well-developed omega pattern in leaf bases; vascular bundles forming a poorly developed omega pattern in cataphyll bases. Xylem of the leaf and cataphyll base bundles composed of tracheids arranged in radiating files. Tracheids showing annular to

scalariform thickenings. Phloem consisting of files of thick- and thin-walled cells. Epidermis of leaf and cataphyll bases a single layer of thin-walled rectangular to polygonal cells with straight anticlinal walls. Stomata occurring on both upper and lower surfaces of leaf and cataphyll bases, cylocytic and amphicyclocytic. Mat of long unbranched hairs present between leaf and cataphyll bases.

Etymology. The name is derived from the Navajo term *dijoli*, meaning round, spherical, globular, and refers to the presumed shape of the fossils before compression.

Holotype. MNA G7.257.

Paratypes. PFNP 1352, PFNP 2471.

Stratigraphic occurrence. Lower part of the Petrified Forest Member of the Chinle Formation.

Age. Late Triassic (Keuper) Age.

DISCUSSION

Dark and light bodies similar to those observed in some of the cells of the pith and the ground tissue of the leaf bases of this fossil (Pl. 4, Figs. *k–n*) have been reported (Gould, 1971) to occur in certain cells of *Lyssoxylon* Daugherty (1941), the only other cycad stem known from the Chinle Formation. Perhaps the dark bodies are cell nuclei and the light ones are starch grains as suggested by Gould (1971).

In cross section the meandering medullar bundles of *Charmorgia* (Pl. 2, Fig. *j*) are similar to those of the living cycads *Encephalartos altensteinii* (Greguss, 1972, Plate 15, Figure 5) and *E. septertrionales* (Greguss, 1968, Plate 61, Figure 2).

It is interesting to note that the three oldest known, structurally preserved Cycadalean stems *(Charmorgia* gen. n., *Lyssoxylon,* and *Michelilloa),* which are of late Triassic age, have a single zone of secondary xylem and the oldest known cycad with several zones is of Middle Jurassic age. This suggests that a single zone is basic for the class and that complications with repeated zones of xylem arose after the Triassic.

The ducts of *Charmorgia* are similar to the mucilage canals of several living cycads including *Bowenia serrulata, Ceratozamia mexicana, Cycas revoluta,* etc. (Greguss, 1972). However, unlike those canals, we do not know anything about the composition of the materials in the ducts of *Charmorgia.* They also are similar to those in the cycad *Lyssoxylon grigsbyi* from the Upper Triassic of Arizona and New Mexico (Gould, 1971, Figure 35).

The structure of the bundles in the leaf and cataphyll bases of *Charmorgia* (as interpreted here) and the arrangement of the cells is noteworthy because they differ so radically from those of the living cycads (cf. Figs. 3*d* and 4*d*). In the living cycads (*Cycas*, for example) the xylem cells are irregularly arranged (aligned in *Charmorgia*), the protoxylem is near the center of the bundle (peripheral in *Charmorgia*), there is a large amount of centripetal metaxylem (small amount in *Charmorgia*), and a small amount (if any) of centrifugal metaxylem (large amount in *Charmorgia*). Thus there is no change in the structure of the bundle of *Charmorgia* from the leaf traces in the cortex where they are endarch and show the same proportions of tissues. Interestingly, the leaf base bundles of the other Chinle cycad, *Lyssoxylon* Daugherty, and the Cretaceous cycadeoid *Cycadeoidea dacotensis* also show a structure and cell arrangement more similar to that of *Charmorgia* than to *Cycas*

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(cf. Figs. 3d and 4d with Gould, 1971, Figures 19-21). If the presence of centripetal wood in the leaf and cataphyll base bundles is a primitive character as suggested by some authors (e.g., Sporne, 1974), then perhaps these fossils should be considered advanced, since they show only small amounts (if any) of this tissue. On the other hand the alignment of the xylem cells may be a primitive feature characteristic of the early cycads and the Cycadeoidaceae.

Presumably the hairs on the leaf and cataphyll bases of *Charmorgia* are bi-celled like the hairs in the living cycads (Stevenson, 1981). However, I have been unable to observe the small basal cell that those hairs include although the long filiform apical cell is preserved (Pl. 3, Fig. *h*), as are the hair scars on the epidermis (Pl. 3, Fig. *f*). The apical cell of the hairs in *Charmorgia* compares closely with the apical cells in the hairs of *Dioon edule* and *Encephalartos hildebrandtii* (see Stevenson, 1981, Figures 40, 41). The hair scars found in *Charmorgia* are similar to those in the Chinle cycad, *Lyssoxylon* (see Gould, 1971, Figures 23-24).

COMPARISONS

As shown in Table 2 the fossil that *Charmorgia* gen. n. resembles most closely is *Bororoa* Petriella (1972) from the Paleocene of Argentina. The others listed in the table are columnar stems, mostly 5 cm or less in diameter, although *Michelilloa* and *Menucoa* (also columnar) are much larger (10-60 cm in diameter). *Charmorgia* gen. n. falls within the size range of *Bororoa*, and both genera have closely spaced rhombic persistent leaf bases. Internally they are similar, as they both have medullary vascular strands and the secondary wood shows alternate bordered pits. There are significant differences: *Bororoa* has several zones of secondary xylem (a single zone in the new genus), and all of the persistent leaf bases of *Bororoa* are the same approximate size (in the new genus the large leaf bases are scattered among much smaller cataphyll bases).

Charmorgia gen. n. does not compare at all closely with *Lyssoxylon* Daugherty em. Gould (1971) from the Chinle Formation (Table 2). That stem is columnar and shows four-lobed persistent leaf bases (a squat stem with rhombic leaf and cataphyll basis in *Charmorgia* gen. n.) and its pith does not contain medullary vascular bundles (present in *Charmorgia* gen. n.). Similarities include a single zone of secondary xylem, girdling leaf traces which are external to the vertical traces, and leaf traces which may have undergone secondary growth. Also the cellular contents are preserved in parts of both fossils.

Although *Charmorgia* gen. n. shows many characters

Table 2. Comparison of some of the characteristics of *Charmorgia* gen. n. with those of certain other fossil cycadealean stems

	Charmorgia gen. n.	*Lyssoxylon* Daugherty, 1941; em. Gould, 1971	*Leptocycas* Delevoryas and Hope, 1971	*Michelilloa* Archangelsky and Brett, 1963	*Sewardioxylon* Gupta, 1960, 1971; Sharma, 1971	*Fascisvarioxylon* Jain, 1962	*Nilssonicladus* Kimura and Sekido, 1975	*Menucoa* Petriella, 1969	*Bororoa* Petriella, 1972
Age and locality	Late Triassic, Arizona	Late Triassic, Arizona and New Mexico	Late Triassic, North Carolina	Triassic, Argentina	Middle Jurassic, India	Middle Jurassic, India	Early Cretaceous, Japan	Early Tertiary, Argentina	Paleocene, Argentina
Growth habit	Short and squat	Columnar	Columnar	Probably columnar	Columnar	Columnar	Slender long shoot with dwarf shoots	Columnar	Short and squat
Stem diameter (cm)	24-30	2.5-4.6	3-5	10±	3	1.8-2.3	Long shoot: 0.6; Dwarf shoot: 0.4-0.5	40-60	12.5-45
Leaf and cataphyll base spacing	Closely spaced	Closely spaced	Widely spaced	N.R.	Closely spaced	Closely spaced	Closely spaced on dwarf shoot	Closely spaced	Closely spaced
Leaf and cataphyll base shape	Elliptical to rhombic	Four lobed	Rhombic	N.R.	Rhombic	Rhombic	Rhombic	Rhombic	Rhombic
Leaf base width (cm)	Leaf: 1.9-8.2 Cataphyll: 1.2-3.6	0.7-1.3	N.R.	N.R.	N.R.	Leaf: 0.7 Cataphyll: N.R.	0.8	3.0	0.8-3.1
Leaf trace shape in cortex	Round to fan shaped	Triangular to fan shaped	N.R.	Round	N.R.	Trough-shaped	N.R.	Round to oval	Round to oval
Position of girdling leaf traces	External to vertical traces	External to vertical traces	N.R.	N.R.	N.R.	N.R.	N.R.	External to vertical traces	N.R.
Stele type	Monoxylic	Monoxylic	N.R.	Monoxylic	Polyxylic	Monoxylic	N.R.	Polyxylic	Polyxylic
Pitting of secondary xylem	Bordered pitting	Bordered pitting	N.R.	Spiral, scalariform and bordered pitting	Bordered pits with tertiary spiral thickening	Bordered to scalariform pitting	N.R.	Bordered pitting	Bordered pitting
Medullary vascular strands	Present	Absent	N.R.	Absent	Present	Present	N.R.	Absent	Present

Note: N.R., not recorded. The stem called *Bucklandia* Presl which is supposed to belong to the Cycadales or the Cycadeoidales is not included in this table because most specimens are too poorly preserved to characterize clearly. Furthermore, the three species of *Bucklandia* which have been studied anatomically have cycadeoidalean features. The hypothetical stems in the reconstructions of the fossil cycadalean plants given by Lilienstern (1928), Florin (1933), and Harris (1961) are also excluded from the table. Girdling leaf traces which are characteristic of the Cycadales have not been reported in *Michelilloa*, *Sewardioxylon*, or *Fascisvarioxylon*, but these genera are included in the table because they show other cycadalean characters and therefore are usually attributed to that order.

found in the living cycadaleans (see Table 1), it does not compare closely with any single living member of the order. Rather, the new genus combines the features of several. It has, for example, both mucilage canals and meandering medullary bundles as in *Encephalartos* and *Macrozamia* (Greguss, 1968). *Charmorgia* also has a persistent armor composed of leaf and cataphyll bases similar to that of those genera, but does not have several zones of secondary xylem as they do. The new genus has an armor of persistent leaf and cataphyll bases and a single zone of xylem, as in the living *Dioon* and *Ceratozamia,* but those genera do not have medullary vascular bundles. The new genus does share a number of characters with the living cycad *Cycas circinaliis.* For example, both species have an aerial stem although it is columnar in the living form, not short and thick as it is in *Charmorgia.* In addition, both species have an armor composed of persistent leaf and cataphyll bases which have thin flanges. The arrangement of vascular bundles in the leaf and cataphyll bases is strinkingly similar (cf. Figs. 3*a* with 4*a,* and 3*b* with 4*b*) in the two species, but the xylem is centripetal in the living species (Figure 4*e*) whereas it is centrifugal in *Charmorgia* (Figure 3*e*). Also, the resin ducts and epidermis in both genera are very similar. *Cycas circinaliis,* however, has several zones of wood in the stem (a single zone in *Charmorgia*) and no medullary vascular bundles (present in *Charmorgia*).

When living, *Charmorgia* probably looked very much like the example of *Encephalartos altensteinii* illustrated by Wieland (1906, Figure 110) and of *Dioon edule,* also given by that author (1906, Figure 119). In gross form it also could have looked much like certain species of *Cycadeoidea,* such as *C. nana,* a so-called pygmic species illustrated by Wieland (1906, p. 263, Plate 6, Figure 3).

CONCLUSIONS
By Late Triassic time there was a plant with a short thick aerial stem resembling that of Cycadeoidales (Late Jurassic —Early Cretaceous) and of the living *Encephalartos* in general external appearance. This plant, *Charmorgia* gen. n., shared several anatomical features with certain Cycadeoidaceae and several living cycads. *Charmorgia* gen. n., however, agrees with at least some of the Cycadales and differs from the Cycadeoidaceae in some key features including its medullary vascular bundles, girdling leaf traces, omega arrangement of leaf base bundles, origin of vascular bundles in the leaf bases from several leaf traces, and cyclocytic to amphicyclocytic stomata.

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The Petrified Forest and its Vertebrate Fauna in Triassic Pangaea

by Edwin H. Colbert

ABSTRACT

The Petrified Forest of Arizona, known world-wide for the fossil logs exposed in the Upper Triassic sediments within its boundaries, is less well known for its equally important fossil vertebrates. These fossils, consisting of lungfish of the genus *Ceratodus*, semionotid fishes, large stereospondyl amphibians of the genus *Metoposaurus*, various thecodont reptiles such as phytosaurs (*Rutiodon*), aetosaurs (*Desmatosuchus* and *Typothorax*), as well as large rauisuchids, saurischian dinosaurs, especially the coelurosaurian, *Coelophysis*, a huge dicynodont therapsid, *Placerias*, and other reptiles as well, constitute a fauna that is characteristic of the Upper Triassic sediments in other parts of the world. This fauna and faunas very similar to it are found in other areas of western North America, along the Atlantic seaboard from Nova Scotia to Georgia, in central Europe, in peninsular India, China, and Thailand. Many of the elements of the fauna are found in the southern continents that once comprised the ancient continent of Gondwanaland, notably Africa and South America. Thus, although the Upper Triassic vertebrates of the Petrified Forest are spectacular, particularly because of their abundance and excellent preservation, they are not unique. They are the local representatives of closely related vertebrate faunas that in late Triassic times lived across the far reaches of the great Pangaean supercontinent.

INTRODUCTION

The Petrified Forest of Arizona is justly famous throughout the world for the remarkable concentrations of fossil logs to be seen within its boundaries. These logs, beautifully fossilized and often of great size, are the prime attractions that bring visitors by the hundreds of thousands each year to the Forest. Less well known, but of particular interest and significance to the paleontologist, are the fossils of fishes, amphibians, and reptiles that occur in the Petrified Forest. Such fossils will be the subject of this paper. (Breed and Breed 1972.)

It is not the purpose of the present contribution to describe the vertebrate fauna of the Petrified Forest in detail; rather, the thrust of this paper will be aimed at a consideration of the Petrified Forest vertebrates as they are related to vertebrates of correlative age found in other parts of North America and in other parts of the world. It is hoped with such a survey to emphasize the fact that the fossils of the Petrified Forest, especially the fossil vertebrates, are of more than local interest; rather, they are the local manifestations of vertebrate life that extended across much of the area of the great ancient supercontinent, Pangaea.

It is a part of the thesis here set forth that the fossils of the Petrified Forest must be viewed in this context; that they must be seen as the remains of animals once living in a world far different from the world with which we are acquainted. For the far-flung researches in geophysics, geology, and paleontology of the past three decades would seem to indicate in strong terms that the concept of Pangaea is valid. In late Paleozoic and early Mesozoic time, the Pangaean supercontinent, with its northern and southern hemisphere components Laurasia and Gondwanaland, respectively, was intact; only with the advent of very late Triassic history did the rifting of Pangaea begin. The existence of the still intact supercontinent was a fact of prime importance influencing the development of terrestrial animals living in what is now Arizona, as well as such animals living elsewhere in that ancient world. This forms a background for the evaluation of the Upper Triassic tetrapod fauna of the Petrified Forest and its relationships to contemporaneous faunas in other regions.

THE SEDIMENTS OF THE PETRIFIED FOREST

The topography and the truly spectacular scenery of the Petrified Forest are developed for the most part in exposures of the Chinle Formation of late Triassic age. The Chinle beds here are variously developed, consisting of siltstones and sandstones of differing composition, the softer sediments commonly eroded into rounded hills and badlands, the sandstone lenses frequently standing out as resistant ledges. All of the sediments are colorful, with bands of red, purple, gray, white, and other hues lending to the scene the variegated panoramas that have impressed the eyes of visitors throughout the years. Indeed, the northern part of the Forest, where the upper parts of the Chinle Formation are exposed, is dominated by brilliant red sediments that make up a part of the Painted Desert—El Desierto Pintado of the Spanish explorers. These diverse sediments of the Petrified Forest have been designated as the *Petrified Forest Member* of the Chinle Formation, representing the typical and most widely distributed fossiliferous layers within the Chinle sequence. In its type area, the Petrified Forest Member shows a tripartite division, with the prominent Sonsela Sandstone bed separating upper and lower units of the member.

Several members in addition to the Petrified Forest Member have been recognized as making up the full extent of the Chinle Formation. It is generally agreed that the Shinarump conglomerate, frequently considered in earlier works as distinct from the Chinle Formation, is properly

the lowest member of the sequence. In some areas, the Petrified Forest Member is immediately above the Shinarump; in others, the Monitor Butte Member is interposed between the Shinarump and Petrified Forest members. Still another member, the Mesa Redondo, is between the Shinarump and the Monitor Butte in the Defiance Plateau, but this interposition is not to be seen in the Petrified Forest region. Finally, in some parts of the Petrified Forest area the Owl Rock member is above the Petrified Forest Member. (Repenning et al. 1969.)

In its broader aspect, the Chinle Formation is representative of the Upper Triassic throughout southwestern North America. It and its contained fossils are to be compared with the Dockum beds of Texas and New Mexico, the Popo Agie of Wyoming, a part of the Newark Series of eastern North America, the type Keuper of central Europe, the Maleri Formation of central India, the Lufeng beds of China, the Forest Sandstone of Rhodesia, the Red Beds and Cave Sandstone of the Stormberg Series of South Africa, and the Ischigualasto and Los Colorados beds of Argentina. Faunal relationships are closer in some cases than in others, but all of these horizons and their fossils, so widely distributed throughout the world, may be compared to a greater or lesser extent with the Chinle Formation, as will be done below. (Colbert and Gregory 1957.)

FOSSIL VERTEBRATES
OF THE PETRIFIED FOREST
It was mentioned above that the Petrified Forest Member of the Chinle Formation consists, in the Petrified Forest,

of a lower and an upper unit, separated by the Sonsela Sandstone. Vertebrate faunas are found in both units showing some interesting contrasts, the one with the other. In both the lower and upper units are lungfish of the genus *Ceratodus*, similar to the modern Australian lungfish, and heavily scaled semionotid fishes as well. The large stereospondyl amphibian *Metoposaurus* is abundant in the lower unit, but relatively rare above the Sonsela Sandstone. Its place in the upper unit seems to be largely taken by a new long-bodied metoposaurid, to be described by J. R. Bolt. Thecodonts are the predominant reptiles in the Petrified Forest, and of these, the phytosaurs are the most common. The genus *Rutiodon* is present both below and above the Sonsela Sandstone; the upper unit is distinguished by the species *Rutiodon tenuis*. Thecodonts other than phytosaurs are generally abundant and varied. Perhaps the best known are the large, armored stagonolepids or aetosaurids, *Desmatosuchus* and *Typothorax*, the former in the lower unit, the latter in the upper unit in association with *Rutiodon tenuis*. Rauisuchid thecodonts, although sparse in the Petrified Forest, are especially noteworthy by virtue of a huge carnivorous genus, recently discovered. They are abundant at St. Johns, Arizona, some fifty miles to the east. The genus *Poposaurus*, formerly considered as a dinosaur but now recognized as a thecodont, is present both at St. Johns and at the Petrified Forest in the lower unit. The small ornithosuchid thecodont, *Hesperosuchus*, originally described from north central Arizona, is present also at the Petrified Forest, as are other thecodonts of this type. Dinosaurs are comparatively sparse in the Petrified Forest, but

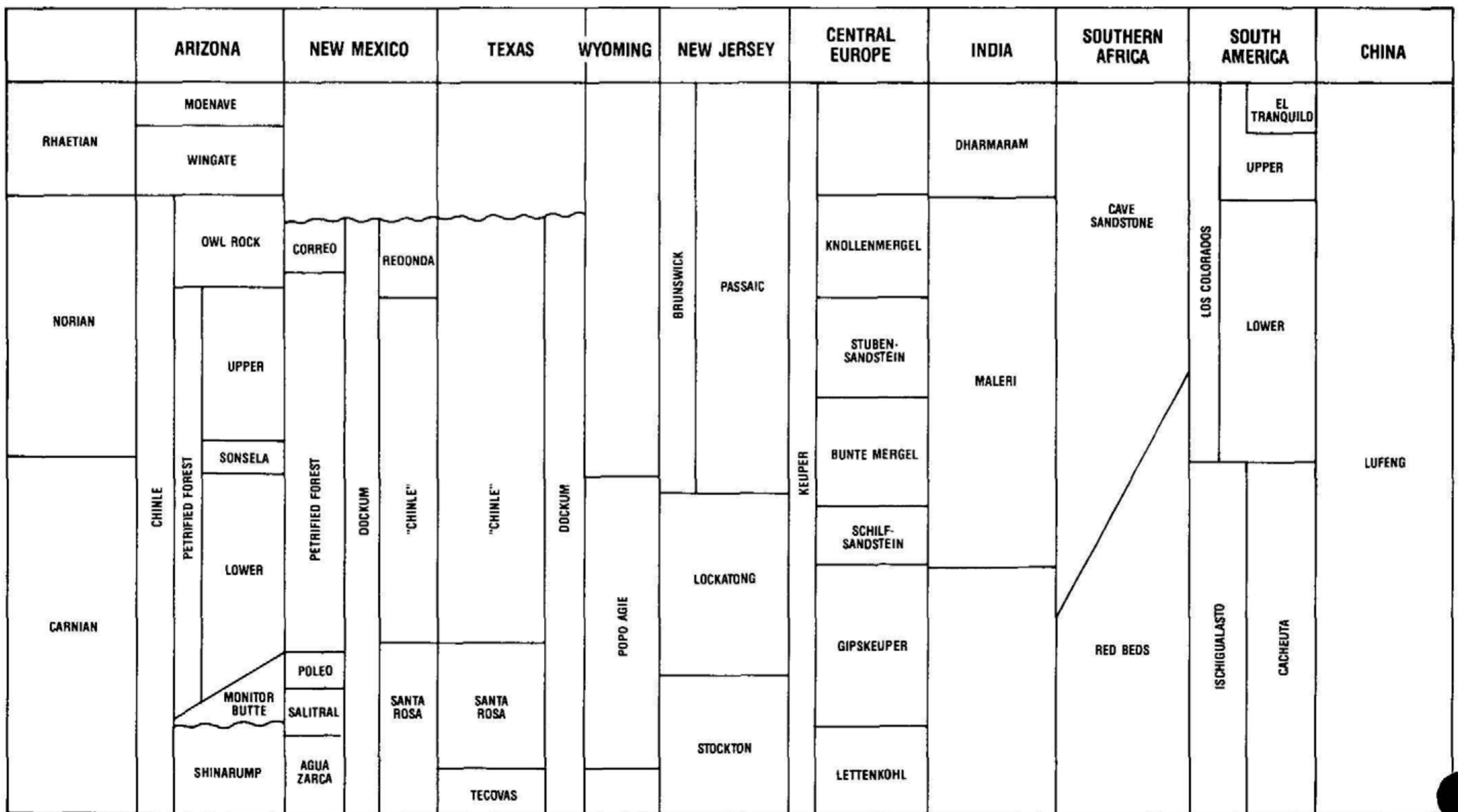|		ARIZONA	NEW MEXICO	TEXAS	WYOMING	NEW JERSEY	CENTRAL EUROPE		INDIA	SOUTHERN AFRICA	SOUTH AMERICA		CHINA
RHAETIAN		MOENAVE							DHARMARAM			EL TRANQUILO	
		WINGATE										UPPER	
NORIAN	CHINLE	OWL ROCK	CORREO	REDONDA		BRUNSWICK PASSAIC	KEUPER	KNOLLENMERGEL		CAVE SANDSTONE	LOS COLORADOS	LOWER	
		UPPER						STUBEN-SANDSTEIN	MALERI				
		PETRIFIED FOREST SONSELA	PETRIFIED FOREST	DOCKUM "CHINLE"	"CHINLE" DOCKUM			BUNTE MERGEL			ISCHIGUALASTO CACHEUTA		LUFENG
CARNIAN		LOWER			POPO AGIE	LOCKATONG		SCHILF-SANDSTEIN		RED BEDS			
		MONITOR BUTTE POLEO	SALITRAL	SANTA ROSA	SANTA ROSA	STOCKTON		GIPSKEUPER					
		SHINARUMP	AGUA ZARCA	TECOVAS				LETTENKOHL					

Figure 1. Correlation chart to show the world-wide relationships of Upper Triassic formations.

fossils, for the most part still to be identified, have been found both above and below the Sonsela Sandstone. It is now evident that the well-known coelurosaurian genus *Coelophysis*, so plentiful at Ghost Ranch, New Mexico, is present at a level comparable to the upper unit in the Petrified Forest area. The large dicynodont therapsid *Placerias*, abundantly present at St. Johns, is indicated as a constituent of the lower unit fauna in the Petrified Forest. At St. Johns are found procolophonids—the last of the cotylosaurs—and trilophosaurs (well known from the Dockum beds of Texas), and these would seem to be present at the Petrified Forest as well, in the sediments below the Sonsela Sandstone. Finally, there should be mentioned the peculiar little euryapsid reptile *Tanytrachelos*, known from abundant materials in the Newark beds of the eastern seaboard and now tentatively identified as present in the Petrified Forest region, specifically at St. Johns. (Olsen 1979.)

UPPER TRIASSIC VERTEBRATES ELSEWHERE IN NORTH AMERICA AND THEIR RELATIONSHIPS TO THOSE OF THE PETRIFIED FOREST

In the Dockum Group, there is the same general association of tetrapods as seen at the Petrified Forest, variously present in the several horizons of this sequence. Dockum sediments are found in northeastern New Mexico, extending east into the Texas panhandle, and in Texas directly east of the southeastern corner of New Mexico. Here one sees predominantly red siltstones and sandstones and shales, evidently deposited under conditions similar to those that controlled the deposition of the Chinle beds. In Texas, the
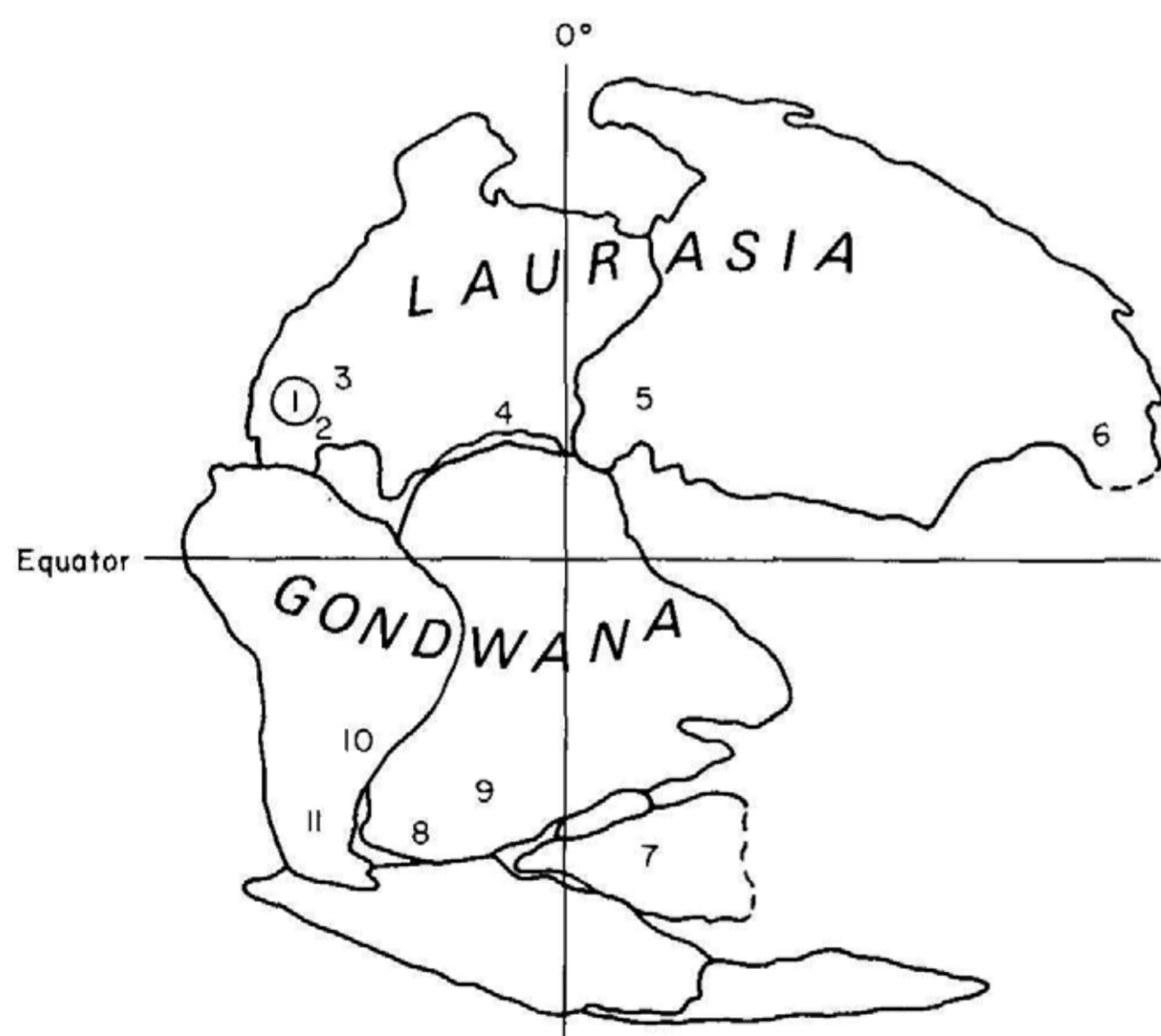
Figure 2. Pangaea in late Triassic time, showing important tetrapod localities. (1) Chinle, Petrified Forest, Arizona; (2) Dockum, Texas; (3) Popo Agie, Wyoming; (4) Newark, Eastern North America; (5) Keuper, Europe; (6) Lufeng, China; (7) Maleri, India; (8) Red Beds and Cave Sandstone, South Africa; (9) Forest Sandstone, Zimbabwe; (10) Santa Maria, Brazil; (11) Ischigualasto and Los Colorados, Argentina.

Dockum Group has been divided into the Tecovas Formation below, the upper part of which may be more or less equivalent to the Petrified Forest Member, capped by the Santa Rosa Sandstone or the Trujillo Formation. In southeastern New Mexico, the Dockum consists of the Santa Rosa Sandstone below, succeeded by a shale member in part equivalent to the Petrified Forest Member, and followed in turn by the Redonda member, while to the north is a lower shale unit, again generally equivalent to the Petrified Forest Member, followed in turn by the Sloan Canyon Formation and the Sheep Pen Sandstone.

Gregory has recognized several successive zones in the Dockum, distinguished in part by their phytosaurs. In the lowest level are the primitive phytosaurs *Paleorhinus* and *Angistorhinus*, associated with *Metoposaurus* and *Desmatosuchus*. Succeeding this is an upper zone with the phytosaur *Nicrosaurus*, with aetosaurs but no metoposaurs. Finally, at the top of the sequence in the Redonda Sandstone, is an undetermined phytosaur and theropod tracks. In this succession, one sees rather different occurrences than those at the Petrified Forest. Moreover, *Paleorhinus* and *Angistorhinus* at the base of the Dockum are more primitive than any phytosaurs at the Petrified Forest. (Case 1922, Gregory 1957, 1969.)

These last two named phytosaurs are found in the Popo Agie beds of Wyoming, which sediments occur in limited exposures and would seem to represent Triassic levels lower than the Petrified Forest Member. *Anaschisma*, a stereospondyl distinct from *Metoposaurus*, is present in the Popo Agie beds as are the rauisuchians *Heptasuchus* and *Poposaurus*, *Dolichobrachium*, a thecodont, and *Eubrachiosaurus* and *Brachybrachium*, therapsids that may be comparable to *Placerias*. (Branson 1927, Branson and Mehl 1929.)

Upper Triassic beds in eastern North America make up in part the Newark Group, an extensive series of rocks that comprise not only sediments and volcanics of late Triassic age, but also of early Jurassic age as well. These rocks are exposed in valleys and basins along the eastern seaboard, from Nova Scotia on the north, to the Connecticut Valley of Connecticut and Massachusetts (Lull 1953), the Northern Valley of New Jersey, on through Virginia, the Carolinas, and Georgia. These strata are perhaps more complex and varied than the Upper Triassic beds of the Southwest, and frequently represent facies that are not to be found in the Chinle, Dockum, and Popo Agie beds.

Much work has been done in recent years on the age relationships of rocks comprising the Newark Group; the subject is too involved and complex to be discussed in detail at this point. For the present purpose some attention will be given to the Newark beds as exposed in New Jersey, since these sediments have been extensively explored for fossils in recent years, and have yielded a vertebrate fauna of considerable dimensions.

Here three Triassic levels may be distinguished; a lower Stockton Formation, above that the Lockatong Formation, and at the top the Passaic Formation. (Olsen 1980a.)

Some of the vertebrates seen in the western Triassic are present here; *Metoposaurus* and *Rutiodon* in the Stockton and Lockatong beds, and theropod dinosaurs (represented mainly by tracks, as is the case in the Connecticut Valley) in the Lockatong and Passaic beds. There are, however, various vertebrates in the Newark Group that are absent

Figure 3. A reconstruction of late Triassic life, based upon fossils from the Petrified Forest Member of the Chinle Formation. Lower left, *Metoposaurus;* middle left, *Hesperosuchus;* top left, *Coelophysis.* Lower right, *Rutiodon;* top right, *Desmatosuchus.* Included among the plants are araucarian trees, horsetails, cyads, and ferns. (From Colbert, *The Age of Reptiles,* 1965. Weidenfeld and Nicolson, London; Norton, New York.)
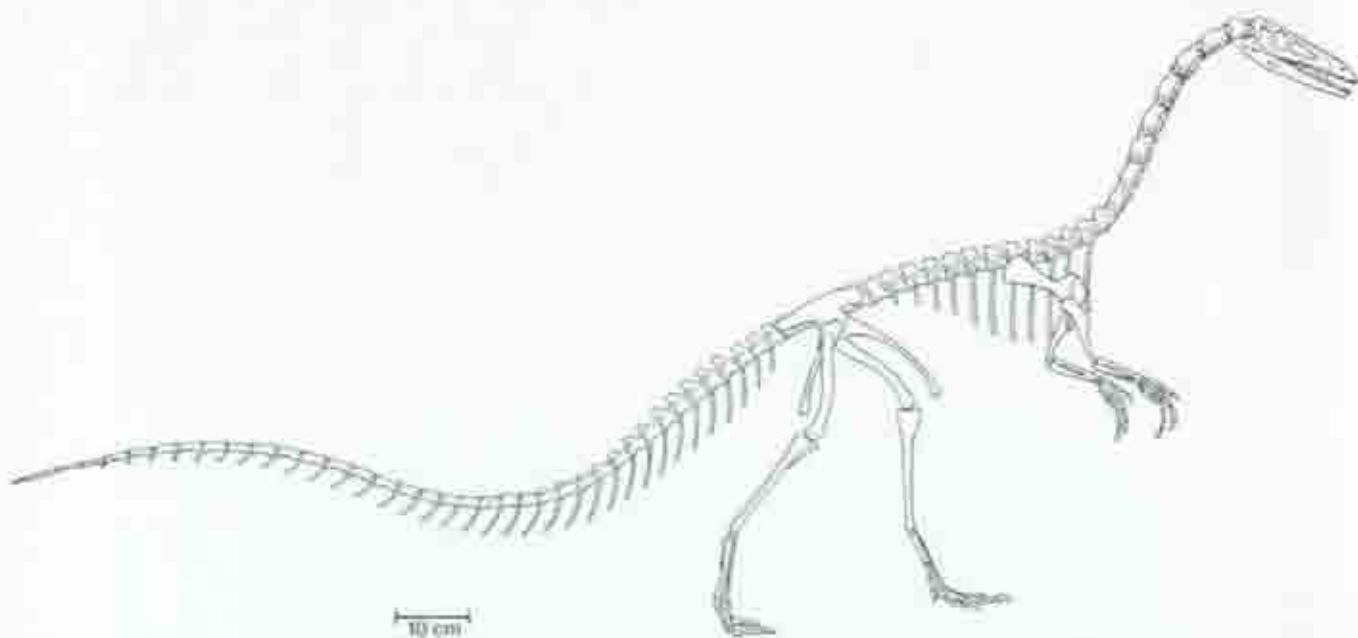

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Figure 4. *Coelophysis,* a coelurosaurian dinosaur from the Petrified Forest Member of the Chinle Formation.
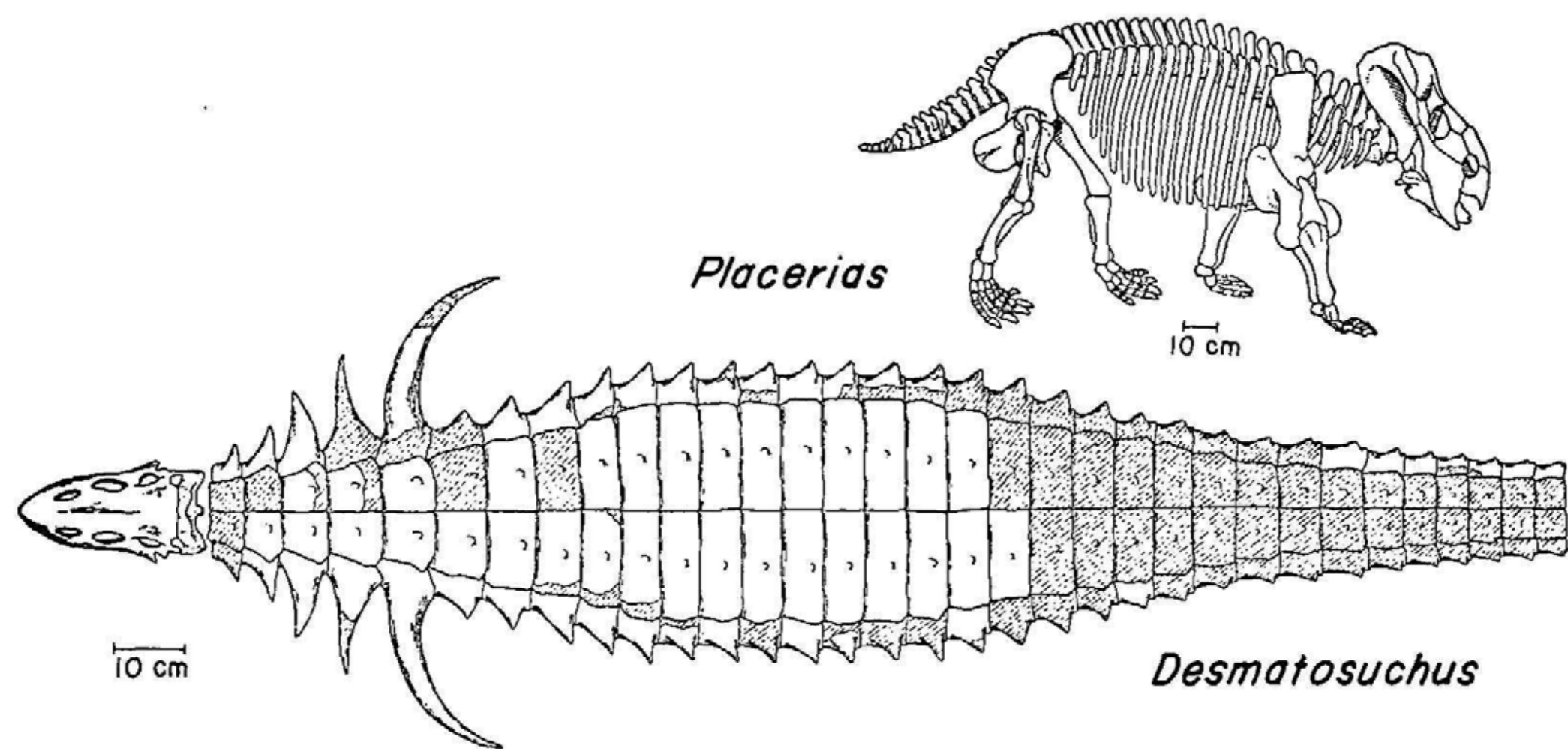
Figure 5. *Placerias,* a dicynodont therapsid, and *Desmatosuchus,* an armored thecodont, from the Petrified Forest Member of the Chinle Formation. (From *Museum of Northern Arizona Bulletin 47,* 1972.)
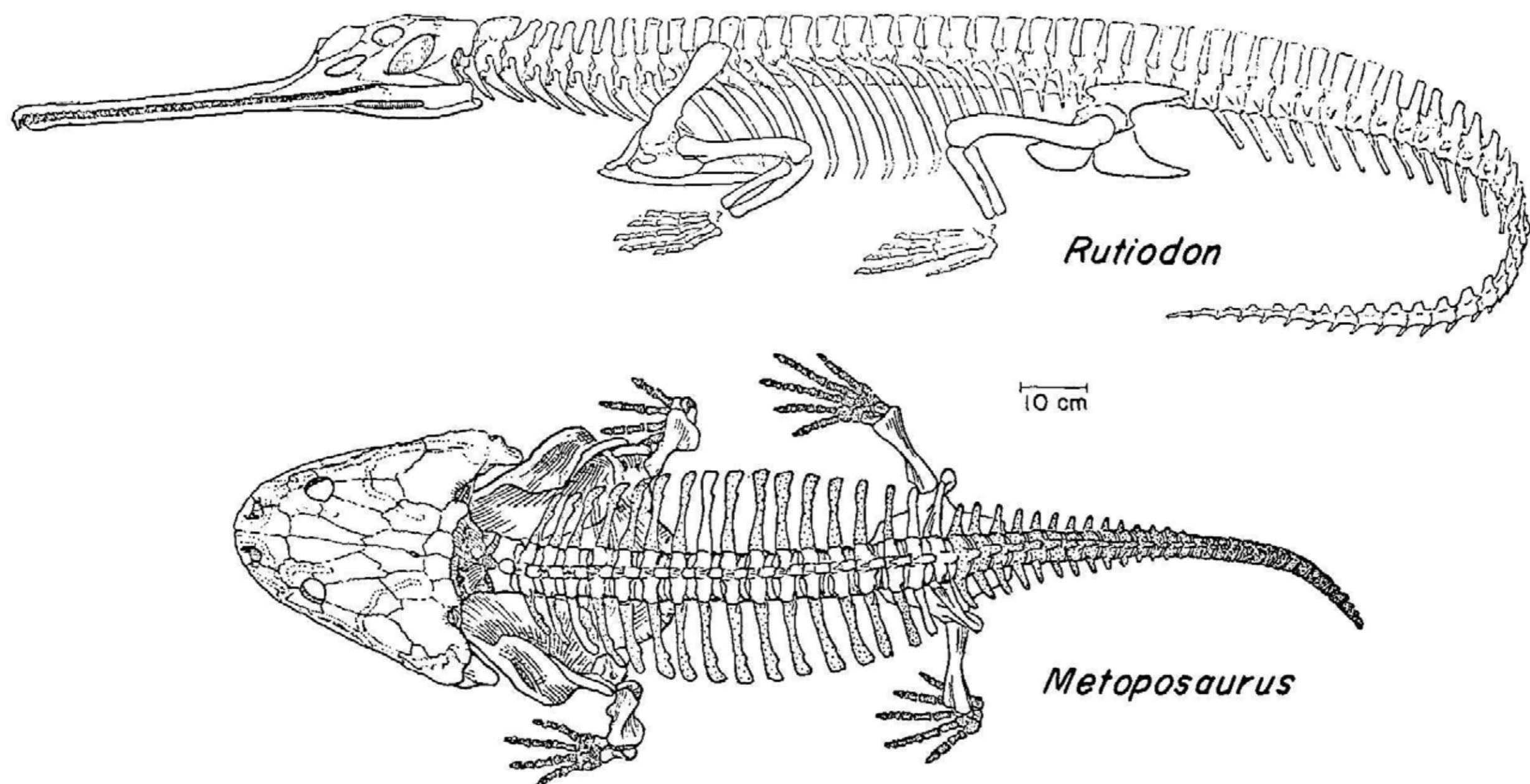

Figure 6. *Rutiodon,* a phytosaur, and *Metoposaurus,* a labryinthodont amphibian, from the Petrified Forest Member of the Chinle Formation. (From *Museum of Northern Arizona Bulletin 47,* 1972.)

or only sparsely represented in the western Triassic, these being for the most part genera of small size, preserved in fine-grained shales that are not usually present in the western sediments. In this region we see, therefore, the preservation of a facies hitherto not encountered.

There is good reason to think that some of the small vertebrates of the Newark beds were also living in what is now western North America but were not generally preserved because of adverse conditions of sedimentation. Even so, it should be pointed out, some similarities exist. Thus semionotid fishes, typical of the Lockatong and Passaic Formations, have been found sparingly in a few Chinle exposures.

In the Lockatong Formation, a lacustrine deposit, is the coelacanth fish *Diplurus*, discovered in an unprecedented concentration when excavations were made for the foundation of the library at Princeton University. The little cotylosaur, *Hypsognathus*, is a member of the Passaic

fauna, matched by a related form, *Sphodrosaurus*, found in Pennsylvania. And in the Lockatong Formation are some especially interesting reptiles of very small size, specialized for life in shallow ponds—namely, *Tanytrachelos*, recently identified in Arizona, and an as-yet-unnamed genus presently called the "deep-tailed swimmer," the relationships of which are only to be guessed at. (The skull is not preserved.) Finally, there should be mentioned the unusual gliding eosuchian, *Icarosaurus*, characterized by the elongation of the ribs to support a membrane that allowed this reptile to sail from tree to tree, much as does the modern lizard, *Draco*, of the Orient. Recently discovered bone fragments would seem to indicate that *Icarosaurus* may have been present in the Chinle Formation in Arizona. A counterpart to *Icarosaurus* is *Kuehneosaurus* from the Upper Triassic beds of the Bristol Channel, England. (Olsen 1980a, 1980b, Olsen et al. 1978.)
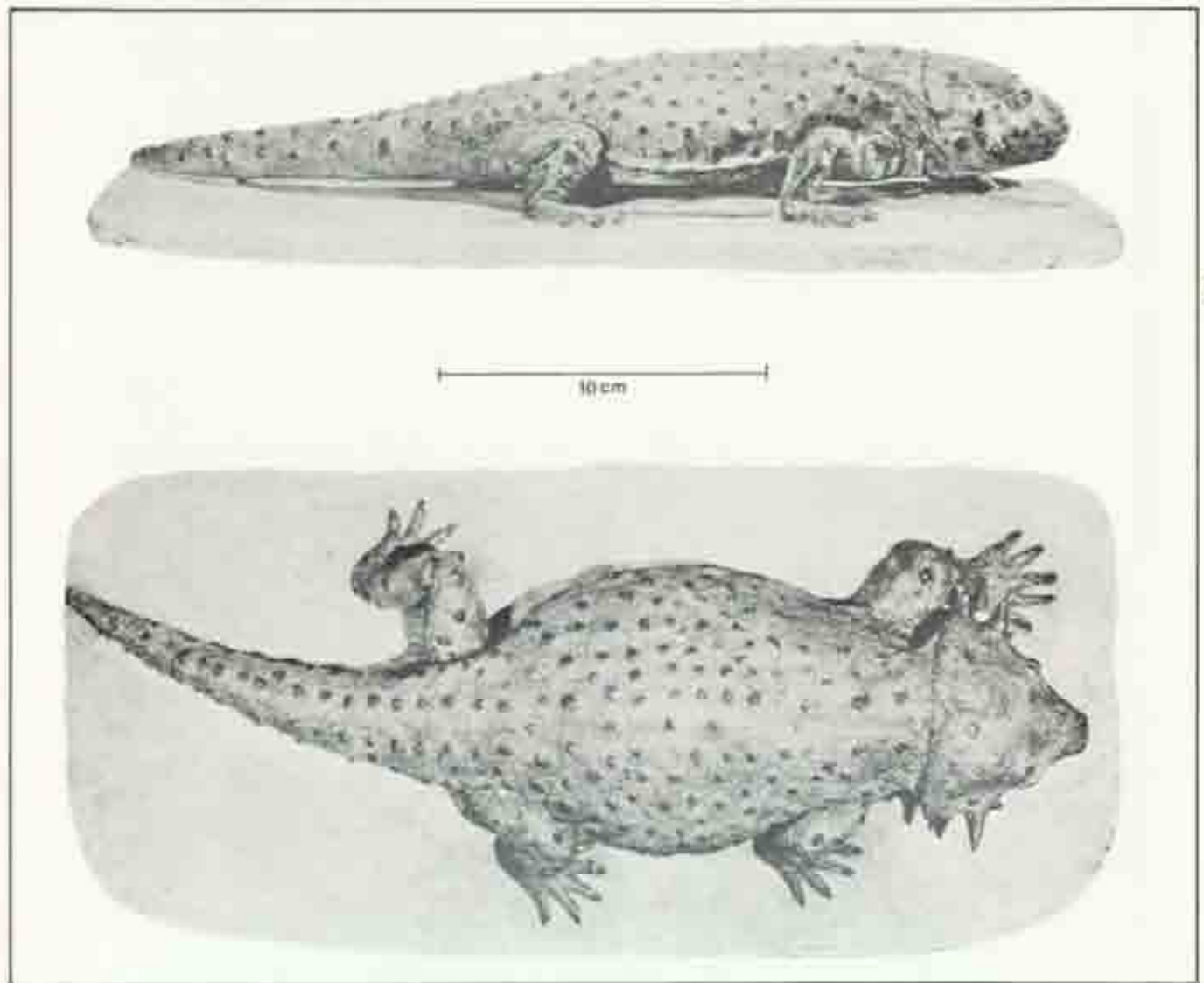

Figure 7. *Hypsognathus*, a procolophonid reptile, from the Passaic Formation of the Newark Group. (From *Bulletin of the American Museum of Natural History*, Vol. 86, 1946.)

In spite of differences in detail, there is a general similarity among the backboned animals that lived across this North American part of ancient Laurasia. Metoposaurid amphibians and phytosaurs were perhaps the most ubiquitous of the animals of that time, frequenting the rivers and lakes that abounded on a continent that was near sea level and had a tropical climate. Primitive dinosaurs roamed the higher ground, as did various thecodont reptiles, some large, some small and lightly built, these latter in effect the structural progenitors of the first dinosaurs even though contemporaneous with the ancient theropods. In some regions, there were large dicynodont therapsids—the last of their line. In the rivers and ponds of the time were numerous semionotid fishes, characterized by rhombic scales of shining enamel, as well as lungfishes closely related to the modern lungfish of Australia. Small freshwater coelacanths were also abundant. Sharing the shallow lakes and streams with these fishes were small aquatic reptiles, while in the tropical forests of that time were gliding reptiles, seeking their protection in the upper reaches of the trees.

UPPER TRIASSIC VERTEBRATES BEYOND NORTH AMERICA AND THEIR RELATIONSHIPS TO THOSE OF THE PETRIFIED FOREST

The ultimate comparison when considering Triassic rocks and fossils is with the type Triassic of central Europe, the three-fold sequence of rocks from which the name *Triassic* is derived. This triad is, of course, made up from bottom to top of the Buntsandstein, Muschelkalk, and Keuper, with the Rhaetic often added to the top of the series in a position more or less transitional to the Jurassic. (French scholars commonly place the Rhaetic at the base of the Jurassic.) It is the Keuper with which we are concerned. (Brinkmann 1960.)

The Keuper, in turn, has been divided into a series of zones, these being from bottom to top the Lettenkeuper (or Lettenkohl), Gypskeuper, Schilfsandstein, Buntemergel, Stubensandstein, and Knollenmergel. Each has its characteristic association of tetrapods, many of which transcend the limits of a single zone. An exploration of the details of faunal associations and limits will not be made at this place; rather, attention will be given to certain very characteristic genera of amphibians and reptiles with which similar or identical genera of the Chinle, and especially the Petrified Forest Member, may be compared. (Geyer and Gwinner 1964.)

The representation of labyrinthodont amphibians in the Keuper is more extensive than what is seen in the Chinle Formation, so that a considerable roster of amphibian genera typify the Upper Triassic of central Europe. Perhaps the most familiar of these is the large stereospondyl *Mastodonsaurus*, which ranges throughout the vertical extent of the Keuper. It has long been known, and its representation may be seen in books published as early as the mid-nineteenth century. This capitosaurid shares the Keuper with more restricted capitosaurids, such as *Capitosaurus* and *Cyclotosaurus*, both limited to the Schilfsandstein, Buntemergel, and Stubensandstein, as well as with the brachyopid stereospondyl *Plagiosaurus*, found in the upper half of the Keuper. In the present connection, however, the stereospondyl of especial interest is *Metoposaurus*, occurring in the Schilfsandstein and Buntemergel. Here is a direct link between Germany and Arizona, the significance of which is immediately obvious.

The association of phytosaurs with metoposaurs, one of the most striking features of the Petrified Forest area, is true in southern Germany, where the Keuper is particularly well exposed. Here are found *Nicrosaurus* and *Ebrachosuchus* (a junior synonym of *Paleorhinus* according to Gregory), the former ranging through the Schilfsandstein, Buntemergel, and Stubensandstein, the latter found in the Buntemergel.

The other reptiles that so characterize the Chinle Formation are also mirrored in the Keuper (or more properly vice versa), notably armored thecodonts as exemplified by *Aetosaurus* (Stubensandstein) and theropod and other dinosaurs found particularly in the Stubensandstein and Knollenmergel. These dinosaurs are various, and the same is becoming evident so far as the Petrified Forest Member is con-
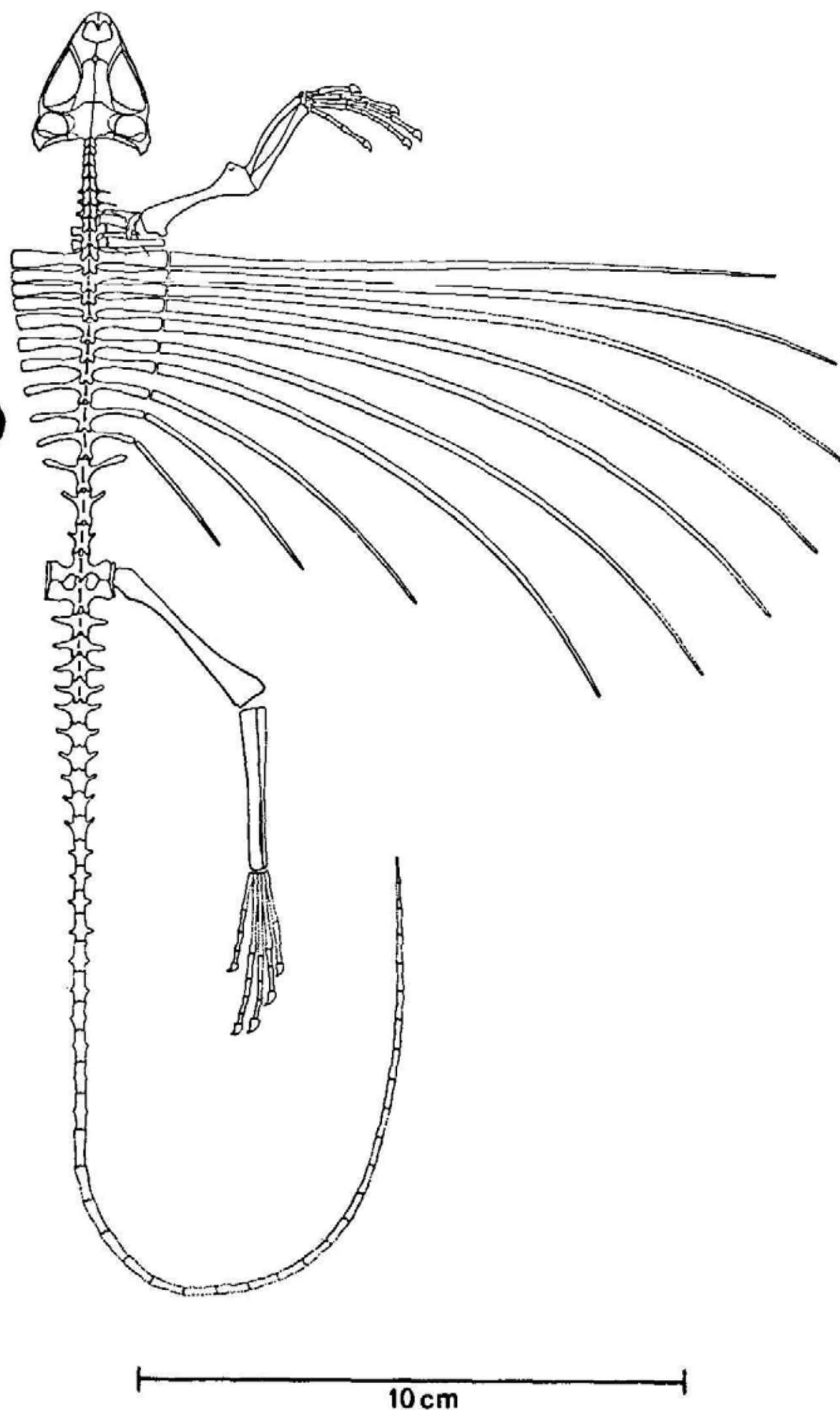

Figure 8. *Icarosaurus*, a gliding reptile from the Lockatong Formation of the Newark Group, and possibly from the Petrified Forest Member of the Chinle Formation. (From *Bulletin of the American Museum of Natural History*, Vol. 143, 1970.)

10 cm

cerned. Some are small, such as *Halticosaurus*, and may be compared with *Coelophysis*. Others such as the prosauropod dinosaur *Plateosaurus* are of considerable size, thus representing early evidences of the trend to giantism that was to so characterize dinosaurian evolution. (Wild 1978.)

In these several genera, we see resemblances that link the Upper Triassic tetrapods of Arizona with those of the type Upper Triassic in central Europe. There are certain differences that should be noted. For instance, in the Lettenkeuper, representing the base of the Upper Triassic in Germany, as well as in the overlying Gypskeuper, there are "seallike" nothosaurs and the peculiar placodonts, these latter reaching, in the genus *Henodus*, a culmination of what seems to us as bizarre specializations. All of these were shallow-water marine reptiles and, of course, are indicative of an environment within early Keuper time that did not exist in the region where Chinle sediments were being deposited.

Perhaps a more valid difference is to be found in the presence of the ancestral turtles *Proganochelys* and *Proterochersis* in the Stubensandstein and Knollenmergel. No such reptiles have been found in the Chinle beds, but recent discoveries have revealed turtles in the Kayenta Formation of Arizona, stratigraphically higher and temporally later than the Chinle. Is it possible that the chelonians had their origins in what is now central Europe, and reached western North America at a date significantly later than the time of their origin? Is it possible that the terrestrial turtles of very late Keuper time were the terrestrial analogs of the marine or shoreline placodonts of early Keuper time? *Henodus*, with its broad, flattened, armored body, short limbs, and strange skull, would in a way seem to have anticipated the turtles. No such reptiles as *Henodus* or its allies have been found in North America.

In central India, the Upper Triassic is represented by the Maleri Formation, which physically is not unlike the Chinle Formation, consisting of red sandstones and siltstones. Moreover, the Maleri fauna shows some remarkably close resemblances to the Chinle fauna, especially the association of those fossils found below the Sonsela Sandstone. In the Maleri beds are lungfish of the genus *Ceratodus*, a characteristic fish of the Petrified Forest member. Also, *Metoposaurus* is present in the Maleri beds, as are phytosaurs of the genus *Parasuchus*. Fossils indicative of armored thecodonts and indications of coelurosaurian dinosaurs are also recorded from the Maleri sediments. One significant difference between the Maleri and Chinle assemblages is the presence in India of a rhynchosaur, *Paradapedon*. The rhynchosaurs are large, heavy reptiles with peculiarly adapted skulls in which modified premaxillary bones take the place of upper teeth. These reptiles, supposedly related to the modern rhynchocephalians, are more typical of Gondwana faunas than of Laurasian faunas. Perhaps peninsular India in its Triassic position was a sort of crossroads, where elements from the two ancient supercontinents mingled. Yet, in spite of this seemingly discordant member of the Maleri fauna, its tetrapod association is, on the whole and so far as it can be judged, closely comparable to the Petrified Forest assemblage. (Huene 1940, Jain et al. 1964; Kutty and Roy-Chowdhury 1970, Robinson 1967.)

The close resemblances between the Maleri and Chinle faunas are echoed in the Upper Triassic Norian of Thailand, where there is an association of phytosaurs with the capitosaurid amphibian, *Cyclotosaurus*.

Peninsular India seemingly was closely associated with Africa in late Triassic time, so it is not surprising to find that many of the resemblances linking India to Arizona are also found in Africa. Perhaps one of the most striking cases is the coelurosaurian dinosaur, *Syntarsus*, from the Forest Sandstone of Zimbabwe, a theropod that echoes the structural adaptations that typify *Coelophysis*. The two dinosaurs are amazingly similar; differences are mainly those of detail, especially in certain features of the pelvis and feet. One cannot help but feel when viewing *Coelophysis* and *Syntarsus* side by side that there must have been close intercontinental contacts between these dinosaurs in late Triassic time. (Raath 1969.)
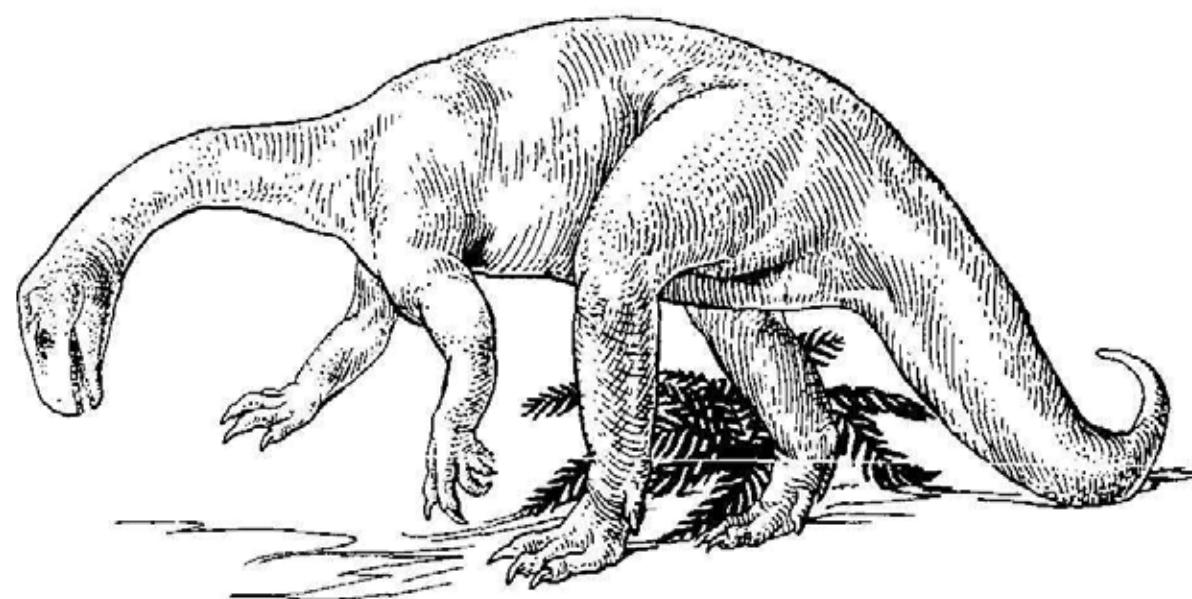

Figure 9. *Plateosaurus*, a prosauropod dinosaur, from the Keuper of southern Germany. (From Colbert, *The Age of Reptiles*, 1965. Weidenfeld and Nicolson, London; Norton, New York.)
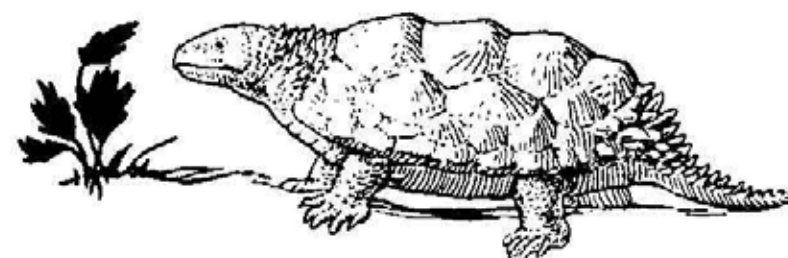

Figure 10. *Proganochelys*, a turtle, from the Keuper of southern Germany. (From Colbert, *The Age of Reptiles*, 1965. Weidenfeld and Nicolson, London; Norton, New York.)
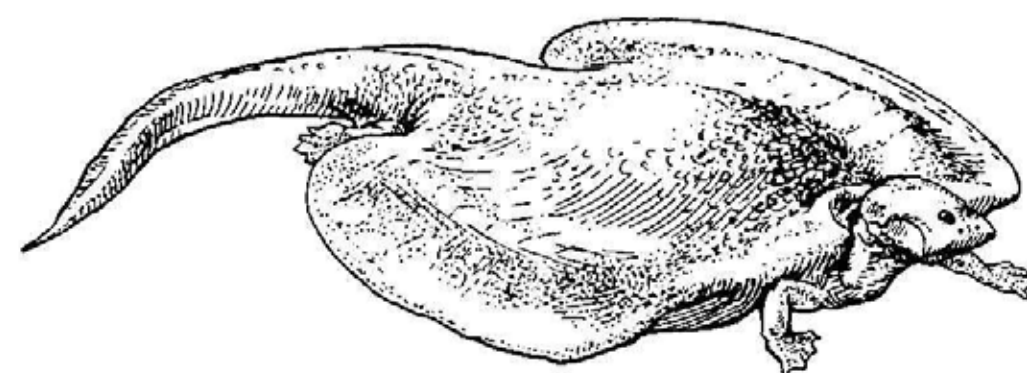

Figure 11. *Henodus*, a placodont reptile, from the Keuper of southern Germany. (From Colbert, *The Age of Reptiles*, 1965. Weidenfeld and Nicolson, London; Norton, New York.)

The more extensive comparisons between Africa and Arizona are to be found in the faunal associations in the Red Beds and Cave Sandstone of South Africa. In both of these formations are numerous saurischian dinosaurs, some of which are also present in Europe and in North America. Many of the South African Red Beds and Cave Sandstone reptiles, however, find their counterparts in the Kayenta Formation of Arizona, which places them somewhat outside the limits of this review. (Haughton 1969; Haughton and Brink 1954.)

Such are the early crocodilians and such are the ornithischian dinosaurs, first represented in the geologic record by *Fabrosaurus*, *Lesothosaurus*, and *Heterodontosaurus* in Africa, and by *Scutellosaurus* in the Kayenta beds of Arizona. Such especially are the tritylodonts, which are mammal-like reptiles of very distinctive form. *Tritylodon* of the Red Beds is mirrored in a new tritylodont from the Kayenta Formation. It has a close counterpart as well in *Bienotherium* from China. (Colbert 1981; Young 1951.)

Bienotherium is from the Lower Lufeng Formation in Yunnan. In this same horizon is *Pachysuchus*, supposedly a phytosaur, as well as pseudosuchian thecodonts, a protosuchian, and the prosauropod dinosaur *Lufengosaurus*, closely related to the German genus, *Plateosaurus*. Thus, the Chinese Lufeng fauna shows certain resemblances to the Keuper, Chinle, and Kayenta associations, and may perhaps be correlated with some of the late Triassic tetrapods of southern Africa. (Young 1946, 1951.)

Continuing this round robin of comparisons, we may return to southern Africa and from there across to South America, for the Triassic links between the two southern continents are strong. In Argentina, Upper Triassic rocks are represented by the Ischigualasto Formation, above which is the Los Colorados Formation, the former being generally equivalent to the lower part of the Keuper, the latter to the upper Keuper and perhaps the Rhaetic as well. In the Ischigualasto beds are found a stereospondyl amphibian, *Promastodonsaurus*, a considerable array of thecodont reptiles including rauisuchids (but no phytosaurs), two saurischian dinosaurs, *Herrerasaurus* and *Ischisaurus*, an ornithischian dinosaur, *Pisanosaurus*, some cynodont therapsids, *Proexaertodon* and *Exaertodon*, and some advanced kannemeyerid dicynodonts. In addition, there is a rhynchosaur, *Scaphonyx*, abundantly present also in the Santa Maria beds of Brazil and evidently closely related to *Paradapedon* of India. This association of tetrapods overall has a strong African cast; there is little to indicate an intimate North American connection.

The Los Colorados beds, however, do show some Laurasian relationships in the contained fauna. The thecodont *Pseudhesperosuchus* is, according to Bonaparte, closely related to *Hesperosuchus* from the Chinle of Arizona.
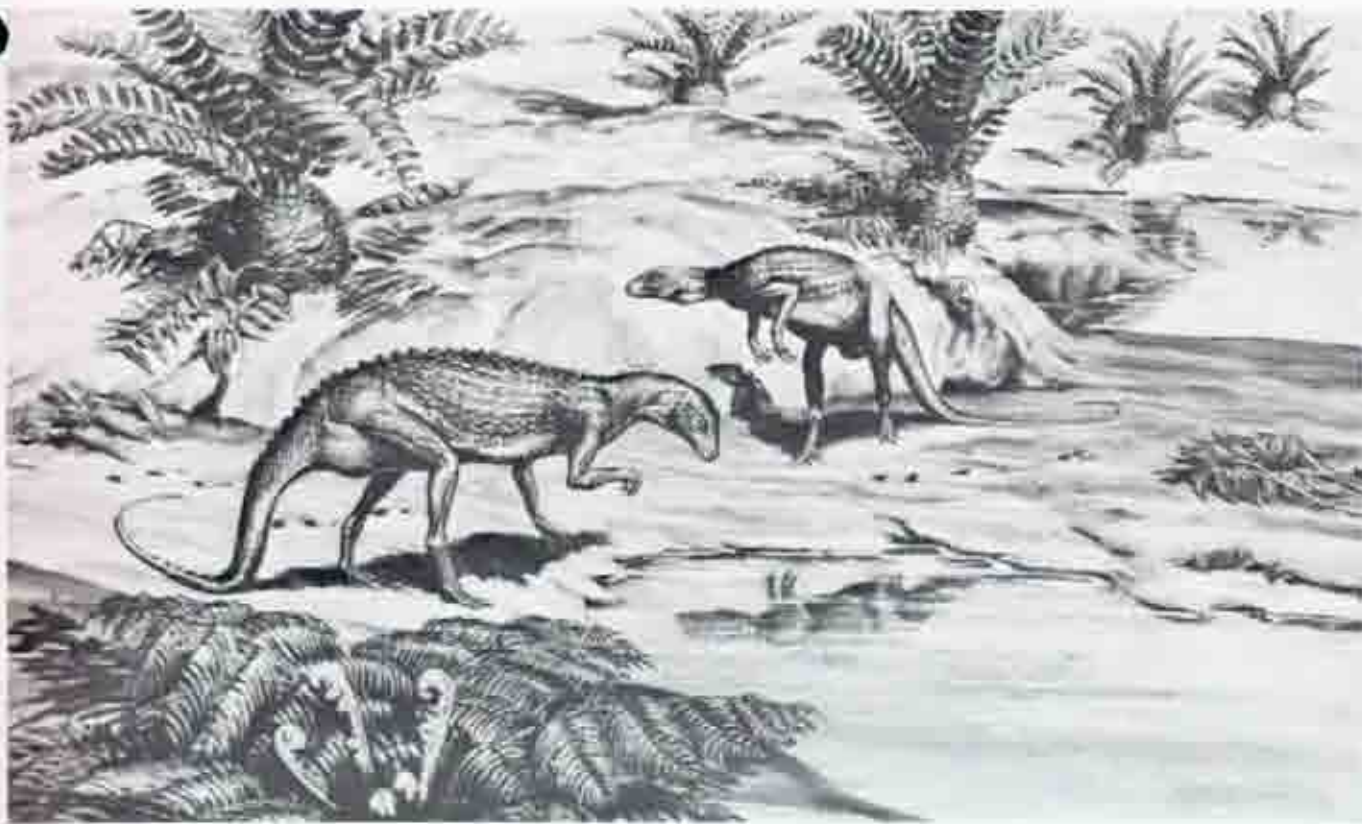

Figure 12. *Scutellosaurus*, an early ornithischiand dinosaur, from the Kayenta Formation. (Photograph courtesy of Z.V. Spinar. Reconstruction by L. Dédek.)
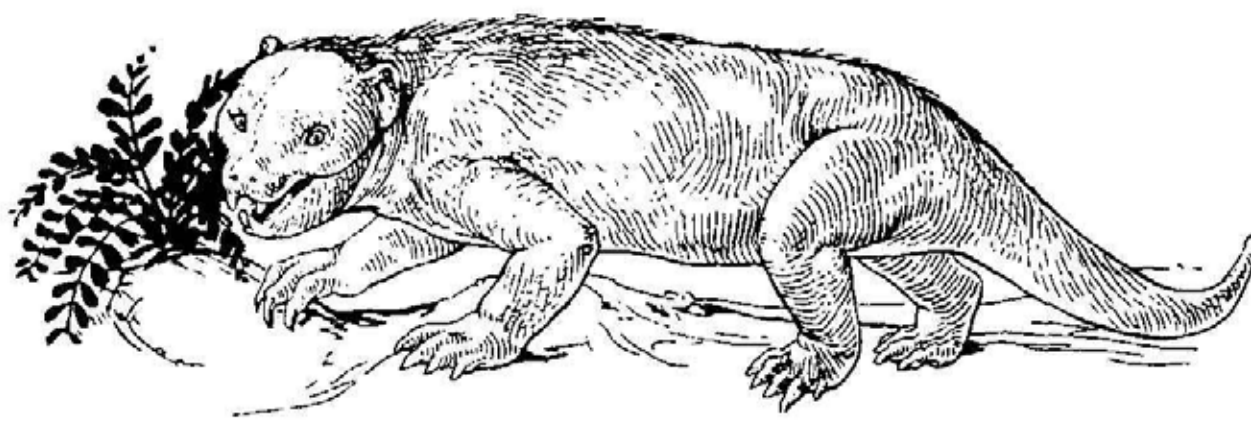
Figure 13. *Bienotherium,* a mammal-like reptile from the Lower Lufeng Formation of China. (From Colbert, *The Age of Reptiles,* 1965. Weidenfeld and Nicolson, London; Norton, New York.)
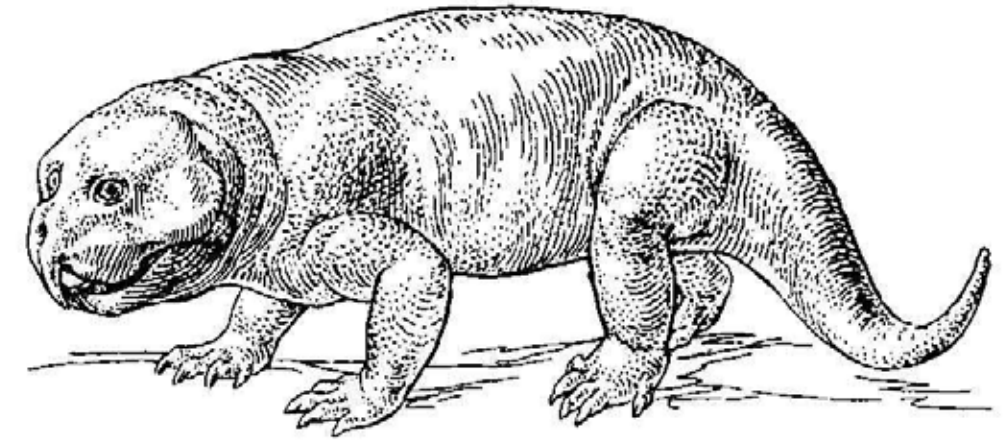

Figure 14. *Scaphonyx,* a rhynchosaur from the Ischigualasto Formation of Argentina. (From Colbert, *The Age of Reptiles,* 1965. Weidenfeld and Nicolson, London; Norton, New York.)

Likewise, the early crocodilian *Hemiprotosuchus* is, according to the same authority, related to *Protosuchus* from Arizona (this genus present in horizons somewhat higher than the Chinle). *Plateosaurus,* so well known from the Keuper of Germany, is rather abundantly present in the El Tranquilo beds of Argentina, which are correlative with the Los Colorados. And, finally, *Tritylodon* is recorded from the Los Colorados—a link not only with the African Red Beds but also with the Lufeng of China and the Kayenta of Arizona. (Bonaparte 1970.)

CONCLUSION

This comparative review, which has been concerned with certain diagnostic fossils rather than with a detailed account of all the faunas under consideration, would seem to indicate that there are very strong similarities between the fossils found in the Petrified Forest member of the Chinle Formation at Petrified Forest not only with fossils in other North American late Triassic vertebrate faunas, but also with the amphibians and reptiles characteristic of the type Keuper in central Europe. Moreover, resemblances extend beyond the type Triassic, to the Upper Triassic of central India, in some degree to the beds of the same age in western China, to the remarkably productive Upper Triassic sediments of southern Africa, and finally, somewhat tenuously, to the Upper Triassic of South America.

All of these resemblances point to the fact that during late Triassic time the world of Pangaea was still one world, with broad corridors of communication between the several regions within that great supercontinent. The process of rifting, probably in its initial stages during the final years of Triassic history, had not proceeded to the extent that there were oceanic barriers of consequence to prevent faunal interchanges throughout the extent of the Pangaean land mass.

Of course, there were differences in faunal relationships, probably based to a large degree on the geographic separation between faunas—as is the case today. The North American late Triassic tetrapods consisted of closely related local faunas, as might be expected among terrestrial tetrapods living within an unbroken land mass, and this condition extended to the tetrapods of central Europe—at that time evidently contiguous to the North American continent. As one proceeds away from the European center, the faunal resemblances become less comprehensive and more concerned with individual elements of the faunas as, for example, in Asia. And as one proceeds southwardly into the

Gondwanan moiety of Pangaea, the mixture of southern elements with "Petrified Forest" tetrapods becomes evident. This is to a degree apparent in central India, more so in Africa, and particularly so in South America.

Thus, one may visualize the amphibians and reptiles of Petrified Forest as comprising a fauna with wide geographic relationships. It is a fauna that in a broad view was part of a world-wide development of terrestrial life. Indeed, in late Triassic time, the Pangaean world was truly one world, with Petrified Forest a part of that world. So it is that the significance of the fossils found in Petrified Forest extends far beyond the limits of Arizona, to touch upon lands now far distant, even to lands on the far side of our world of today.

Table 1. The worldwide distribution of Triassic tetrapods characteristic of the Chinle Formation in the Petrified Forest

	Petrified Forest	New Mexico	Texas	Wyoming	New Jersey	Central Europe	India	Southern Africa	South America	China
Amphibia Stereospondyls	X	X	X	X	X	X	X		X	
Reptilia Procolophonids	X					X	X			
Trilophosaurs	X		X							
Tanystropheans	X					X	X			
Ornithosuchids	X						X		X	
Poposaurids	X			X						
Rauisuchids	X			X					X	
Stagonolepids	X	X	X			X	X	X		
Phytosaurs	X	X	X	X	X	X	X			X
Coelurosaurs	X	X				X	X	X	X	
Carnosaurs	X		X			X	X		X	X
Prosauropods	X					X	X		X	X	X
Dicynodonts	X			X					X	X

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Aetosaur Dermal Armor from the Late Triassic of Southwestern North America, with Special Reference to Material from the Chinle Formation of Petrified Forest National Park

by R. A. Long and K. L. Ballew

ABSTRACT

Four genera of stagonolepidid thecodonts are recognized in the Late Triassic Chinle Formation of southwestern North America, and these all occur at Petrified Forest National Park. At the park, three species are found in the lower unit of the Petrified Forest Member, below the Sonsela Sandstone. These are *Calyptosuchus wellesi,* gen. nov., sp. nov., *Desmatosuchus haplocerus,* and rare *Paratypothorax* sp. *Calyptosuchus wellesi* is especially abundant. Lower Petrified Forest member stagonolepidids commonly occur with rutiodont phytosaurids lacking advanced temporal regions ("*Rutiodon* group A"). *Typothorax coccinarum* is a remarkable, wide-bodied stagonolepidid restricted to the upper levels of the Petrified Forest Member, often associated with advanced rutiodonts ("*Rutiodon* group B").

Calyptosuchus, Desmatosuchus, and *Paratypothorax* are also found with "*Rutiodon* group A" in the upper Tecovas Formation (middle Dockum Group) and its equivalents in Texas. The former two stagonolepidids are frequently encountered outside the Petrified Forest in northeastern Arizona. A single record of *Calyptosuchus* is known from New Mexico. *Typothorax,* which is abundant at the Petrified Forest, is found in only one other area, Rio Arriba County, New Mexico, where it occurs in some abundance with "*Rutiodon* group B."

Paratypothorax andressi, gen. nov., sp. nov., is known entirely from its dermal armor collected long ago at Heslach, near Stuttgart, Germany. The scutes of this species often have been incorrectly attributed to a phytosaur. The North American material referred to *Paratypothorax* is, unfortunately, very incomplete.

Stagonolepidid armor eventually may prove to be as useful a tool in biostratigraphic studies of the American continental Late Triassic as phytosaur specimens have been in the past.

INTRODUCTION

During the summers of 1981 and 1982, field parties from the University of California discovered 34 sites in Petrified Forest National Park that produced more than 850 pieces of aetosaur dermal armor. This material was not localized either geographically or stratigraphically, but occurred throughout the park in levels just above the newspaper sandstone (see Billingsley, this volume, for geologic terminology) near the base of the lower unit of the Petrified Forest member of the Chinle Formation, up to the black forest sandstone high in the upper unit. Aetosaurian armor found below the Sonsela Sandstone is dissimilar to that recovered above the Sonsela. Comparisons of the Petrified Forest specimens with those of the two known Chinle aetosaur genera, *Desmatosuchus* and *Typothorax,* demonstrate their presence in the park.

Two large collections of Chinle aetosaurs were made outside the park by the University of California under the direction of Prof. C. L. Camp in the early 1930s; these came from the *Placerias* Quarry, near St. Johns, Arizona, and the Canjilon Quarry of Ghost Ranch, New Mexico. Examination of this material, as well as the University of Michigan collections amassed by Prof. E. C. Case from the Tecovas Formation (Dockum Group) of Texas, and the Cope collection housed at the American Museum of Natural History, made in the Chinle Formation of northcentral New Mexico, has revealed a greater diversity of stagonolepidid genera in the American Southwest than has heretofore been recognized (Gregory, 1953B). This diversity can be demonstrated in the park (Fig. 1).

Study of this material has made it evident that a suite of characters can be recognized in aetosaur dermal armor, and these can be utilized in establishing taxonomic divisions. Preliminary diagnoses and descriptions of the armor of four genera are introduced here. These will be supplemented elsewhere by more detailed descriptions of the armor, an investigation of the non-integumentary osteology, and comparisons with foreign stagonolepidids (Long in prep.; Long, Parrish and McCrea in prep.). The appendicular and ventral scutes are very incompletely known in American forms; these will be reported on at another time.

The differences displayed in aetosaur armor are reinforced by those observed in the cranial, axial, and appendicular skeleton when associated specimens have been available.

The nature of dorsal armor is intimately associated with body form, and contrary to previous literature, not all aetosaurs possessed a narrow, crocodile-like carapace. At least two genera (*Typothorax* and *Paratypothorax* n. gen.) with extremely wide, straplike paramedian scutes, exhibited discoidal carapaces superficially resembling those of trionychid turtles and the placodont, *Henodus.*

Much confusion has existed concerning southwestern aetosaurs (see Gregory, 1953B, for a historical review). Gregory attempted to clear up this dilemma and was, in part, successful. He was able to show that *Desmatosuchus spurensis* and *Episcoposaurus haplocerus* were conspecific as were *Typothorax coccinarum* and *Episcoposaurus horridus.* Gregory also provided a detailed description of the holotype of *D. haplocerus* and was the first to publish illustrations of this material. However, we believe Gregory erred in following Sawin (1947) in his conclusions that two
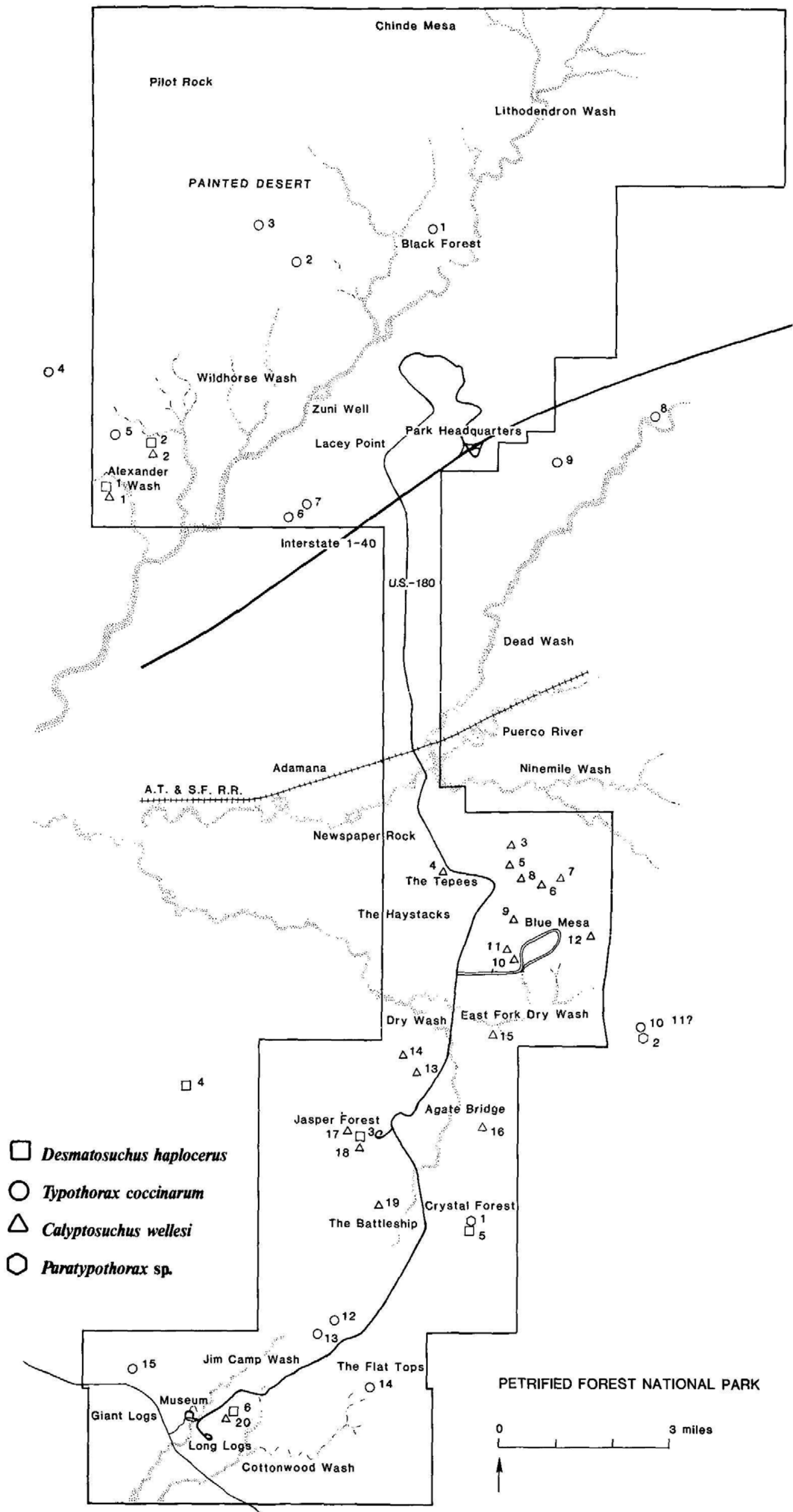
Chinde Mesa

Pilot Rock

Lithodendron Wash

PAINTED DESERT

○ 3
○ 1
Black Forest

○ 2

○ 4

Wildhorse Wash

Zuni Well

○ 8

Lacey Point

Park Headquarters

○ 5 □ 2
△ 2

○ 9

Alexander
□ 1 Wash
△ 1

○ 6 ○ 7

Interstate 1-40

U.S.-180

Dead Wash

Puerco River

Adamana

Ninemile Wash

A.T. & S.F. R.R.

Newspaper Rock

△ 3
△ 5
4 △
The Tepees
△ 8 △ 7
△ 6

The Haystacks

9 △ Blue Mesa
12 △
11 △
10 △

Dry Wash

East Fork Dry Wash
△ 15

○ 10 11?
⬡ 2

□ 4

△ 14
△ 13

Jasper Forest
Agate Bridge
17 △ □ 3
18 △
△ 16

□ Desmatosuchus haplocerus

○ Typothorax coccinarum

△ Calyptosuchus wellesi

⬡ Paratypothorax sp.

△ 19
Crystal Forest
The Battleship
○ 1
□ 5

○ 12
○ 13

○ 15
Jim Camp Wash
The Flat Tops

○ 14

PETRIFIED FOREST NATIONAL PARK

Giant Logs
Museum
□ 6
△ 20

0   3 miles

Long Logs

Cottonwood Wash

Figure 1. Petrified Forest National Park, Arizona.

aetosaur skeletons collected near Otis Chalk, Texas, were referable to *Typothorax*.

These skeletons have been largely used in erroneously redefining Cope's genus (Gregory, *ibid.*, Walker, 1961). Evidence revealing the generic separation of *T. coccinarum* and *"T."* *meadei* will be presented elsewhere (Elder and Long, in prep.).

Gregory *(ibid.)* defined the dermal armor of North American aetosaurs in broad terms. Under *"Typothorax"* he included armor of several mixed taxa. The characters he used to segregate the armor of *Desmatosuchus* and *"Typothorax"* were vague.

Desmatosuchus armor was characterized as exhibiting: (1) posteromedial raised bosses; (2) angulated lateral plates with stout spines projecting outward from the angle; (3) pectoral spines; (4) coarse ornamentation with shallow pitting up to 1 cm. in diameter; and (5) plates of greater thickness than those of *Typothorax* (Gregory, *ibid.*, p. 15).

Typothorax armor was characterized as exhibiting: (1) low conical or pyramidal eminences near the center of the posterior edge of the median plates; (2) angulate, lateral plates with dorsal and lateral flanges meeting at a sharp angle below the bases of projecting lateral spines; (3) no enlarged pectoral spines; (4) shallow ornamentation of round, uniform-sized pits about one-half of a centimeter in diameter except on smooth anterior flanges and on bosses and spines which are covered with fine punctuation; and (5) plates being relatively thin (Gregory, *ibid.*, p. 8).

Our investigations indicate the presence of the following stagonolepidids in the western North American Late Triassic during Chinle and middle-upper Dockum deposition:

(1) *Desmatosuchus haplocerus*, a highly distinctive form that can be redefined on the basis of two lots of material; these include (a) UMMP 7476, much of a skeleton including a well-preserved skull but lacking caudal dermal armor (contrary to statements in Case, 1922); this specimen is the holotype of *Desmatosuchus spurensis*; and (b) a wealth of material from the *Placerias* Quarry (UCMP Loc. A269) including over a thousand bones and scutes representing at least fourteen individuals. The UCMP collection supplements Case's material.

(2) *Typothorax coccinarum*, an aberrant, extremely wide-bodied aetosaur whose peculiar characters can be amply demonstrated from three partial skeletons (UCMP 34255, 34248, 34259) and numerous isolated plates and bones from the Canjilon Quarry.

(3) *Calyptosuchus wellesi*, gen. n., sp. n., an aetosaur with armor resembling that of *Stagonolepis* but differing in its possession of cervical horns and prominent caudal bosses and numerous features in its nonintegumentary osteology. This new aetosaur is described from several sources of material. These include: (a) UMMP 13950, the holotype, representing the posterior half of a skeleton with dorsal armor in place (Case 1932); (b) UMMP 7470, a pelvis, vertebrae, and a number of dermal plates (Case 1922, 1929, 1932, Gregory, *ibid.*); (c) hundreds of disarticulated bones and plates representing at least seven individuals from the *Placerias* Quarry; (d) MNA Pl. 3202, a series of paramedian and lateral plates from the cervical and anterior dorsal region of a single individual; and (e) UCMP 27225, much of a carapace. This last specimen is particularly valuable in exhibiting numerous complete lateral plates from the dorsal region as well as a number of ventral plates.

(4) *Paratypothorax* sp., a stagonolepidid possessing huge, straplike paramedian scutes reminiscent of those of *Typothorax*, but these are distinctive in their ornamentation. This aetosaur is poorly represented in the North American Triassic. Isolated paramedial plates (UMMP 8858, 8859, 9600) were found in the Tecovas Formation of Texas (Case 1932). In the Petrified Forest, several incomplete paramedian scutes and a single, partial lateral scute were collected. The North American material, such as it is, compares closely with that of a new form, *Paratypothorax andressi* gen. n., sp. n., which is briefly described in this report from numerous, well-preserved dermal plates collected long ago from the Stubensandstein of Heslach, Germany (Meyer, 1861, 1865; Huene 1913; Gregory, 1953A; etc.).

The biostratigraphic potential of stagonolepidid remains in Petrified Forest National Park and elsewhere in the North American Triassic will be discussed later in this report.

Repositories

Specimens noted in this paper are located in the following collections (hereafter referred to by abbreviations only).

AMNH—American Museum of Natural History
ANSP— Academy of Natural Sciences, Philadelphia
MCZ— Museum of Comparative Zoology, Harvard University
MNA— Museum of Northern Arizona
PFNP— Petrified Forest National Park
PPHM— Panhandle Plains Historical Museum
PU— Princeton University
SMNS— Staatliches Museum fur Naturkunde, Stuttgart
TMM— Texas Memorial Museum, Austin
UA— University of Arizona, Tucson
UCMP— Museum of Paleontology, University of California
UMMP—Museum of Paleontology, University of Michigan
USNM— National Museum of Natural History
YPM— Peabody Museum of Natural History, Yale University

SYSTEMATIC PALEONTOLOGY

Class Reptilia
Order Thecodontia
Suborder Aetosauria
Family Stagonolepididae*

Desmatosuchus Case, 1920

Episcoposaurus Cope, 1887 (in part).
Type Species. *Episcoposaurus haplocerus* Cope, 1892, p. 129–131.
Known Distribution. Late Triassic, late Carnian/?early Norian of Texas and Arizona.
Diagnosis. (Armor) A large stagonolepidid with a narrow carapace; armor with thin anterior laminae rather than raised bars. Cervical paramedian armor thickened and elongated resulting in fewer segments than underlying vertebrae. Ornamentation of scutes consists of large, deep, oblong pits and a latticework of high ridges. Sculpturing primarily random, though a slight pattern of radiation is sometimes indicated. Paramedian eminences are always small, conical, and never in contact with the posterior margin of

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*See Walker's excellent monograph on *Stagonolepis* for a diagnosis of the Stagonolepididae (Walker, 1961. p. 182-183).

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the scute. Medial and lateral margins of paramedian scutes are thickened with complex tongue-and-groove articulations with neighboring scutes. Caudal scutes show well-defined sculpturing and with little, if any, transverse arching. Lateral scutes of neck and body horned; those over the shoulders are huge and recurved posterodorsolaterally. Lateral scutes of tail show rounded knobs; the anteriormost caudal scute is especially prominent.

Description. *Paramedian scutes* of the cervical region are elongated, resembling rectangles with their anterolateral corners sheared off. They are greatly thickened with medial and lateral margins exhibiting complicated tongue-and-groove articulations with the corresponding scutes. The anterior margins are raised bars. Low knobs are present on the upper surface of the posterior third of each plate. Ornamentation is faintly punctate. The number of cervical paramedian scutes does not correspond with the number of underlying cervical vertebrae; five segments of armor apparently cover the neck region. Paramedian scutes of the dorsal region are moderately expanded (width of plate never much in excess of twice its length) and of normal stagonolepidid proportions compared to skeletal dimensions (width of plate probably less than half the femoral length). No anterior bar is present in post-cervical paramedian scutes; instead, a large, thin lamina of bone projects anteriorly below the preceding plate. Ornamentation consists of a series of large, deep pits and grooves showing little if any radiate pattern. Dorsal eminences are never prominent or in contact with the posterior margin of the scutes. Paramedian scutes of the caudal region display well-defined random punctuation and large anterior laminae. Dorsal eminences remain small and are situated as in the more anterior scutes. These plates show little or no transverse arching and have rugose medial and lateral borders.

Lateral scutes of the cervical region are moderately angulated into dorsal and lateral flanges with the edge produced into a well-developed "horn." Dorsal flange thick with rugose, tongue-and-groove, slightly concave articular surface for union with the paramedian scute. Lateral flange is of similar dimensions to the dorsal flange, though thinner. Both flanges exhibit slight pitting. Horns are dorsolaterally directed with sharp anterior edges. Lateral scutes of the dorsal region are also thick and angulate with horns. Behind the shoulders, they become progressively smaller and blunter. Ornamentation is similar to that of the dorsal paramedian scutes. Lateral scutes of the caudal region have anterior laminae and deep, random pitting, and exhibit curved, thickened ventral margins. Eminences occur as blunt knobs, circular or polygonal in cross-section, which decrease in size posteriorly. Anterior caudal scutes are moderately arched, while the more posterior scutes are flat. The first caudal scute is very large and thick.

(Abbreviations: ant., anterior; cr., crest; dor., dorsal; em., eminence; fl., flange; lam., lamina; lat., lateral; mar., margin; med., medial; sc scute; sp., spinous; su., suture; vent., ventral.)
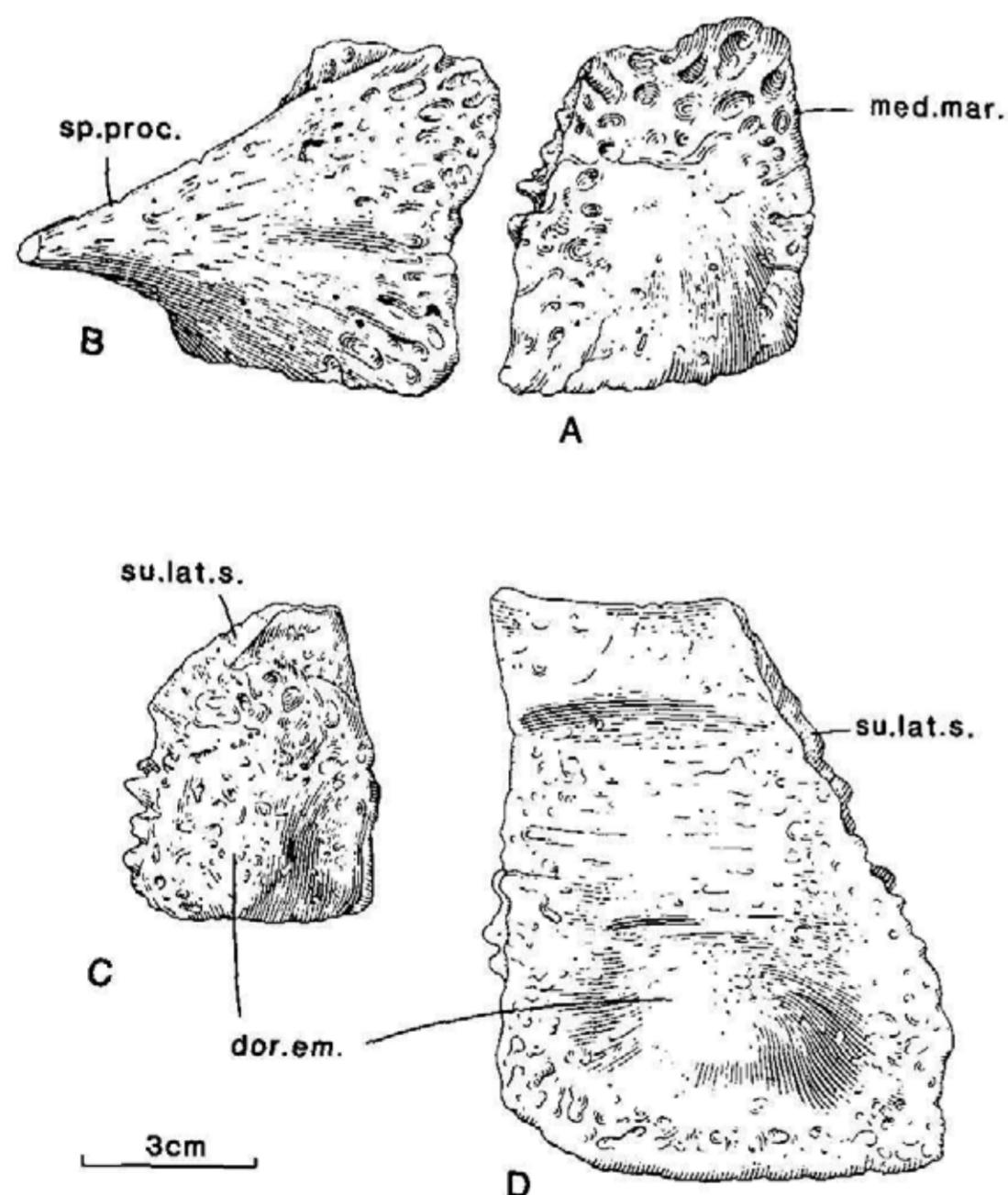

Figure 2. *Desmatosuchus haplocerus,* scutes of the anterior presacral region, superior view. *a,* UCMP A169/126825, left mid-cervical, paramedian scute; *b,* UCMP A169/126826, left mid-cervical, lateral scute; *c,* UCMP A269/126833, left anterior cervical, paramedian scute; *d,* UCMP A269/78748, right pectoral, paramedian scute.
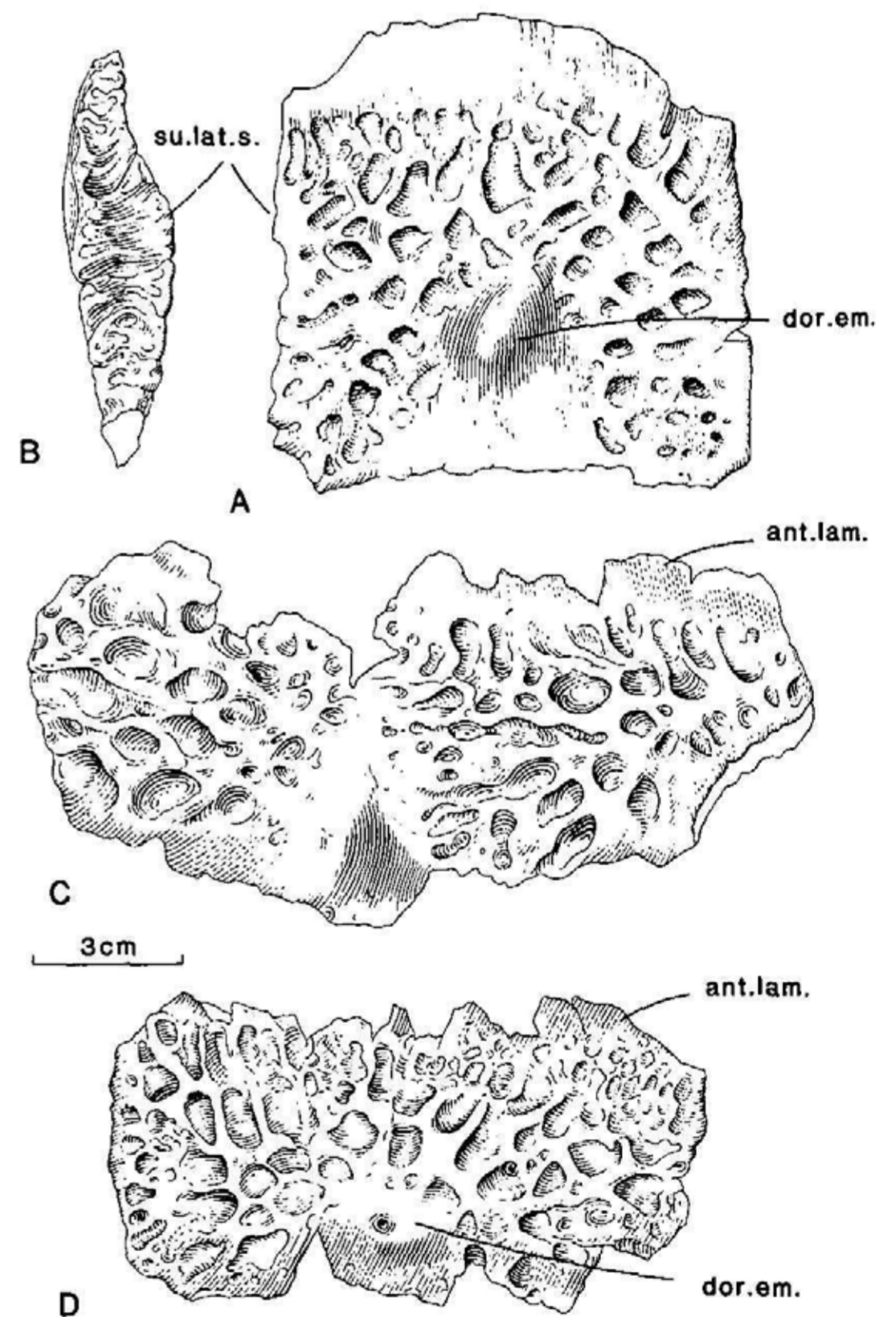

Figure 3. *Desmatosuchus haplocerus,* paramedian scutes of the dorsal region. *a, b,* UCMP A269/78747, anterior dorsal scute in superior and lateral views; *c,* UCMP A269/126830, mid-dorsal scute, superior view; *d,* UCMP A269/126829, posterior dorsal scute, superior view. (Abbreviations as in Fig. 2.) *Note:* In this and the following captions, "dorsal" relates to the dorsal vertebral segment of the body, rather than to the superior plane of the body.
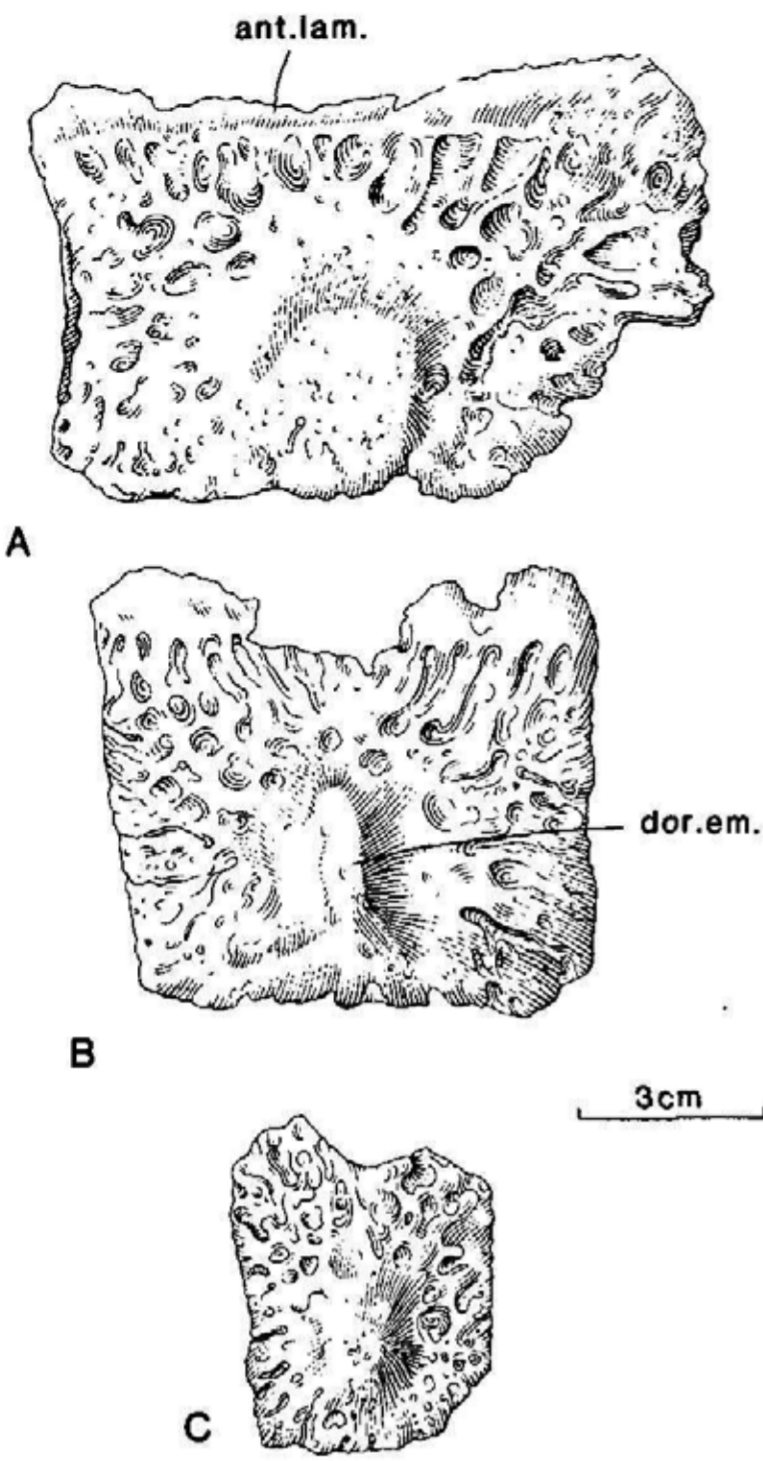
Figure 4. *Desmatosuchus haplocerus,* paramedian scutes of the caudal region, superior view. *a,* UCMP A269/126828, anterior caudal scute; *b,* UCMP A269/126827, mid-caudal scute; *c,* UCMP A269/126824, posterior caudal scute. (Abbreviations as in Fig. 2.)
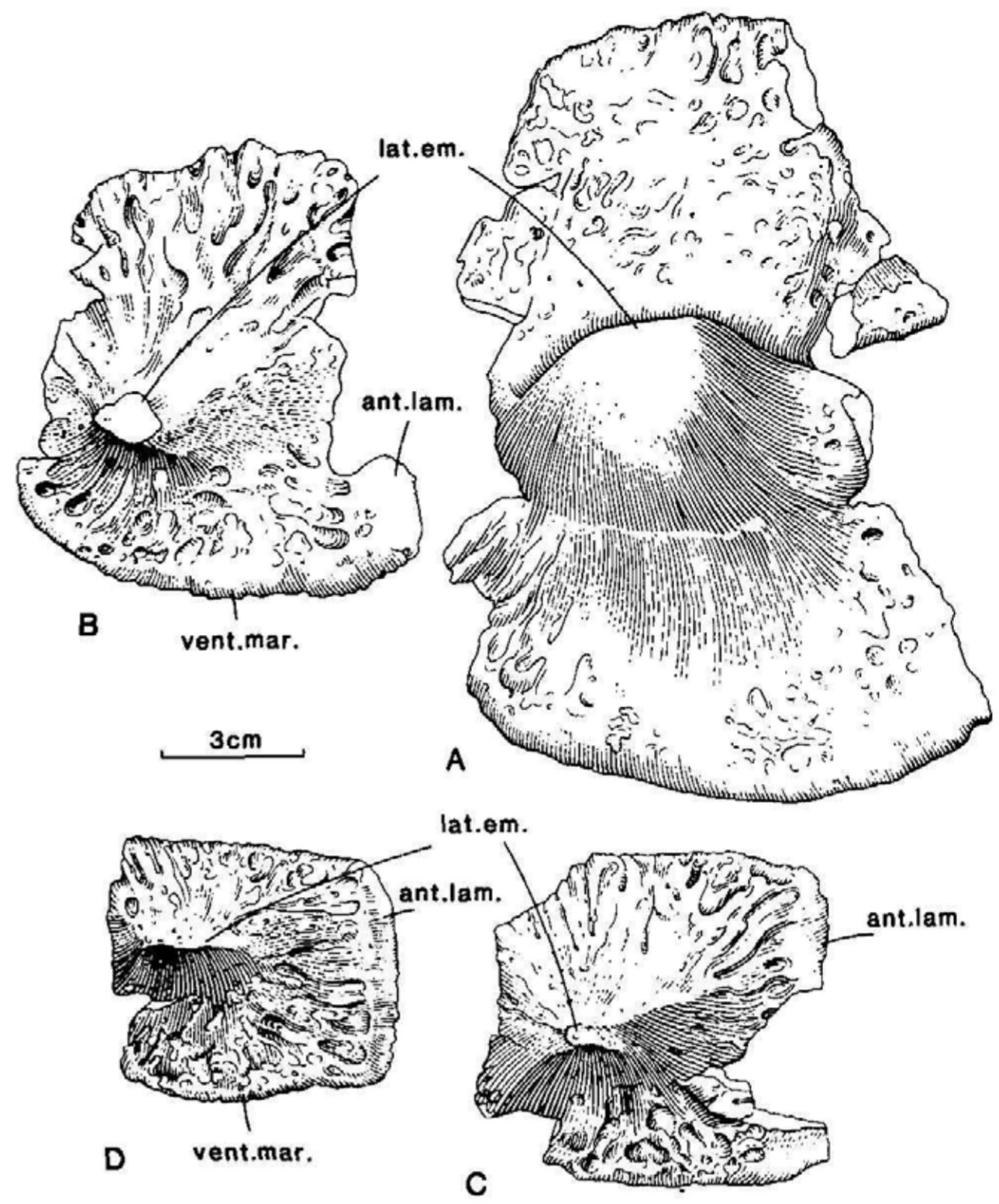

Figure 6. *Desmatosuchus haplocerus,* right lateral scutes of the caudal region, lateral view. *a,* UCMP A269/126821, anterior-most caudal scute; *b,* UCMP A269/126817, mid-caudal scute; *c, d,* UCMP A 269/126815, mid-caudal scutes. (Abbreviations as in Fig. 2.)
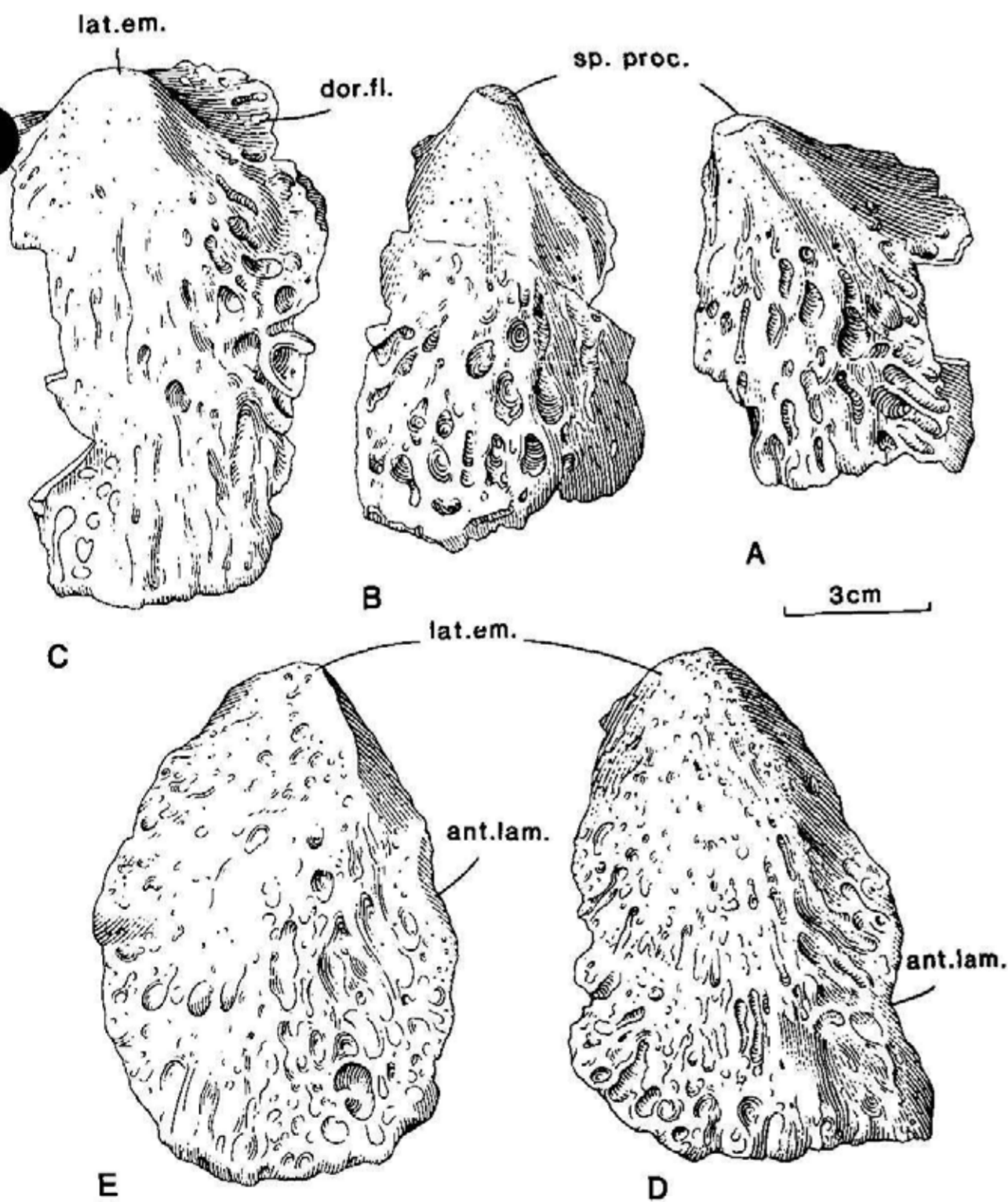

Figure 5. *Desmatosuchus haplocerus,* right lateral scutes of the dorsal region, lateral view. *a,* UCMP A269/126831, anterior dorsal scute; *b,* UCMP A269/126836, anterior dorsal scute; *c,* UCMP A269/126832, mid-dorsal scute; *d,* UCMP A269/126835, posterior dorsal scute; *e,* UCMP A269/126834, posterior dorsal scute. (Abbreviations as in Fig. 2.)
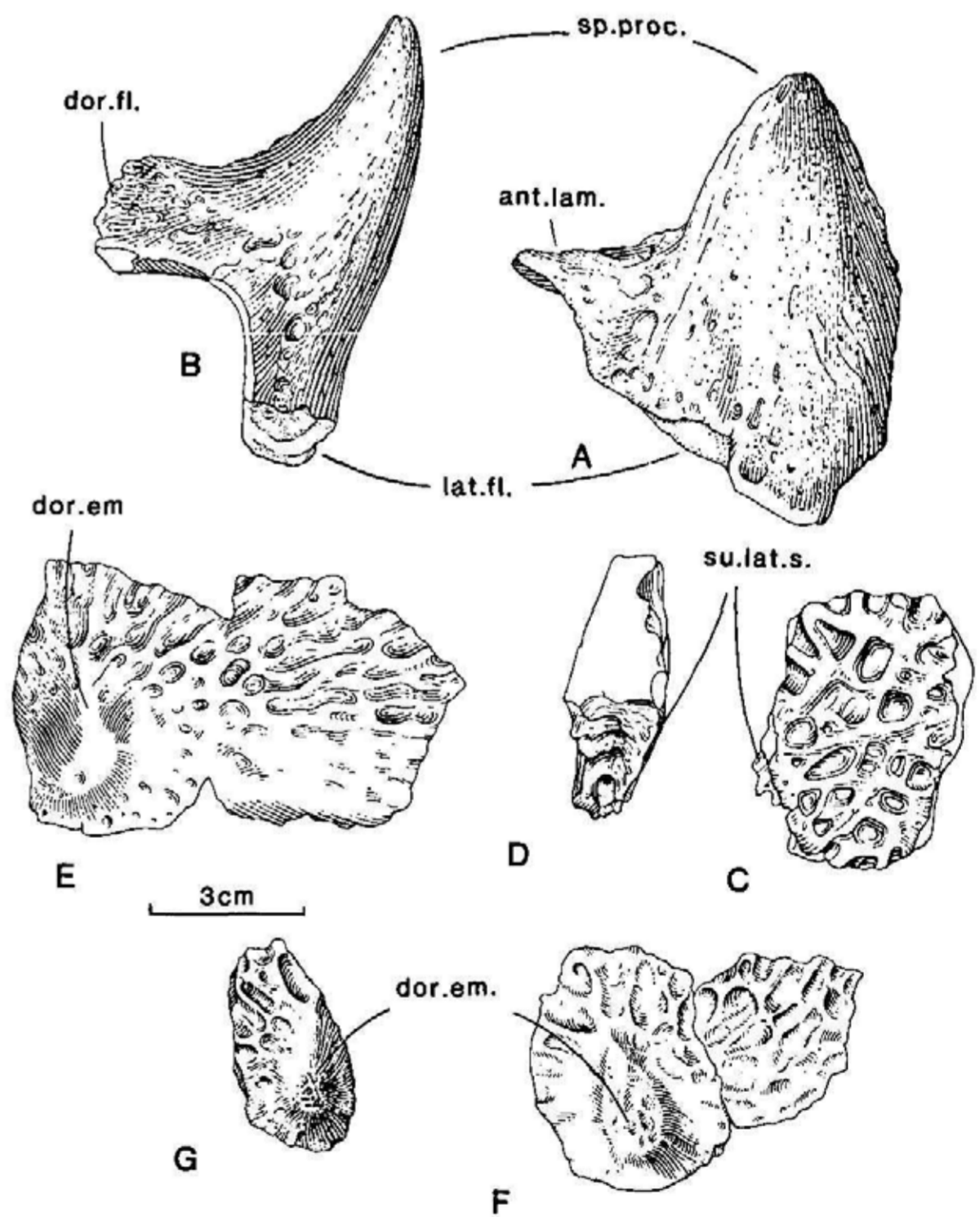

Figure 7. *Desmatosuchus haplocerus,* scutes from Petrified Forest National Park and vicinity. *a, b,* MNA Pl. 697, left lateral scute from the cervical region, *a,* lateral view, *b,* posterior view; *c, d,* NPS 355, fragment of a left, anterior, dorsal paramedian scute, *c,* superior view, *d,* lateral view; *e,* UCMP V82238/126838, mid-dorsal paramedian scute, superior view; *f,* MNA Pl. 3172, mid-dorsal paramedian scute, superior view; *g,* UCMP V82238/126837, fragment of a paramedian scute, superior view. (Abbreviations as in Fig. 2.)
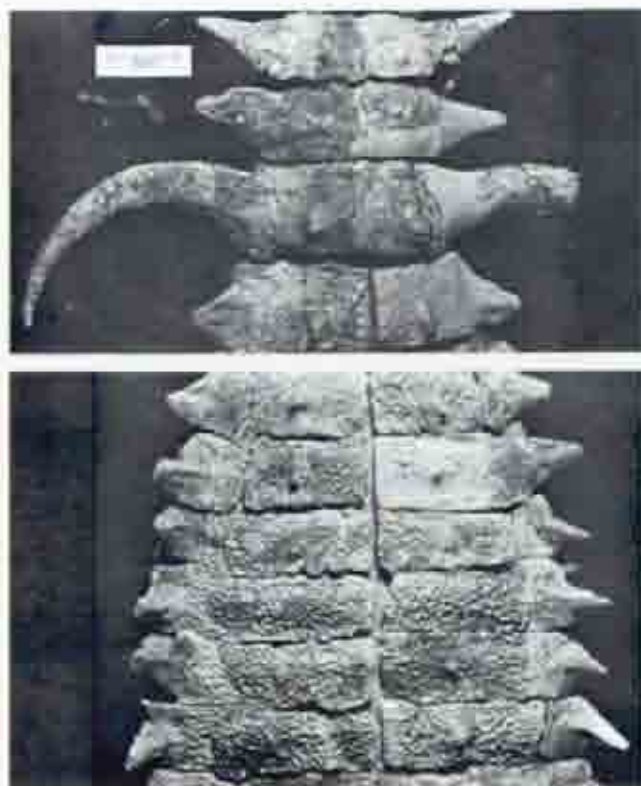
Locality: "Near windmill in top pasture 3 miles north of Dockum, Dickens Co., Texas" (Gregory, 1953B, p. 15).

Horizon: Dockum Group, Tecovas Formation, late Carnian/(?early Norian), late Triassic.

Collector: W. F. Cummins, 1891.

Diagnosis: (as for genus).

Hypodigm: (see text).

Typothorax Cope, 1875

Episcoposaurus Cope, 1887 (in part).

Type Species. *Typothorax coccinarum* Cope, 1875, p. 265.

Known Distribution. Late Triassic, Norian of New Mexico and Arizona.

Diagnosis. (Armor) A large stagonolepidid with a discoidal carapace; dermal armor with raised anterior bars. Cervical paramedian scutes probably thin, straplike and corresponding with segments of cervical vertebral column; paramedian scutes of back remarkably wide, with random ornamentation and little if any development of prominences. Ornamentation consists of a series of pits smaller and more shallow than those of *Desmatosuchus*. These are primarily sub-circular though some oblong pitting is occasionally exhibited. Paramedian scutes of the dorsal region are strengthened by means of ventral swellings or "struts." The lateral plates of cervical region bear horns, those of the body are keeled, but without horns. The caudal scutes are thin with faint, radiate ornamentation and bear small, conical eminences.

Description. *Paramedian scutes* of the cervical region are unknown. However, the closely corresponding form of the lateral cervical scutes of *Typothorax* with those of *Calyptosuchus* which exhibits wide, straplike paramedian scutes on the neck, suggests the former genus may also have had wide, rectangular paramedian scutes protecting the neck rather than the elongated, thickened paramedian scutes seen in *Desmatosuchus*. Paramedian scutes of the dorsal region are greatly expanded (width of plate more than 3.5 times its length) and enormous relative to skeletal dimensions (width of plate 1.4 times the length of the femur). The anterior margin of each scute is a thickened bar bordering a distinct trough running the width of the scute. Ornamentation consists of small, shallow pits randomly placed. No furrowing or radiate pattern is seen anterior to the caudal region. Dorsal eminences, when present, are small and conical, always in contact with the posterior margin of the scute. A thick, rounded strut is well developed on the anterior half of the ventral surface of each scute to give added support to these immense dermal plates. The paramedian scutes of the caudal region bear small conical eminences medial to the midline and these are in contact with the posterior margin of each scute. An anterior bar is present and the scutes exhibit moderate transverse arching. The lateral and medial margins are thin and smooth. Ornamentation is a series of rays and furrows in the anterior caudal region. More posteriorly, a faint radiate pattern of incised lines can be seen.

Lateral scutes of the cervical region are not completely known, but the material available is very similar to that of *Calyptosuchus*, as already mentioned. These scutes are markedly angulated into dorsal and lateroventral flanges. A large posterolaterally directed horn is present. The dorsal flange has a thin, deeply concave medial margin for articulation with the paramedian scute. Lateroventral flange is a large, thin plate with faint ventral radial sculpturing. An anterior bar is probably present, but this region is missing in existing material. The lateral scutes of the dorsal region are moderately thick and strongly angulated into dorsal and ventral flanges. No horns are present although the flanges converge into sharp, lateral edges giving the lateral margin of the carapace a

Plate 1. *Desmatosuchus haplocerus*, UCMP

Top, carapace, cervical and pectoral regions, showing enlarged pectoral horns. Superior view.
Bottom, same, dorsal region. Superior view.

Crosby County, Texas.

Desmatosuchus haplocerus (Cope 1875)
Plate 1; text figures 2-7

Episcoposaurus haplocerus Cope, 1892, p. 129-131; Wilson, 1950, p. 113-114, Figs. 1-3.

Desmatosuchus spurensis Case, 1920, p. 524-529, figs. 1-4; Case, 1921, p. 133-147, pl. 3; Case, 1922, p. 26-48, figs. 7-20, pls. 5-10; Case 1929, p. 50-51, fig. 21.

Phytosaur Case, 1922, p. 70, pl. 13A, text fig. 27B.

Phytosaurus? Case, 1932, p. 72-73, pl. 4, figs. 2-3.

Desmatosuchus haplocerus Gregory, 1953B, p. 14-24, figs. 1-14; Walker 1961, p. 179-181, fig. 24D.
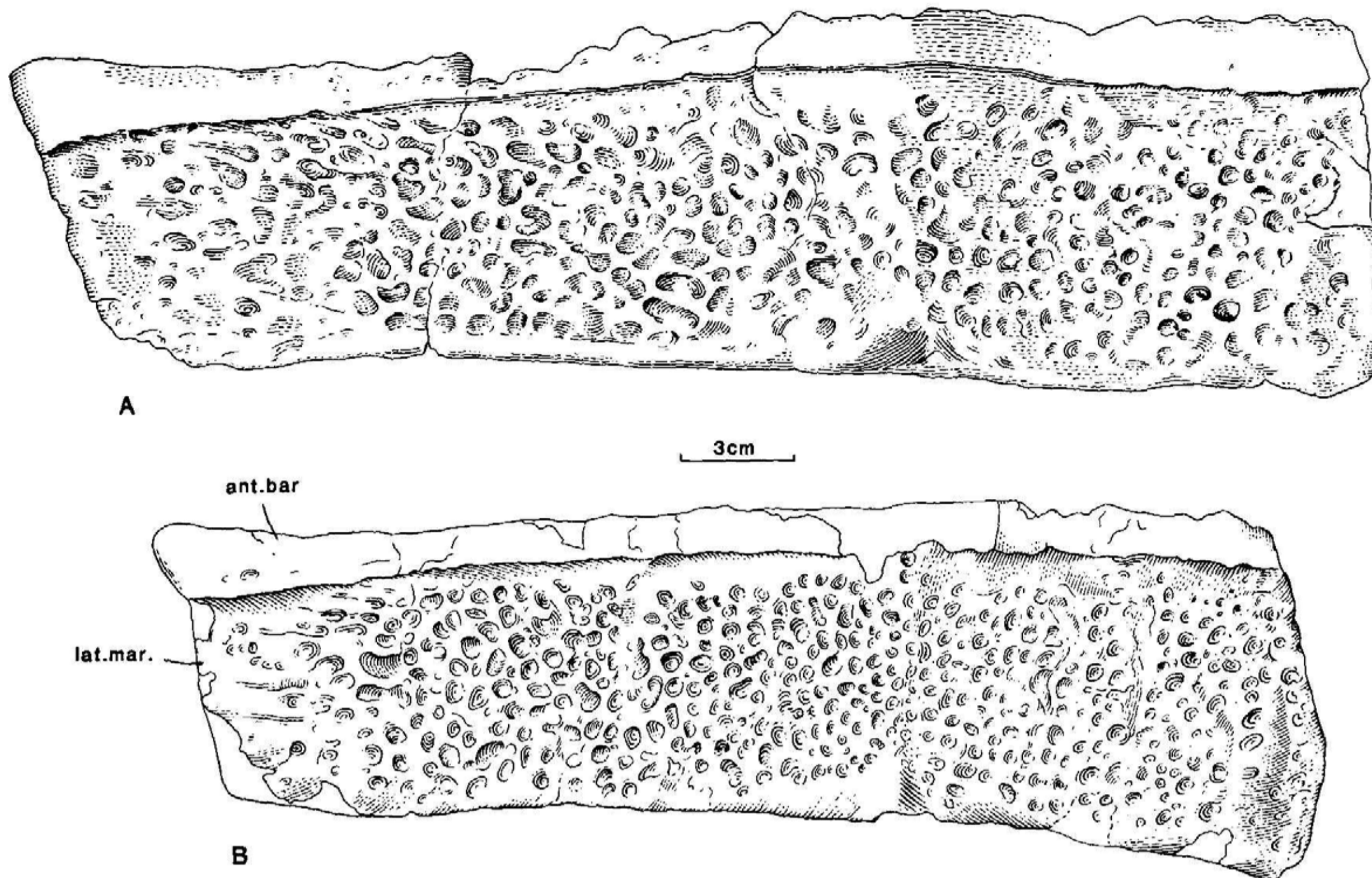
Typothorax Walker, 1961, p. 184.

Figure 8. *Typothorax coccinarum*, left paramedian scutes of the dorsal region, superior view. *a*, UCMP V2816/126980; *b*, UCMP V2816/1269803. (Abbreviations as in Fig. 2.)
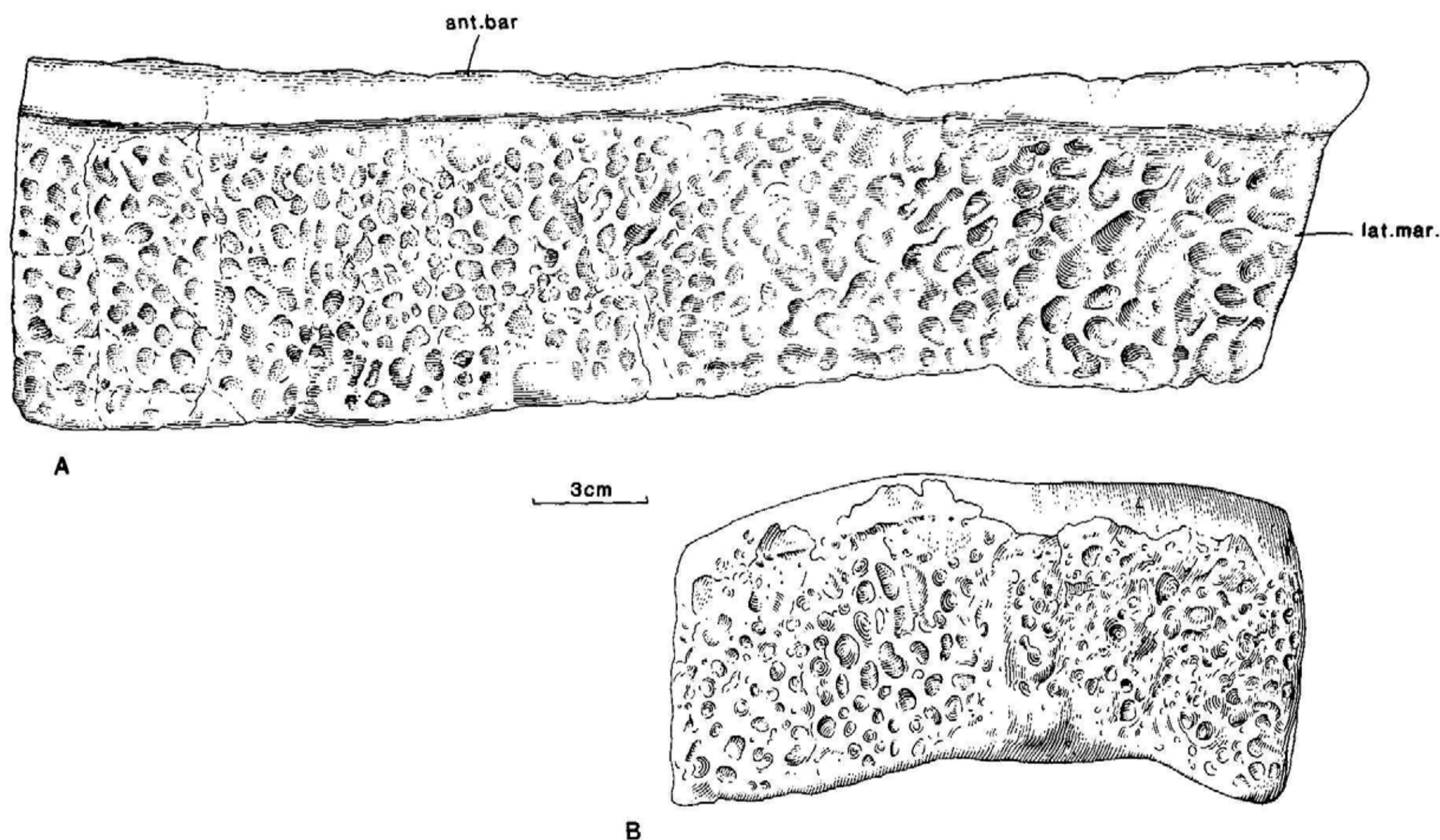

Figure 9. *Typothorax coccinarum*, paramedian scutes, superior view. *a*, UCMP V2816/126804, right dorsal scute; *b*, UCMP V2816/126802, left, anterior caudal scute. (Abbreviations as in Fig. 2.)

rough outline. A large anterior bar is present on the lateroventral flange. Ornamentation is a series of shallow pits and grooves showing little or no radiating pattern. Dorsal flange has a straight articular union with the paramedian scute. Lateral scutes of the caudal region have a strong pattern throughout. These scutes are very thin and flat with dorsal eminences mere ridges lying close to the medial margin of the scutes. The ventral margins are gently sinuous and not thickened. An anterior bar is present.
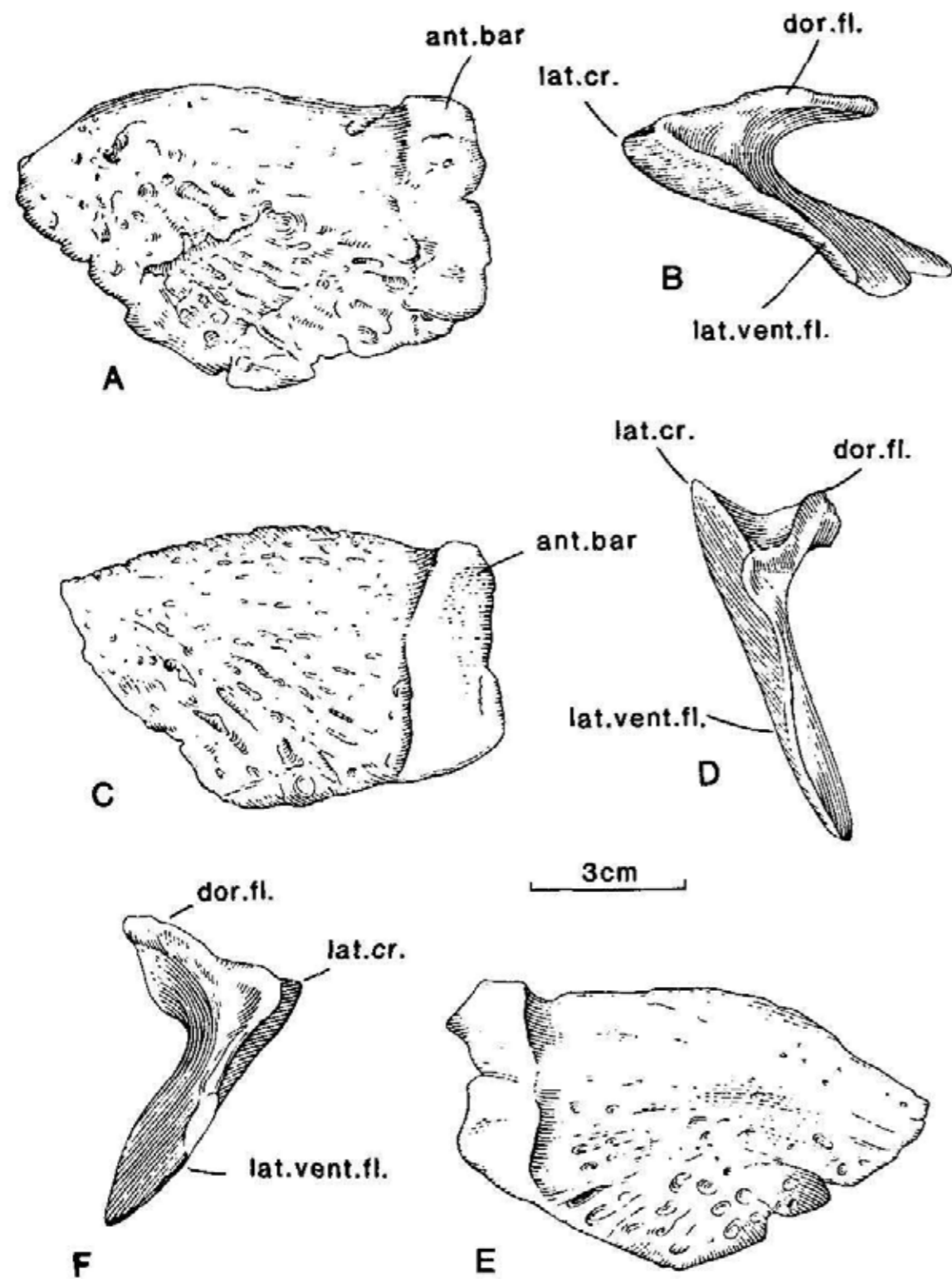
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Figure 10. *Typothorax coccinarum*, lateral scutes, dorsal region, in lateroventral (*a, c, e*) and anterior (*b, d, f*) views. *a, b*, UCMP V2816/126842, right scute; *c, e*, UCMP V2816/126841, left scute. (Abbreviations as in Fig. 2.)
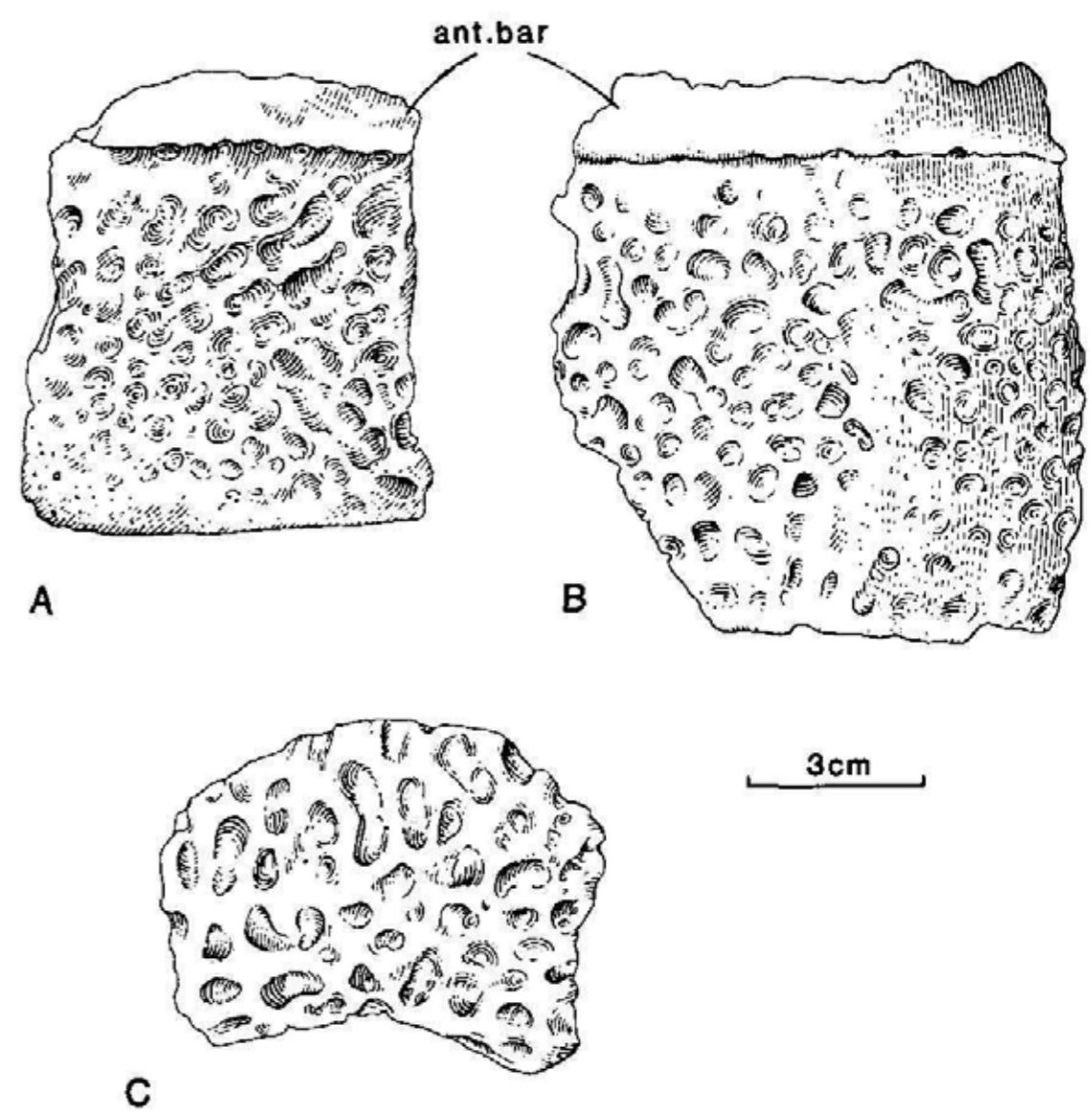
Figure 12. *Typothorax coccinarum*, fragments of dorsal, paramedian scutes from Petrified Forest National Park, superior view. *a*, UCMP V82240/126806; *b*, UCMP V82240/126808; *c*, UCMP V82272/126843. (Abbreviations as in Fig. 2.)
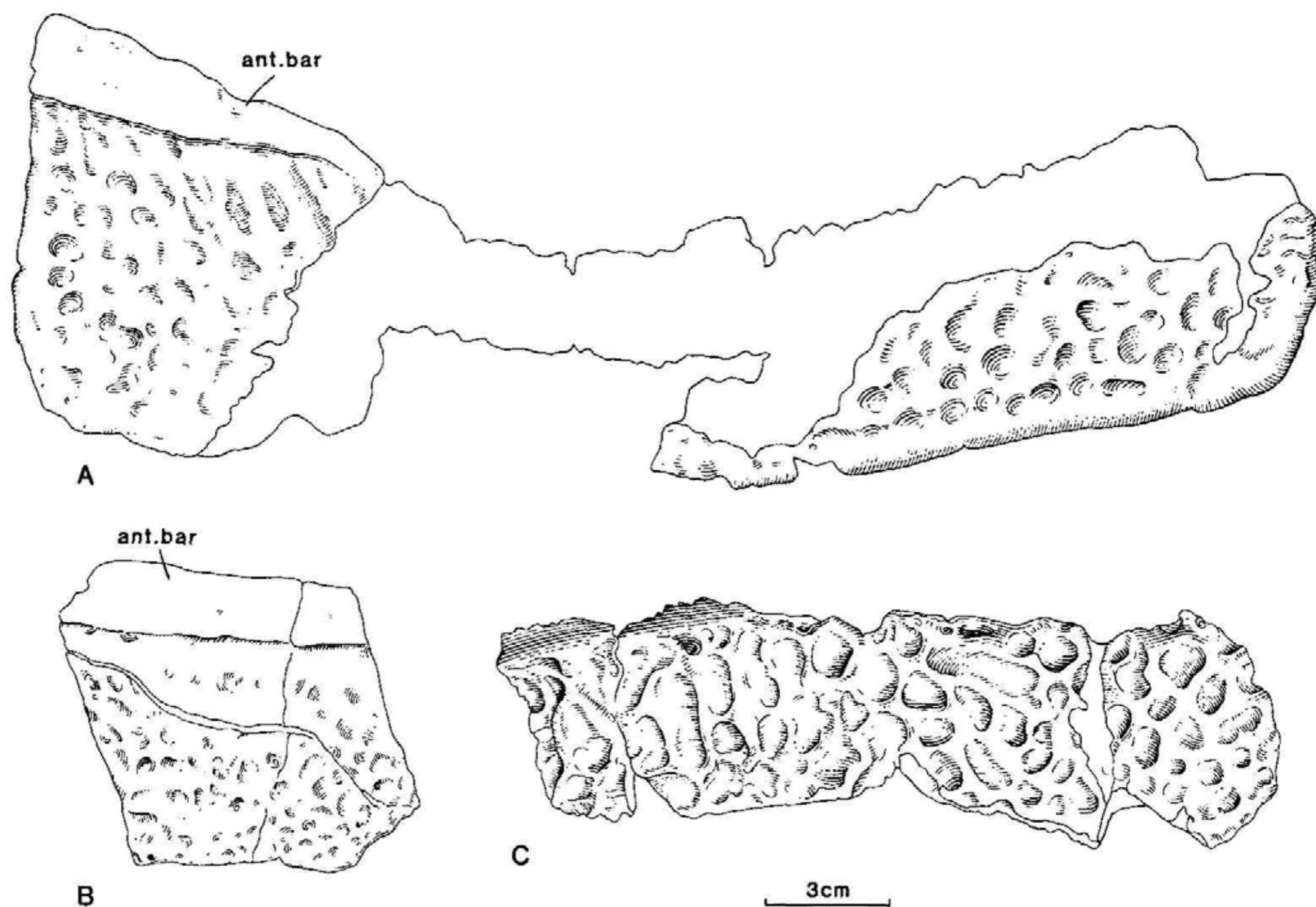
Figure 11. *Typothorax coccinarum*, paramedian scutes from Petrified Forest National Park, superior view. *a*, UCMP V82040/126805, right, dorsal scute; *b*, UCMP V82267/126807, fragment of dorsal scute; *c*, UCMP 7043/27019, fragment of left, dorsal scute. (Abbreviations as in Fig. 2.)

Typothorax coccinarum Cope 1875
Plates 2, 3; text figures 8-12

Typothorax coccinarum Cope, 1875, p. 265; Cope, 1877, p. 29-30, Pl. 22, Figs. 1-9; Cope, 1887, p. 210-213, Pl. 1; Von Huene, 1915, p. 485-490, figs. 1-10; Camp, 1930, p. 143; Sawin, 1947, p. 233; Gregory, 1953B, p. 9-11.

Episcoposaurus horridus Cope, 1887, p. 213-1217; Von Huene, 1915, p. 492-499, figs. 12-15, 18, 19, 21-24.

Type Specimen. USNM 2585, fragments of dermal plates (Cope 1877, p. 29-30, pl. 22, figs. 4, 5, 9).

Locality. "...at Cerro Blanco, near Gallina in Rio Arriba County, New Mexico" (Camp, 1930, p. 143.)

Horizon. Chinle Formation, upper Petrified Forest Member, ?Norian, Late Triassic.

Collector. E. D. Cope, 1874.

Diagnosis. (as for genus).

Hypodigm. (see text).

Calyptosuchus, New Genus

Type Species. *Calyptosuchus wellesi*, new species.

Etymology. GR. *Kalyptos*, covered, and *suchus*, crocodile.

Known Distribution. Late Triassic late Carnian/?early Norian of Texas, Arizona and New Mexico.

Diagnosis. (Armor) A large stagonolepidid with a narrow carapace; armor with anterior bars. Cervical armor segmented in accordance to underlying vertebrae; paramedian scutes of cervical region are thin and straplike. Lateral, cervical scutes are horned. Ornamentation of presacral paramedian scutes consists primarily of well-defined ridges radiating from a boss on the posterior margin

of the plate. Some pitting is present though indentations are most commonly a series of furrows bordered by the radiating ridges. No ventral "struts" are present. Posterior dorsal and caudal paramedian scutes have especially prominent eminences or "knobs" with straight posterior surfaces. Lateral scutes of body lacking horns, though keels occur. Caudal armor dominated by very large, blunt eminences. Ornamentation of these plates is lacking or present as very faint radiating, incised lines.

Description. *Paramedian scutes* of the cervical region are wide and thin with smooth sinuous lateral articular surfaces. An anterior bar is present. Ornamentation is radiate. A slight ridge marks the position where a "boss" will form further down the carapace. General form of scutes is similar to that of the paramedian scutes in the dorsal region. Paramedian scutes in the neck probably correspond with the number of cervical vertebrae. Paramedian scutes of the dorsal region are moderately wide (width of scute just over twice its length) and are of normal stagonolepidid proportions in relation to the skeletal measurements (width of the scute estimated to be about half the femoral length). No trough occurs behind the anterior bar. Ornamentation is a series of well-defined rays emanating from a boss near the midline of the posterior margin of the scute. These bosses are especially pronounced in the pelvic and caudal regions. Punctation consists primarily of grooves though some pitting also occurs. There is no development of ventral struts. Paramedian scutes of the caudal region are smooth, with very faint radiating incised lines at most. Anterior bar is present. Dorsal eminences are obtuse, very prominent, and always contacting the posterior margin of the scutes. Some degree of transverse arching is present. Medial and lateral scutal borders are thin and smooth.

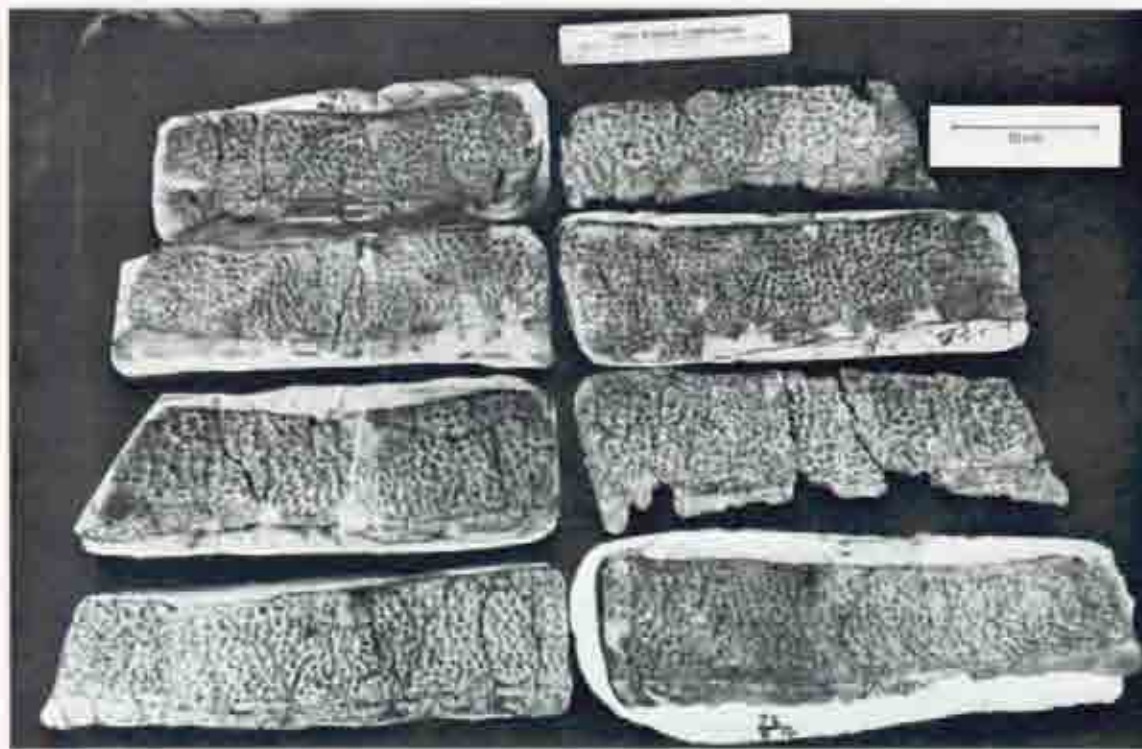*Lateral scutes* of the cervical region are strongly angulate with

Plate 2. *Typothorax coccinarum*, UCMP V2816, several individuals.

Paramedian scutes, dorsal region. Superior view.
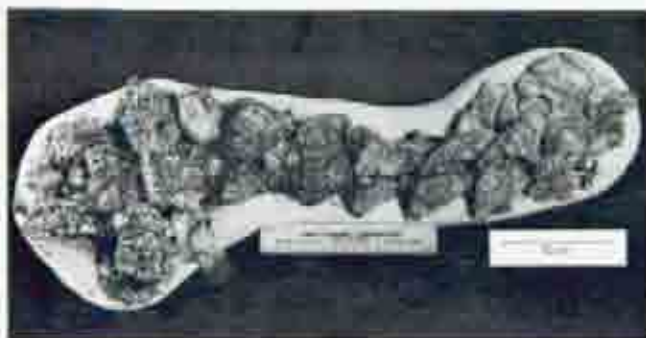
Canjilon Quarry, New Mexico

Plate 3. *Typothorax coccinarum,* UCMP V2816/34255

Left, articulated sequence of left lateral scutes, posterior dorsal region. Lateroventral view. *Right,* caudal armor.

Canjilon Quarry, New Mexico

dorsal and lateroventral flanges present. Posterolaterally directed horns are present. Ventrolateral flange is a wide, thin sheet exhibiting an anterior bar and radiate ornamentation of faint incised lines. Dorsal flange is much less developed than the ventrolateral flange, and it has a strongly concave medial margin for articulation with the paramedian scute. Ornamentation of the dorsal flange consists of faint grooves and pits that are much less marked than those of the ventrolateral flange. Lateral scutes of the dorsal region are thin and exhibit little angulation, so the entire dorsal surface of the scute represents a single plane rather than distinct flanges. An anterior bar is present. There is no development of horns, but a ridge appears behind the anterior bar and runs to the posterior margin of the scute. Ornamentation is a series of rays originating from the ridge. Lateral scutes of the caudal regions have anterior bars and faint ornamentation of incised lines radiating from very large eminences that remain large throughout the caudal series and contact the posterior margin of the scutes. All lateral scutes of the tail have strong transverse arching.

Calyptosuchus wellesi, new species
Plates 4, 5; text Figures 13–16

Phytosaur Case, 1922, p. 73–74, Fig. 28B; Case, 1929, p. 49–52, Fig. 21; Case, 1932, p. 57–72, Figs. 1–6.
Typothorax cf. *coccinurum,* Gregory, 1953B, p. 12–13, Fig. 16.
Desmatosuchus haplocerus, Gregory, 1953B, p. 16.
Desmatosuchus, Walker, 1961, p. 181.
Typothorax, Walker, 1961, p. 181.
Phytosaurus cf. *gregori,* Gregory, 1962, p. 682.
Type Specimen. UMMP 13950, "...a considerable portion of the armor...with the associated vertebrae. The segment of armor extended from the mid-dorsal to the mid-caudal region" (Case, 1932, p. 57). Also a crushed pelvis. (Case, 1932, p. 57–72, fig. 1, pls. 1–3.)
Etymology. The new species is named for Dr. S. P. Welles, whose encouragement benefited this study.
Locality. Northeast of Rotten Hill, near the breaks of Cerita de la Cruz Creek, probably in easternmost Oldham County, Texas.
Horizon. Dockum Group, Tecovas Formation, late Carnian/?early Norian, Late Triassic.
Collector. E. C. Case, 1931.
Diagnosis. (as for genus).
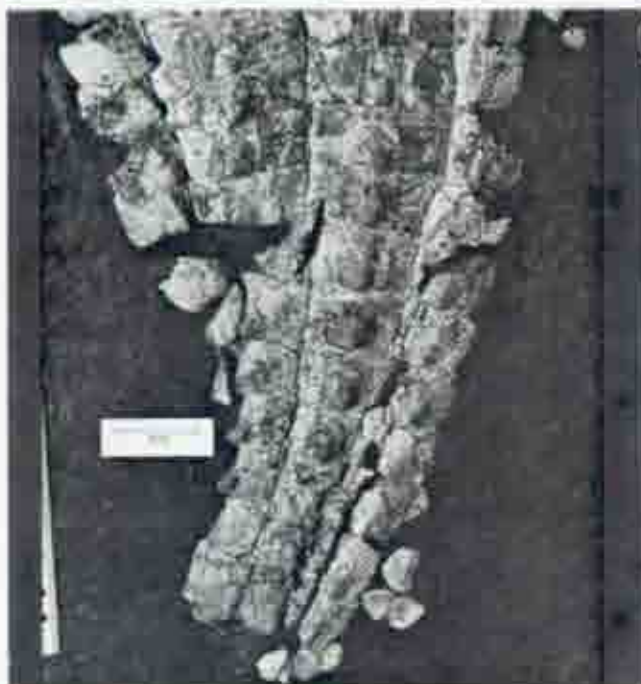Hypodigm. (see text).

Plate 4. *Calyptosuchus wellesi,* UMMP 13950, type.

Top, carapace; posterior dorsal, pelvic, and anterior caudal regions. Superior View.
Bottom, anterior and mid-caudal regions. Superior view.

Potter County, Texas
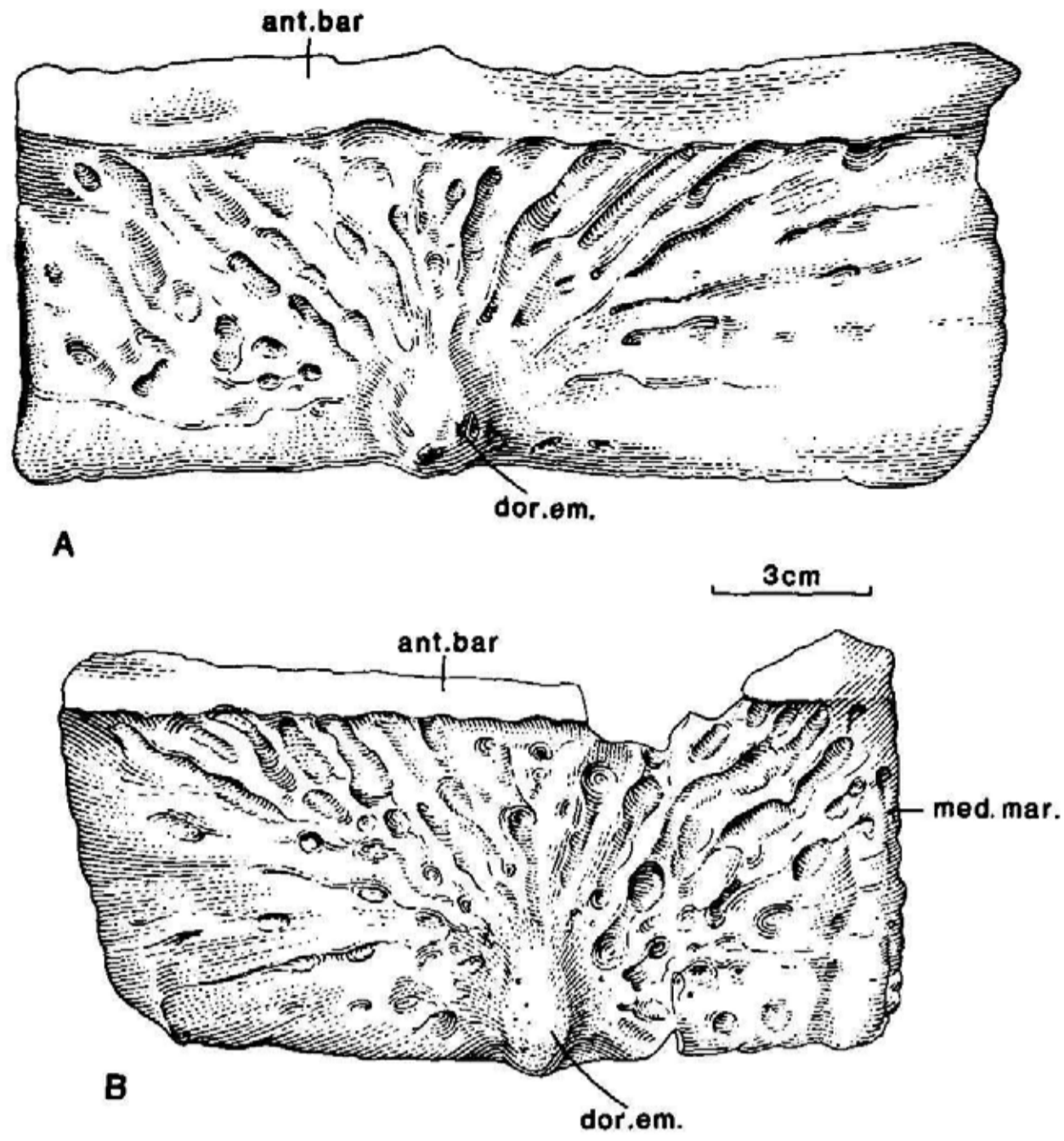
Figure 13. *Calyptosuchus wellesi,* dorsal paramedian scutes, superior view. *a,* UCMP V3205/36656, right side; *b,* MNA Pl. 2930, left side. (Abbreviations as in Fig. 2.)
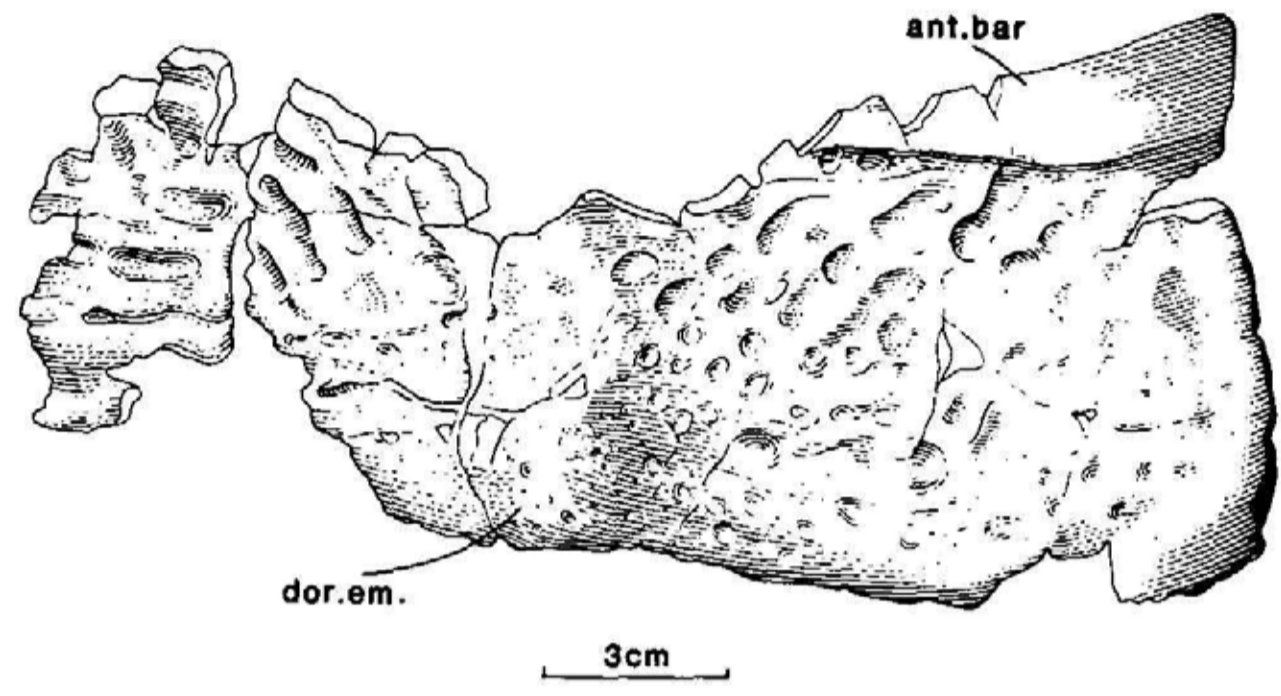
Figure 15. *Calyptosuchus wellesi,* scute collected at Petrified Forest National Park; UCMP 7042/84916, right, anterior dorsal paramedian scute, superior view. (Abbreviations as in Fig. 2.)
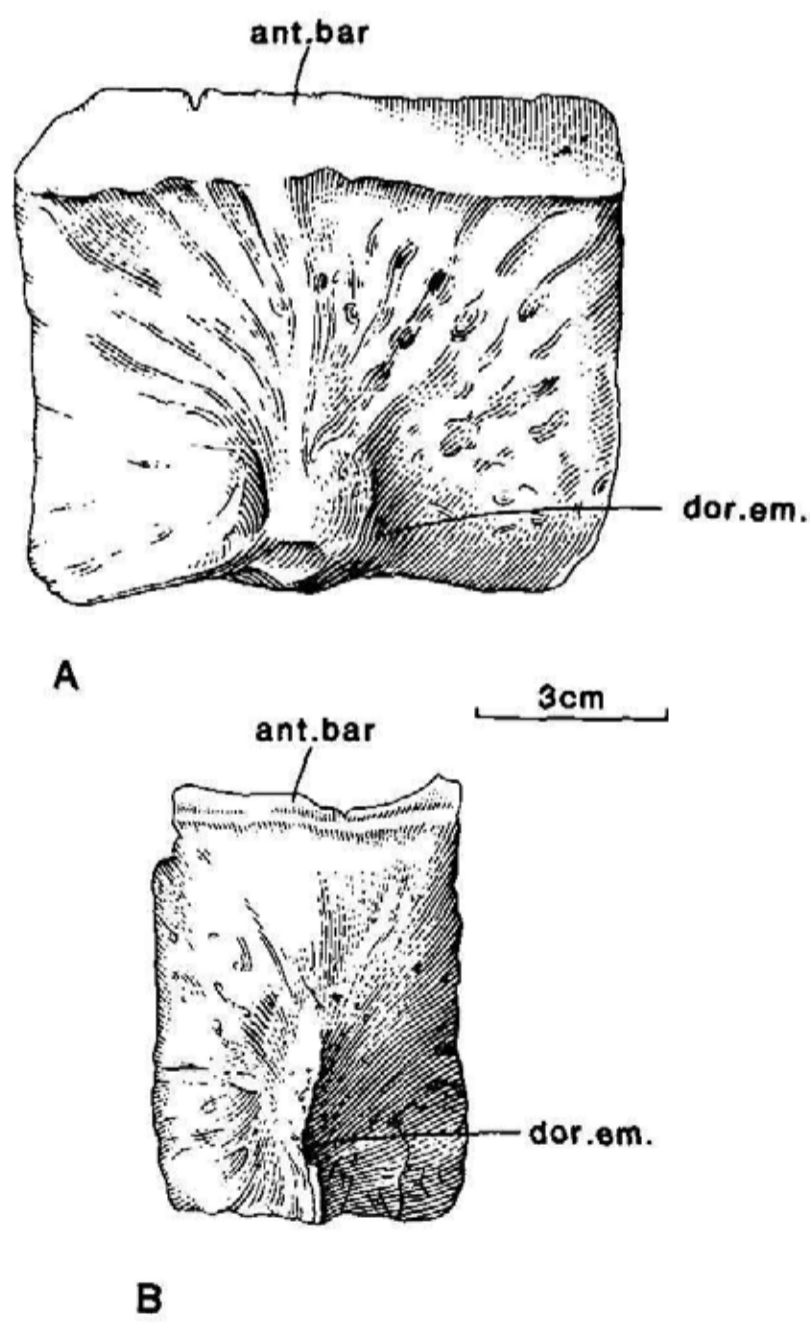
Figure 14. *Calyptosuchus wellesi,* paramedian scutes of the caudal region, superior view. *a,* UCMP V3205/36656, right anterior caudal scute; *b,* UCMP A269/126801, left, mid-caudal scute. (Abbreviations as in Fig. 2.)

Figure 16. *Calyptosuchus wellesi,* left lateral scutes of the dorsal region, from a single individual, dorsolateral view; UCMP 7307/27225. *a, b,* anterior dorsal scutes; *c, d,* mid-dorsal scutes. (Abbreviations as in Fig. 2.)

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Plate 5. *Calyptosuchus wellesi* UCMP V82249/126844

Paramedian scutes, dorsal region. Superior view.

North of Agate Bridge, PFNP

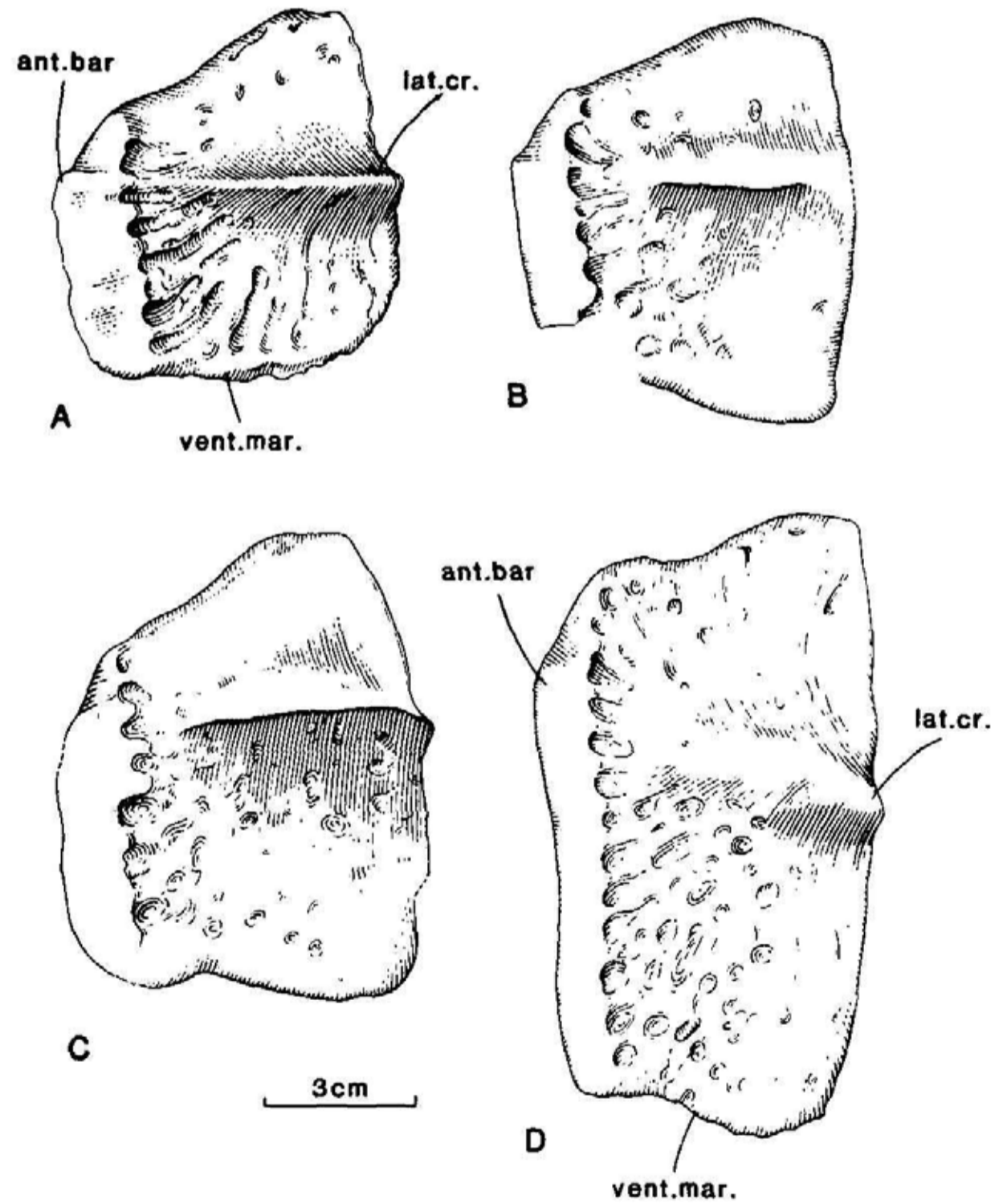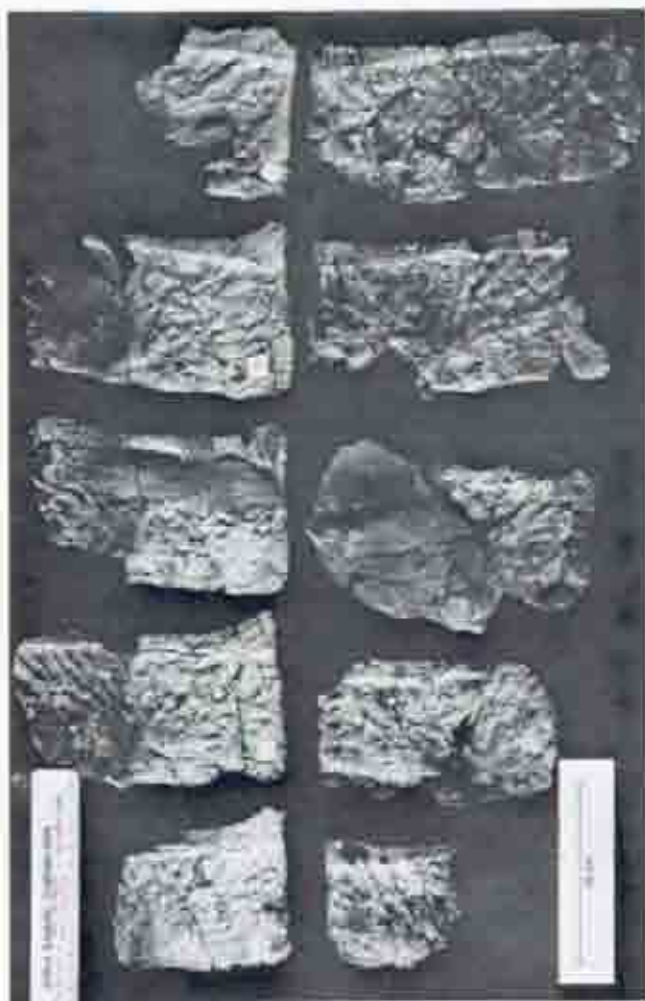In 1982, several poorly preserved dermal plates of the large stagonolepidid were found at a single site at Crystal Forest. Three or more incomplete paramedian scutes of the dorsal region and a single lateral scute were discovered together and probably belong to a single individual. Originally, it was believed this specimen represented a particularly large *Calyptosuchus wellesi* individual, but after more careful examination, this is no longer considered to be the case. The Crystal Forest aetosaur differs from *C. wellesi* in possessing much wider paramedian scutes sculptured with ridges and furrows paralleling the longitudinal axis of each plate (*C. wellesi* exhibits much shorter, oblique ridges and furrows); strongly hooked eminences with concave posterior margins (*C. wellesi* has blunt eminences with straight or convex posterior margins); and horned lateral scutes in the dorsal region (*C. wellesi* has no postcervical horns).

This reptile seems to be remarkably rare in the North American Triassic. In addition to the Crystal Forest specimen, only four paramedian scutes of this form are known from this continent (see below). However, the *Belodon* beds of the lower Stubensandstein

(upper Middle Keuper) of Heslach, near Stuttgart, Germany, have produced numerous rectangular scutes which are very similar to the American material (von Meyer 1861, 1865).

The Heslach scutes were found with bones of the phytosaur *Nicrosaurus kapffi*, leading several workers to conclude the armor was of phytosaurid origin (von Meyer, *ibid.*; E. Fraas, 1896, von Huene 1911, 1913; Gregory, 1962; etc.). Numerous typical phytosaur trapezoidal osteoderms also are found at Heslach, but these are usually referred to *Belodon plieningeri*. One German worker has recently illustrated *Nicrosaurus* in possession of both types of armor (Wild, 1974). After examining great numbers of aetosaurian scutes, we find it difficult, if not impossible, to accept these views. The Heslach armor consists of huge, rectangular paramedian scutes with anterior bars, strong radial ornamentation, sinuous lateral articulating surfaces, prominent eminences exhibited on posterior dorsal and caudal plates, and well-developed cornuate lateral scutes composed of dorsal and lateroventral flanges. This combination of dermal characters is unmistakably stagonolepidid.

The close association of phytosaur skulls and postcrania with stagonolepidid armor at Heslach is not surprising. The holotypes of *Desmatosuchus haplocerus*, *Episcoposaurus horridus*, and *Typothorax coccinarum* were mixed with phytosaur bones which confused their original describer. A partial skeleton of *Calyptosuchus wellesi* was found in a pit with the holotype skull of *"Phytosaurus" doughtyi*. E. C. Case commented on this last occurrence, "Fossil material is so scarce and dispersed in the locality that the association of the two as parts of one individual is fairly certain" (Case, 1932, p. 74). Camp also erred when describing aetosaur-phytosaur associations at the Canjilon Quarry in New Mexico, "Material collected by us....in 1928 includes four skulls probably but not definitely associated with the characteristic dermal plates of this genus *(Typothorax)*. These apparently show that *Typothorax* is a true longirostral phytosaur" (Camp, 1930, p. 143).

The Heslach locality has produced a number of reptile taxa. Walker correctly noted that an ilium originally referred to *Nicrosaurus kapffi* (von Meyer, 1861, p. 327-328, Pl. 41, Fig. 1-2; von Huene, 1922, p. 75, Fig. 29) in fact belongs to a *Poposaurus*-like reptile (Walker, 1969, p. 471).

Paratypothorax, New Genus

Type Species. *Paratypothorax andressi*, new species

Etymology. Gr. *Para*, near, beside; *typos*, impression; and *thorax*, cuirass or breastplate; in reference of the similarity of this genus to *Typothorax*.

Known Distribution. Late Triassic; late Carnian/?early Norian of Arizona and Texas; Norian of Germany.

Diagnosis. (Armor) A large stagonolepidid with a discoidal carapace; armor with anterior bars. Cervical armor unknown. Dorsal paramedian scutes are strongly expanded and have radiate ornamentation. Anterior paramedian scutes with small eminences or keels; more posterior plates (from the posterior dorsal and caudal regions) have very large, hooked prominences which are situated medially. Lateral scutes of body bear horns.

Description. Paramedian scutes of the cervical region are not definitely known although some small, wide scutes in the SMNS may be paramedian neck scutes. Paramedian scutes of the dorsal region are greatly expanded (width of largest scutes are 3.5 times their lengths) as in *Typothorax*. No distinct trough occurs behind the anterior bar. Ornamentation consists of prominent grooves and ridges radiating from posteromedially situated eminences. These eminences become very large in the posterior dorsal, pelvic, and caudal areas, and are more medially positioned than in other stagonolepidids, being on the inner quarter of the scutes. These bosses are as large or even larger than those of *Calyptosuchus* but they differ in exhibiting sharp anterodorsal margins and in being posteriorly hooked with concave posterior margins (in *Calyptosuchus*, the bosses are blunter and have straight or convex
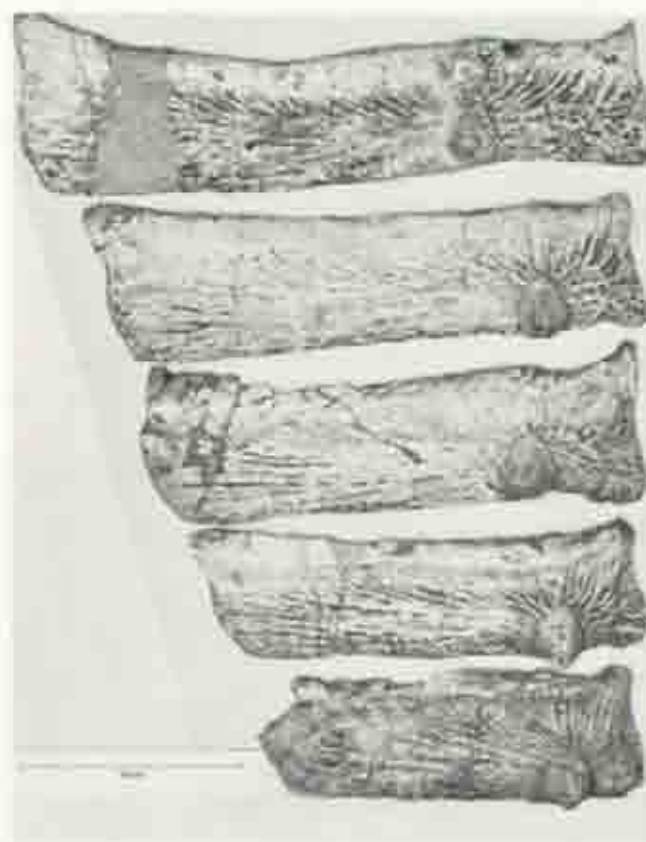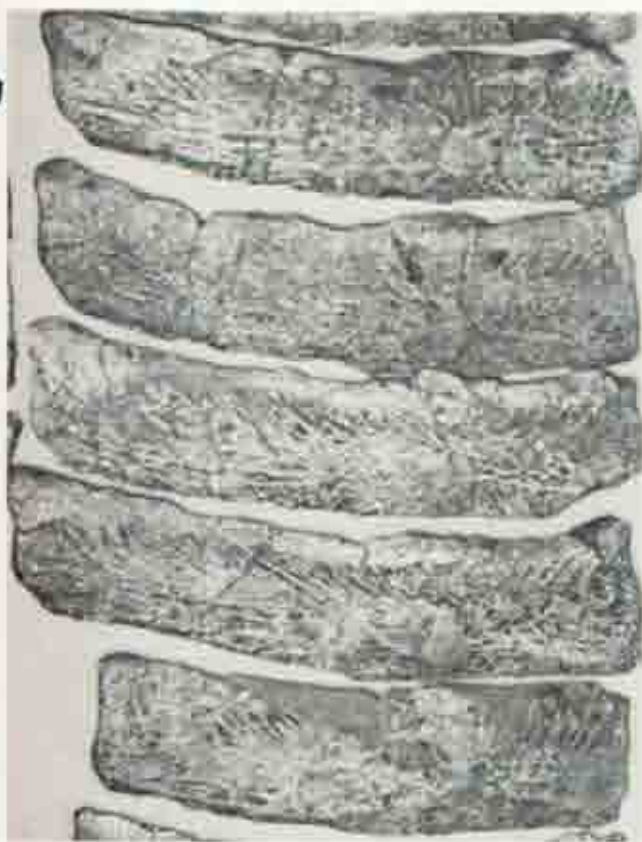
Plate 6. *Paratypothorax andressi*, SMNS, syntypes.

Left, left paramedian scutes, anterior and mid-dorsal regions. Superior view.
Right, left paramedian scutes, posterior dorsal and anterior caudal regions. Superior view.

Heslach, Germany

(Photographs courtesy of S. P. Welles)

posterior surfaces). The eminences always contact the posterior margin of the scutes. Paramedian scutes of the caudal region exhibit anterior bars and transverse arching. Anterior caudal paramedian scutes have well-defined radiate sculpturing, while the more posterior scutes show faint radiate ornamentation. Medial and lateral margins of scutes are apparently smooth.

Lateral scutes of the cervical region are not known with certainty. Lateral scutes of the dorsal region are thick and strongly angulate, exhibiting a general form similar to that of *Typothorax* but differing from the latter in the possession of radiate ornamentation and in the development of small horns throughout. Anterior bars were probably present. Lateral scutes of the caudal region are unknown.

Paratypothorax andressi, new species
Plate 6

Belodon Von Meyer, 1861, p. 337–342, Pl. 43, Figs 1, 2, 4, 5; Von Meyer, Meyer, 1865, p. 118–120, Pl. 28, Fig. 1–9.
Phytosaurus kapffi E. Fraas, 1896, p. 16; Von Huene, 1911, p. 103, Fig. 25; Von Huene 1915, p. 282, Fig. 13; Gregory, 1962, p. 682.
Typothorax Gregory, 1953A, p. 1–6, Figs. 1–4; Gregory, 1953B, p. 5.
Nicrosaurus kapffi Gregory and Westphal, 1969, p. 1297.
Nicrosaurus Wild, 1974, p. 22, Fig. 9.
Type Specimen. SMNS (no number assigned). Anterior caudal

paramedian scute, left side (Plate 6, *right*, second dermal scute from top).

Etymology. Andressi, to honor the family of Chris and Paula Andress, for their considerable interest and hospitality. Mr. Andress is Chief Ranger at Petrified Forest National Park.

Locality. Heslach, near Stuttgart, Württemberg, Germany.
Horizon. Middle Keuper, Stubensandstein, Norian, Late Triassic.
Collector. Unknown.
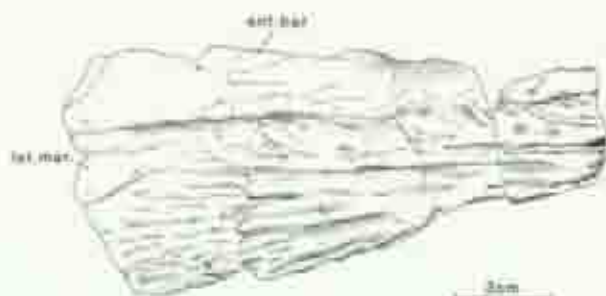**Diagnosis.** (as for genus).
Hypodigm. (see text).

Figure 17. *Paratypothorax* sp., fragment of left paramedian scute from the dorsal region, superior view; UCMP V82238/126839. (Abbreviations as in Fig. 2.)

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Paratypothorax sp.
Plate 7; text Figure 17.

Phytosaurus? Case, 1932, p. 73, 75, 76, pl. 4, Figs. 5, 6.
Specimens. UCMP V82238/126839, 7043/126881, UMMP 8858, 8859, 9600.

Localities. Crystal Forest and Billings Gap, PFNP, Arizona; Crosby County, Texas.

Horizons. Lower unit, Petrified Forest Member, Chinle Formation; Tecovas Formation, middle Dockum Group; late Carnian or early Norian, Late Triassic.

Comments. No differences can be observed between the American and German specimens. However, because of the incomplete nature and geographic separation of the former, it seems advisable to refer this material to *Paratypothorax* sp.

STAGONOLEPIDID ARMOR FROM THE CHINLE FORMATION OF PETRIFIED FOREST NATIONAL PARK

Prior to 1981, aetosaur remains were practically unknown from Petrified Forest National Park. In 1906, naturalist John Muir picked up two fragments of paramedian plates of *Typothorax* (UCMP 126977), probably in the vicinity of the Black Forest, though it is possible Muir's specimens came from elsewhere in the park. In 1921, C. L. Camp collected a single paramedial plate of *Calyptosuchus wellesi* (UCMP 84916, fig. 10) from the southeast corner of Blue Mesa. Camp discovered a fragmentary paramedian plate of *T. coccinarum* (UCMP 27019, fig. 15c) near the type locality of his *"Machaeroprosopus" tenuis*, south of Billings Gap, in 1923. Finally, in 1927 Camp collected scrappy armor of *C. wellesi* (UCMP 26684) in the vicinity of the holotype of *"M." lithodendrorum*, near Lithodendron Wash.

In 1946, E. H. Colbert (AMNH) found a possible aetosaur plate in the vicinity of Billings Gap (E. H. Colbert field notes, 1946, August 15). In 1962, William Breed (MNA) collected a lateral horn (fig. 7a, b) of *Desmatosuchus haplocerus* (MNA Pl. 697), apparently northeast of Delaney Tank (notes of former Park Naturalist Philip VanCleave, March, 1962). In 1979, W. Downs discovered a caudal vertebra of *C. wellesi* (MNA P. 1773) northeast of Agate Bridge.

When one considers the remarkable abundance of phytosaurian and metoposaurian remains found in the park over the past seventy-five years, the paucity of aetosaurs seems evident. Recent work at the Petrified Forest, however, indicates otherwise.
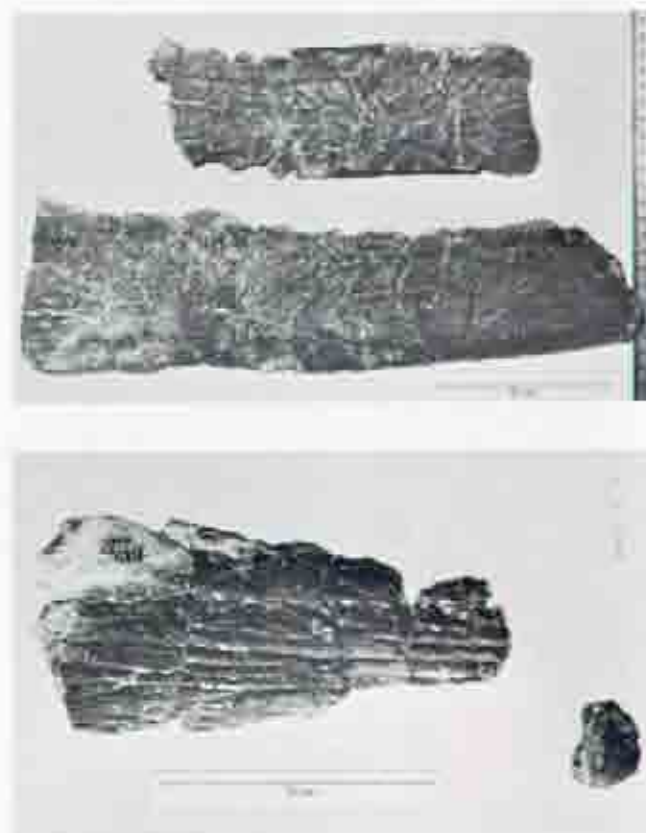
Table 1. A comparison of dorsal dermal armor of western North American Stagonolepididae

Character	Desmatosuchus	Typothorax	Calyptosuchus	Paratypothorax
Paramedian scutes				
Shape of cervicals	Long and thick	Probably short and thin	Short and thin	?
Post-cervicals with anterior bars	No laminae	Yes	Yes	Yes
Expansion of dorsals	Moderate	Great	Moderate	Great
Ornamentation of dorsals	Random	Random	Radiate	Radiate
Size of eminences in posterior dorsal and caudal region	Small	Very small	Large	Large
Eminences contact posterior margin of scute	No	Yes	Yes	Yes
Caudals exhibit strong transverse arching	No	No	Yes	Yes
Lateral scutes				
Cervicals with horns	Yes	Yes	Yes	?
Pectorals bearing large recurved horns	Yes	No	No	Probably not
Dorsals horned or knobbed	Yes	No	No	Yes
Angulation of dorsals	Moderate	Strong	Slight	Moderate
Caudals with strong transverse arching	No	No	Yes	?

Desmatosuchus haplocerus

Specimens of *Desmatosuchus haplocerus* are not common in the park. To date, only six sites yielding dermal plates of this species have been found, all of these occurring in the lower unit of the Petrified Forest Member of the Chinle Formation.

Because of the extreme popularity of the region, exact locality data are not recorded here, but are on file at the UCMP and PFNP headquarters.

LITHODENDRON WASH AREA

(1) Saurian Valley (UCMP Loc. V82251). NW ¼ of SE ¼, Sec. 15, and NE ¼ of SW ¼, Sec. 15, T 19N, R 23E.
Desmatosuchus haplocerus: UCMP 126950, 3 pieces of paramedian plates.
Note: The holotype of the phytosaur *Rutiodon lithodendrorum* (Camp) was discovered on the south side of Saurian Valley in 1921. Loc. V82251 is the western portion of Camp's Loc. 7034 (1930).

(2) Findlay's Fortune (MNA Loc. 302-111). NE ¼ of NE ¼, Sec. 15, T 19N, R 23E.
Desmatosuchus haplocerus: MNA Pl. 3172, a partial paramedian scute from the body (fig. 7f).

JASPER FOREST AREA

(3) Jasper Forest South (UCMP Loc. V82041). On line between SE ¼ and NE ¼ of SE ¼, Sec. 8, T 17N, R 24E.
Desmatosuchus haplocerus: UCMP 126885, 2 portions of a poorly preserved pectoral horn.
Note: This is the same site as MNA Loc. 302-42 (Cifelli et al., 1979).

DELANEY TANK AREA

(4) Delaney Tank Northeast (MNA Loc. 302, no specific locality number). Sec. 2, T 17N, R 23E.
Desmatosuchus haplocerus: MNA Pl. 697, left lateral scute, cervical region (fig. 7a, b).
Note: In 1962, personnel from the MNA picked up *Desmatosuchus* material (see above) from the vicinity of PFNP; unfortunately, no specific locality data for this occurrence exists in the MNA files. However, former Park Naturalist Philip VanCleave, who was present at the time, recorded the discovery of a "rich deposit of rather scrappy Triassic bone materials" coming from the Delaney Tank area, west of the park boundary in Sec. 2, T 17N, R 23E (Naturalist's Monthly Report, March, 1962). This is probably the locality of the *Desmatosuchus* spine listed here.

CRYSTAL FOREST AREA

(5) Crystal Forest (UCMP Loc. V82238). NE ¼ of NW ¼, Sec. 22, T 17N, R 14E.
Desmatosuchus haplocerus: UCMP 126863, 126838, 126837, 126901, 126905, 5 lots consisting of 20 fragments of paramedian scutes (Fig. 7)

LONG LOGS AREA

(6) Long Logs (UCMP Loc. V82042). Near center of SE ¼, Sec. 1, T 16N, R 23E.
Desmatosuchus haplocerus: UCMP 126976, fragment of a paramedian scute.

Typothorax coccinarum

Dermal plates of *Typothorax coccinarum* are known from fifteen sites in the Petrified Forest National Park area; all occurrences are in the upper unit of the Petrified Forest Member. Most of these records are in the northern part of the park, north of Puerco River, where the upper beds are especially abundant though this species is also common in the Flattops region near the southern boundary of the park.

BLACK FOREST AREA

(1) Black Forest (UCMP Loc. V82241). SE ¼ of Sec. 28, T 20N, R 24E.
Typothorax coccinarum: UCMP 126866, 126928-126931, 6 fragments of paramedian scutes.

ZUNI WELL AREA

(2) Zuni Well North 2 (UCMP Loc. V82247). SW ¼ of NE ¼, Sec. 30, T 20N, R 24E.
Typothorax coccinarum: UCMP 126850, 126870, 126942, 126945, 126948, 126949, 6 lots of 30 paramedian scute fragments, 1 lateral scute from the dorsal region.

(3) Zuni Well North 3 (UCMP Loc. V82266). SW ¼ of SW ¼, Sec. 19, T 20N, R 24E.
Typothorax coccinarum: UCMP 126978, 1 fragment of a paramedian scute.

RIM TANK AREA

(4) Rim Tank North (UCMP Loc. V82267). SW ¼ of NW ¼, Sec. 4, T 19N, R 23E.
Typothorax coccinarum: UCMP 126807, 126963, 7 fragments of paramedian scutes (fig. 15b).

LITHODENDRON WASH AREA

(5) Wizard Wash (UCMP Loc. V82272). S ½ of SE ¼, Sec. 10, T 19N, R 23E.
Typothorax coccinarum: UCMP 126843, 126852, 126857, 126964, 126965, 126968-126970, 8 lots of 26 paramedian scute fragments.

LACEY POINT AREA

(6) Inadvertent Hills (UCMP Loc. V82250). SE ¼ of SW ¼, Sec. 18, T 19N, R 14E.
Typothorax coccinarum: UCMP 126861, 126950-126952, 4 lots consisting of 15 paramedian scute fragments and 2 lateral plates of the cervical region.

(7) Lacey Point Southwest 1 (UCMP Loc. V82242). NW ¼ of SE ¼, Sec. 18, T 19N, R 24E.
Typothorax coccinarum: UCMP 126937, 10 fragments of paramedian scutes.

DEAD WASH AREA

(8) Dead Wash 1 (UCMP Loc. V82268). NW ¼ of NE ¼, Sec. 7, T 19N, R 23E.
Typothorax coccinarum: UCMP 126966, fragment of a paramedian scute.

(9) Dead Wash 2 (UCMP Loc. V82269). NW ¼ of SW ¼, Sec. 12, and SE ¼ of SE ¼, Sec. 11, T 19N, R 24E.
Typothorax coccinarum: UCMP 126967, fragment of a paramedian scute.

EAST FORK DRY WASH AREA

(10) Dry Creek Tank Southeast (UCMP Loc. V82040). NW ¼ of SE ¼, Sec. 31, T 18N, R 24E.
Typothorax coccinarum: UCMP 126805, a poorly preserved right paramedian scute of the dorsal region (fig. 15a).

(11) Billings Gap of C. L. Camp (UCMP Loc. 7043). Probably NW ¼ of SE ¼, Sec. 31, T 18N, R 24E.
Typothorax coccinarum: UCMP 27019, an incomplete paramedian scute of the dorsal region (fig. 15c).
Note: UCMP Loc. 7043 is probably the same site as UCMP Loc. V82040. Unfortunately, Camp's field notes and published report (1930) are rather conflicting with regard to the exact location of the Billings Gap site. This is the type locality of *Rutiodon tenuis* (Camp).

FLATTOPS AREA

(12) Flatops Northwest (UCMP Loc. V82258). SE ¼ of SW ¼, Sec. 29, T 17N, R 24E.

Typothorax coccinarum: UCMP 126859, 12 pieces of paramedian scutes.

(13) Flattops West (UCMP Loc. V82259). NE ¼ of NE ¼, Sec. 31, T 17N, R 24E.

Typothorax coccinarum: UCMP 126872, 126956, 126958, 126959, 4 lots of 23 fragments of paramedian scutes.

(14) Karen's Point (UCMP Loc. V82240). SW ¼ of SE ¼, Sec. 23, T 17N, R 24E.

Typothorax coccinarum: UCMP 126806, 126808, 126905, 126907, 126909-126912, 126915-126923, 126925-126927, 23 lots of more than 200 fragments of paramedian scutes and 7 lateral scutes (fig. 16a, b).

GIANT LOGS AREA

(15) Giant Logs North (UCMP Loc. V82271). NE ¼ of SE ¼, Sec. 34, T 17N, R 23E.

Typothorax coccinarum: UCMP 126855, 126860, 126862, 5 fragments of paramedian scutes and 1 lateral scute.

Calyptosuchus wellesi

Scutes of *Calyptosuchus wellesi* have been recovered from twenty sites at Petrified Forest National Park, all in the lower unit of the Petrified Forest Member. The majority of occurrences are in the southern part of the park, south of Puerco River, where the lower beds are well exposed.

LITHODENDRON WASH AREA

(1) Saurian Valley (UCMP Loc. V82251). NW ¼ of SE ¼, Sec. 15 and NE ¼ of SW ¼, Sec. 15, T 19N, R 23E.

Calyptosuchus wellesi: UCMP 126953, parts of 3 paramedian scutes.

(2) Findlay's Fortune (MNA Loc. 302-111). NE ¼ of NE ¼, Sec. 15, T 19N, R 23E.

Calyptosuchus wellesi: NMA Pl. 3175, 6 fragments of paramedian scutes.

TEPEES AREA

(3) Tepees Northeast (UCMP Loc. V82248). SW ¼ of SW ¼, Sec. 14, T 18N, R 24E.

Calyptosuchus wellesi: UCMP 126944, 50 fragments of paramedian scutes.

(4) Tepees Northwest (UCMP Loc. V82273). W ½ of NE ¼, Sec. 22, T 18N, R 24E.

Calyptosuchus wellesi: UCMP 126854, 126856, 2 fragments of paramedian scutes, 1 lateral scute from the tail.

(5) Tepees East (UCMP Loc. V82257). NW ¼ of NW ¼, Sec. 24, T 18N, R 24E.

Calyptosuchus wellesi: UCMP 126979, 1 fragment of a paramedian scute.

BLUE MESA AREA

(6) Blue Mesa North 1 (UCMP Loc. V82233). Near boundary line between NE ¼ and SE ¼, Sec. 23, T 18N, R 24E.

Calyptosuchus wellesi: UCMP 126897, lateral scute of the caudal region.

(7) Blue Mesa North 2 (UCMP Loc. V82236). On line between SE ¼ and NE ¼, Sec. 23, T 18N, R 24E.

Calyptosuchus wellesi: UCMP 126889, 2 pieces of paramedian armor.

(8) Blue Mesa Northwest (UCMP Loc. V82244). Just west of center, Sec. 23, T 18N, R 24E.

Calyptosuchus wellesi: UCMP 126947, eminence of paramedian scute.

(9) Blue Forest of C. L. Camp (UCMP Loc. 7038). On line between NE ¼ of NW ¼ and NW ¼ of NE ¼, Sec. 26, T 18N, R 24E.

Calyptosuchus wellesi: UCMP 126875-126879, 126903, 12 fragments of paramedian scutes and 1 lateral scute.

Note: This material was discovered near the type locality of *Rutiodon adamanensis* (Camp) and at the same level.

(10) Phytosaur Basin of C. L. Camp (UCMP Loc. 7039). NW ¼ of SE ¼, Sec. 26, T 18N, R 24E.

Calyptosuchus wellesi: UCMP 126971, 2 fragments of a paramedian scute.

(11) Phytosaur Basin West (UCMP V82276). NE ¼ of SW ¼, Sec. 26, T 18N, R 24E.

Calyptosuchus wellesi: UCMP 126975, a large paramedian eminence.

(12) Lower Billings Gap of C. L. Camp (UCMP Loc. 7042). NE ¼ of Sec. 25, T 18N, R 24E.

Calyptosuchus wellesi: UCMP 84916, a nearly complete right paramedian scute of the dorsal region (fig. 15).

AGATE BRIDGE AREA

(13) Agate Bridge North (UCMP Loc. V82239). NE ¼ of SE ¼ and SE ¼ of NE ¼, Sec. 4, T 17N, R 24E.

Calyptosuchus wellesi: UCMP 126864, 126906, 3 lots of 14 fragments of paramedian and lateral scutes.

Note: This area includes the type locality of Daugherty's tree-fern. *Itopsidema vancleavei* (Daugherty, 1963).

(14) Agate Bridge Northwest (UCMP Loc. V82249). SW ¼ of NE ¼, Sec. 4, T 17N, R 24E.

Calyptosuchus wellesi: UCMP 126844, partial carapace with a dozen well-preserved paramedian scutes (pl.3).

(15) Agate Bridge Northeast (UCMP Loc. V82243). NE ¼ of NE ¼, Sec. 3, T 17N, R 24E.

Calyptosuchus wellesi: UCMP 126938-126941, 4 lots consisting of about 140 fragments of paramedian scutes and 1 lateral scute.

(16) Agate Bridge Southwest (UCMP Loc. V82245). E ½ of SE ¼, Sec. 10, T 17N, R 24E.

Calyptosuchus wellesi: UCMP 126946, a lateral scute from the cervical region.

JASPER FOREST AREA

(17) Jasper Forest West (UCMP Loc. V82237). SW ¼ of NE ¼, Sec. 8, T 17N, R 24E.

Calyptosuchus wellesi: UCMP 126900, 3 fragments of paramedian scutes.

(18) Jasper Forest South (UCMP Loc. V82041). On line between SE ¼ and NE ¼ of SE ¼, Sec. 8, T 17N, R 24E.

Calyptosuchus wellesi: UCMP 126848, 126849, 125851, 126869, 126882-126884, 126886-126894, 126936, 17 lots of about 200 fragments of paramedian scutes and 4 lateral scutes. This is the richest concentration of aetosaurian armor in the Park.

BATTLESHIP AREA

(19) Battleship Northwest (UCMP Loc. V82261). On line between NE ¼ of SE ¼, Sec. 17, and NW ¼ of SW ¼, Sec. 16, T 17N, R 24E.

Calyptosuchus wellesi: UCMP 126865, 126961, 126962, 3 lots of paramedian scute fragments and a single lateral scute of the neck.

LONG LOGS AREA

(20) Long Logs (UCMP Loc. V82042). Near center of SE ¼, Sec. 1, T 16N, R 23E.

Calyptosuchus wellesi: UCMP 126853, 126895, 126896, a dozen fragments of paramedian scutes.

Paratypothorax sp.

An aetosaurian reptile apparently allied to the European genus *Paratypothorax* occurs at the Petrified Forest but is

very rare. Occurrences of two individuals, both probably from the upper part of the lower unit of the Petrified Forest Member.

CRYSTAL FOREST AREA

(1) Crystal Forest (UCMP Loc. V82238). NE ¼ of NW ¼, Sec. 22, T17N, R24E.

Paratypothorax sp.: UCMP 126839, several incomplete paramedian scutes and a single lateral scute, probably belonging to a single individual.

EAST FORK DRY WASH AREA

(2) Billings Gap of C. L. Camp (UCMP Loc. 7043). Probably NW ¼ of SE ¼, Sec. 31, T18N, R24E.

Paratypothorax sp.: UCMP 126881, paramedian scute in 2 pieces, and a lateral scute.

Note: Camp appears to have collected stagonolepidid scutes from two horizons at his Billings Gap site. The *Typothorax* scute (UCMP 27019) was found in a white sand horizon (Sonsela Sandstone, Billingsley, p.c., 1981) about 10–15 feet below the level of the holotype skull of *Rutiodon tenuis* (UCMP 27018), while the *Paratypothorax* scrap (UCMP 126880) was probably picked up in blue and white shales with metoposaurid float, well below the *Typothorax* level.

STAGONOLEPIDID ARMOR IN THE CHINLE FORMATION EXCLUSIVE OF PETRIFIED FOREST NATIONAL PARK

Desmatosuchus haplocerus

Dermal armor of *Desmatosuchus haplocerus* has been reported from four localities in Arizona, all in Apache County (Brady 1954, 1958, Gregory 1953B, Camp and Welles 1956, Jacobs and Murry 1980). Only Brady decribed any of this material in detail.

In Apache County, *D. haplocerus* is most common in the St. Johns area about forty miles southwest of the Petrified Forest. *Placerias* Quarry (UCMP Loc. A269) produced hundreds of specimens (Camp and Welles 1965, Gregory 1953B, Jacobs and Murry 1980). Nearby, Downs Quarry (MNA Loc. 207N) yielded a few specimens (Jacobs and Murry 1980). In the vicinity of Big Hollow Wash (UCMP Loc. V80003), about two miles northwest of *Placerias* Quarry, material was recently found. At Blue Hills (UCMP Loc. 7307, 7308), 3 miles northeast of St. Johns, numerous small scutes probably representing immature *D. haplocerus* individuals occur with bones of other small reptiles and amphibians.

Other parts of Apache County have yielded isolated *Desmatosuchus* plates. Brady reported pectoral spikes and paramedian scutes eight miles north of Lupton (Brady 1954) and near St. Michaels (Brady 1958). Other specimens in the MNA were found at a clay pit near Allentown and north of Window Rock. It should be noted that Allentown no longer exists.

In Navajo County, Gordon Nelson (Tucson, Arizona) collected a small paramedian scute presumably belonging to a young *Desmatosuchus* from the eastern margin of Rincon Basin, about ten miles northeast of Winslow. Mr. Nelson also reports examining a pectoral spike of this genus in a private collection, also found in Rincon Basin (Nelson, p.c., 1982).

In Coconino County, an incomplete pectoral spike of *D. haplocerus* was discovered at Ward's Bonebed, near Tanner's Crossing (U.A. Collection).

Typothorax coccinarum

The genus *Typothorax* was reported from two localities in Arizona. Scutes were noted from the *Placerias* Quarry in Apache County (Camp and Welles 1956, Gregory 1953B, Jacobs and Murry 1980). Examination of the UCMP and MNA collections reveals that none of the more than 1,000 stagonolepidid dermal plates from the *Placerias* Quarry belong to *Typothorax*. Two aetosaur genera occur in the quarry, *Desmatosuchus* and *Calyptosuchus*, the latter often being mistaken for *Typothorax*.

Typothorax was noted from Ward's Bonebed, in Coconino County, Arizona (Huene 1926). Though no scutes were included with Huene's material, it is necessary to comment upon his identifications in order to avoid possible confusion in the future concerning the distribution of *Typothorax*. Huene's Figure 1, listed as the distal half of a right femur of *T. coccinarum*, is stagonolepidid, but it is not determinate to genus. His Figure 2, listed as the proximal extremity of the right femur of *T. coccinarum*, is the femur of a phytosaur. Huene's Figure 5, labeled the proximal extremity of a left femur of a parasuchian, belongs to an aetosaur.

Elimination of the above records of *Typothorax* suggest a rather restricted distribution of this genus in Arizona. Undoubted Arizona records of *Typothorax* are known only from the upper levels of the Petrified Forest Member in the vicinity of PFNP.

In New Mexico, several occurences of *Typothorax* have been reported. Gregory believed Mehl's Fort Wingate stagonolepidid *Acompsosaurus* "may well be a synonym of *Typothorax*, although the poorly preserved types made such determination difficult" (Gregory, 1953B, p. 25). Unfortunately, Mehl's description (Mehl, 1915) of *A. wingatensis* included no figures of the scutes which formed part of the holotype that was subsequently lost. Mehl, however, did include figures and photographs of the pelvis, and these, when compared with undoubted pelvic remains of *Typothorax* from Canjilon Quarry (see below), indicate an aetosaur distinct from *Typothorax*. Ash (1978, p. 93) recently noted that *Acompsosaurus* came from the Monitor Butte Member of the Chinle Formation, making it the most ancient Chinle aetosaur. *Typothorax* occurs high in the Petrified Forest Member and is the latest Chinle stagonolepidid.

In 1875, Cope named *Typothorax coccinarum*. Cope's original material included remains of aetosaurs and phytosaurs (Gregory, *ibid.*). In 1887, Cope restricted the type of *T. coccinarum* to thin, flat dermal plate fragments bearing numerous small shallow pits. In this same paper, Cope named another stagonolepidid, *Episcoposaurus horridus*. Cope's original material of *E. horridus* included phytosaur and aetosaur specimens. The aetosaur bones were believed by Gregory to represent *Typothorax*. Gregory thought the distictive armor of *E. horridus* merely originated from the caudal region, while the armor originally attributed to *T. coccinarum* was presacral in origin. An undescribed *Typothorax* skeleton (UCMP 34255) from the Canjilon Quarry, with the back and tail scutes clearly associated, confirms Gregory's belief that *E. horridus* is a junior synonym of *T. coccinarum*. Cope (Cope, 1887, Pl. 1, Fig. 1 and 2) illustrated additional scutes of *T. coccinarum* and they exhibit clearly the chief characters of the paramedian plates of the dorsal region of this species. Huene (Huene, 1915)

Table 2. Distribution of stagonolepidid armor at localities in Chinle and Dockum beds (exclusive of Petrified Forest National Park)

	Desmatosuchus	Typothorax	Calyptosuchus	Paratypothorax
Arizona				
Placerias Quarry	X		X	
Downs Quarry	X		X	
Big Hollow Wash	X		X	
Blue Hills	X		X	
Lupton	X			
St. Michaels	X			
Allentown	X			
Window Rock N.	X			
Nazlini			X	
Rincon Basis	X			
Ward Bonebed	X		X	
New Mexico				
Revuelto Creek			X	
Cerro Blanco		X		
Canjilon Quarry		X		
Texas				
White River E.	X			X
Home Creek	X		X	X
North Cedar Mt.	X		X	
Rotten Hill	X		X	
Dockum	X			
Glass Mts.	X			
Otis Chalk	X			
Palo Dura Canyon	X			

described and figured much of Cope's *Typothorax* collection now housed in the AMNH. Camp (Camp, 1930) relocated the type locality of *T. coccinarum* at Cerro Blanco, north of Gallina, Rio Arriba County, New Mexico.

Between 1928 and 1933, UCMP, under the direction of C. L. Camp, excavated an extensive quarry one mile west of the old ranch house at Ghost Ranch, Rio Arriba County, New Mexico. The site is about six miles east of Canjilon Creek, from which it gets its name, the Canjilon Quarry (UCMP Loc. V2816). The phytosaurid, *Rutiodon tenuis* is abundant in the quarry. Ten skulls and four partial skeletons of this species have been collected (Lawler, 1979). Seven other genera of tetrapods also occur at Canjilon; of these, *Typothorax coccinarum* is most common. Three partial skeletons (UCMP 34255, 34248, 34259) and numerous isolated postcranial elements and scutes were collected. No skulls of *T. coccinarum* were found but, with the exception of anterior presacral vertebrae, ribs, and a few distal phalanges, the postcranium is now completely represented by well-preserved material. This will be described in a forthcoming paper. The Canjilon specimens are without doubt conspecific with Cope's fossils. This material has been used in this paper, along with Cope's specimens, for the diagnosis and description of the armor of *Typothorax*.

In the late 1930's, the MCZ collected two partial aetosaur skeletons (MCZ 1487, 1488) from Ghost Ranch. This material, unfortunately, has never been fully prepared. Gregory *(ibid.)* considered the Harvard skeletons to belong to *T. coccinarum*. We agree with Gregory's conclusions. Colbert stated that the MCZ specimens were collected one mile east of the ranch houses (Colbert, 1960, p. 60), but labels with the fossils state they were found one mile west of the ranch house (Parrish, p.c. 1982) indicating the MCZ and UCMP *Typothorax* skeletons were discovered very near to each other, perhaps at the same locality. The famous AMNH *Coelophysis* Quarry was discovered in 1947 at a

horizon at least one-hundred feet above the levels of the UCMP and MCZ excavations (Colbert, 1950, p. 62). No aetosaur material was found at the *Coelophysis* Quarry.

Calyptosuchus wellesi
Dermal armor of *Calyptosuchuas wellesi* has been found at five localities in Apache County. Hundreds of well-preserved bones and scutes were discovered in the *Placerias* Quarry by the UCMP and MNA. As mentioned above, this material was originally referred to *Typothorax* (Camp and Welles 1953, Gregory 1953, Jacobs and Murry 1980). *C. wellesi* is also common at the Downs Quarry (Jacobs and Murry 1980 and at the Big Hollow Wash site. In the Blue Hills, much of a carapace of a single individual (UCMP 27225) was found by Camp in 1926. A number of beautifully preserved paramedian scutes (UCMP 36656) were collected by Camp in 1932 seven miles north of Nazlini Trading Post (UCMP Loc. V3205).

In Coconino County, numerous broken scutes of *C. wellesi* were found at Ward's Bonebed (UCMP Loc. V3309).

STAGONOLEPIDID ARMOR FROM THE DOCKUM GROUP

New Mexico

Quay County
In 1947, J. T. Gregory found aetosaur scutes (YPM 3695, 3696) near a large well-preserved phytosaur skull along Revuelto Creek, in Quay County. Gregory estimated his site to be about 310 feet below the base of the Redonda Formation, in the upper part of the "Chinle" claystone member of the Dockum Group (Gregory 1972, p. 123). Gregory, "with grave doubts", referred these plates to *Typothorax* cf. *coccinarum* and provided a description and drawing of one of the plates (Gregory 1953B, p. 12, Fig. 16). In 1962,

Gregory reconsidered his previous identification and remarked, "that some of the plates that I attributed to *Typothorax*....particularly Y.P.M. no. 3695....are actually scutes of American species of *Phytosaurus*" (Gregory 1962, p. 682). However, Gregory's illustration shows this plate to be the left paramedian scute from the posterior dorsal region of *Calyptosuchus wellesi*. Recently, Kenneth Carpenter (Univ. Colo.) visited Gregory's site and collected much interesting material including additional stagonolepidid armor (J. M. Parrish, p.c., 1982).

Gregory also reported possible *Typothorax* fossils from the Redonda Formation of Apache Canyon and Red Peak, in Quay County (Gregory 1972, p. 123). None of this material has been described, and we have not examined it.

Texas

Crosby County

The Triassic badlands along the east and west banks of White River in southeastern Crosby County, Texas, are famous for their abundance of middle Dockum vertebrates. These sediments represent a southern extension of the Tecovas Formation of the Texas Panhandle. Three of the four known Chinle stagonolepidid genera were also found here.

In 1917, E. C. Case discovered an exceptionally well-preserved skeleton with much of the carapace of *Desmatosuchus haplocerus* (UMMP 7476, Case's holotype of *D. spurensis*) on the east bank of White River (Blanco River of Case) about one-half mile east of the crossing of the old Spur-Crosbyton road (Case 1920, 1922). Bones of a second individual (UMMP 7504) were found with this specimen. In the same area, Case found a right paramedian scute (anterior dorsal region) of *Paratypothorax* sp. (UMMP 9600).

Fossil vertebrates are especially common west of White River. Along Home Creek (Holmes Creek of Case, 1922), a tributary of White River, field parties of UMMP, UT, and UCMP did extensive collecting. A partial skeleton of *Calyptosuchus wellesi* with associated armor (UMMP 7470) was found by Case (Case 1922, 1929, 1932). Scutes of this species (UCMP 11351) were also collected by Gregory in this area. *Desmatosuchus haplocerus* is represented at Home Creek by its pectoral spikes (UCMP 85103, 85106, UT 31172-14), and 2 paramedian scutes of *Paratypothorax* sp. (UMMP 8858, 8859) were found here. The *Paratypothorax* specimens were illustrated and described by Case as "Type 3 dermal plates" (Case 1932, p. 73, Pl. 4, Fig. 5, 6).

In the vicinity of Cedar Mountain, scutes of *Desmatosuchus haplocerus* were found (UCMP 85112, 102345, 102343, UT collection), as well as a partial paramedian scute of *Calyptosuchus wellesi* (UCMP 102347). North of Cedar Mountain, at Dirty Tank, a single paramedian scute of *D. haplocerus* (UCMP 102343) was collected.

Howard County

In 1927 and 1929, Case explored the lower Dockum beds of southeastern-most Howard County. His most notable discovery was a huge, beautifully preserved skull and jaws (UMMP 10336, 10336A) of the primitive phytosaurid, *Angistorhinus megalodon* found between Devils Creek and the Hyman Scott Oil Field, about fifteen miles southeast of Big Spring and two miles northeast of Otis Chalk (Case

1929, 1930). A pectoral spike of *Desmatosuchus* sp. (UMMP 11688) was also collected.

In 1940, Grayson Meade supervised excavations near the Case locality where four quarries were worked. Quarries 1 and 2 produced numerous *Trilophosaurus* specimens, as well as other types of reptiles, amphibians, and fish—but little if any aetosaur material (Gregory 1945). However, Quarries 3 and 3A (UT Loc. 31100 and 31185, respectively), discovered about one mile south of Quarries 1 and 2, and two miles northeast of Otis Chalk, yielded abundant and well-preserved stagonolepidid specimens (Sawin 1947). At Quarry 3A, two skeletons (UT 31185-84a and 31185-84b) of a large, spinescent aetosaur were collected; these form the syntypes of *Typothorax meadei* Sawin. This reptile is very different from the genotype of *Typothroax, T. coccinarum*, and undoubtedly represents a different genus. The Otis Chalk aetosaurs will be reviewed elsewhere (Elder and Long, in prep.)

Potter County

In 1931, Case collected fossils in the Tecovas Formation, northeast of Rotten Hill, along the breaks of Cerita de las Cruz Creek. This locality is about twenty-three miles northwest of Amarillo, in western Potter and eastern Oldham counties. A number of fine specimens including the posterior half of an aetosaur skeleton with armor in place were recovered. The aetosaur skeleton (UMMP 13950) is the holotype of *Calyptosuchus wellesi*. Case published a good, well-illustrated description of this specimen but did not name it (Case 1932). He noted the similarities of the Potter County aetosaur and another skeleton (UMMP 7470) he had discovered in Crosby County a decade earlier. Both specimens belong to the same species. Subsequently, the Rotten Hill skeleton has been erroneously referred to *Typothorax* (Gregory 1953B, p. 12; Walker 1961, p. 181).

The Rotten Hill bonebed has also produced a number of *Desmatosuchus haplocerus* specimens (UMMP V60817, V13026, V13637, V13727, PPHM collection).

Dickens County

In 1891, W. F. Cummins discovered the holotype of *Desmatosuchus haplocerus* (ANSP 14688) 3 miles north of Dockum, in western Dickens County. E. D. Cope described Cummins' aetosaur and established a new species for it, *Episcoposaurus haplocerus* (Cope 1892, p. 129). Gregory redescribed and illustrated this material, which consists of about 30 scutes, 2 caudal vertebrae, ribs, and a fragmentary scapula (Gregory 1953B, p. 16). He was able to demonstrate that it was conspecific with Case's *Desmatosuchus spurensis*. Wilson figured what he considered to be topotypic specimens of *D. haplocerus* which are housed at UT (Wilson 1950, p. 113). Gregory recorded *Typothorax* from Dickens County (Gregory 1972, p. 122). We question this identification on the basis of its geologic occurrence. The Triassic rocks exposed in the region are probably too old to contain remains of *Typothorax*. Gregory, unfortunately, has neither described nor figured this material.

Randall County

Numerous vertebrates have been collected from the Tecovas Formation in Palo Dura Canyon, east of Canyon, in northeastern Randall County. Little has been published on this

material (Schaeffer and Gregory 1961, p. 10; Schaeffer 1967, p. 323; Gregory 1972, p. 122), and no references of stagonolepidid remains have been recorded. George E. Turner (Los Angeles) reports finding a number of pectoral spikes of *Desmatosuchus haplocerus* in Palo Dura Canyon (Turner, p.c. 1981).

Borden County
Gregory reported *Desmatosuchus* from a site in Borden County yielding the primitive phytosaurid, *Paleorhinus*. Presumably this is G. Meade's UT Loc. 31213.

Scurry County
A pectoral spike of *Desmatosuchus* has been reported from the Bissett Conglomerate on the north slope of the Glass Mountains (Colbert and Gregory 1957, p. 1466).

Garza County
Recently, several aetosaur specimens have been found in Dockum sediments near Post, by field parties from Texas Tech supervised by Sankar Chatterjee. This material is being studied by Chatterjee and his associates (Chatterjee, p.c. 1982).

STRATIGRAPHIC LEVELS OF STAGONOLEPIDIDAE AT PETRIFIED FOREST NATIONAL PARK AND ELSEWHERE
Armor of *Calyptosuchus wellesi* has only been recovered in the lower unit of the Petrified Forest Member. Scutes occur just above the newspaper sandstone and are common in the mudstones, shales, and siltstones below the rainbow sandstone and Sonsela Sandstone. No *C. wellesi* remains occur higher than 25 feet below the Sonsela Sandstone.

Desmatosuchus haplocerus is also restricted to the lower unit of the Petrified Forest Member. At Jasper Forest, it occurs with *C. wellesi* in mudstones 25 feet below the Sonsela Sandstone. At Crystal Forest, *D. haplocerus* occurs in the log beds of the rainbow sandstone. In Saurian Valley, north of Lithodendron Wash, it is found with *C. wellesi* in mudstones 20 feet below a massive sandstone which Billingsley *(ibid.)* names the brown sandstone.

Paratypothorax sp. is found at Crystal Forest with *D. haplocerus* in the rainbow sandstone. Its exact horizon at Billings Gap is uncertain.

Typothorax coccinarum never occurs with other stagonolepidids. Its lowest occurence is in the top of the Sonsela Sandstone or just above it in the Billings Gap area. It is common in mudstones and siltstones interspersed between flattops sandstones 1 through 3 and in a conglomeratic layer of flattops sandstone 2(?). In the Painted Desert region, scutes of *T. coccinarum* are found just below the black forest sandstone. *T. coccinarum* is the characteristic stagonolepidid of the upper unit of the Petrified Forest Member in the Park.

The stratigraphic distribution of phytosaurids seems to parallel that of the stagonolepidids. Two kinds of phytosaur skulls (*Rutiodon* spp.) are frequently found in the park (Gregory 1957, p. 13); phytosaurs are the most common fossil vertebrates in the Petrified Forest. Four "species" have been named (Camp 1930, Mehl 1928).

In the lower unit of the Petrified Forest Member, a *Rutiodon* occurs, which we label "*Rutiodon* group A" to avoid taxonomic complications. It is characterized by exhibiting deep, unsculptured squamosals, narrow post-orbital-squamosal bars, and large wide supratemporal fenestrae. Camp's *Machaeroprosopus adamanensis* and *M. lithodendrorum* are representative of this "group" (Camp, *ibid.*).

In the upper unit of the Petrified Forest Member and perhaps in the Sonsela Sandstone, another *Rutiodon* occurs, "*Rutiodon* group B". It is characterized by rod-like squamosals that are strongly sculptured externally and exhibit well-defined longitudinal, lateral grooves, wide post-orbital-squamosal bars, and small, slitlike supratemporal fenestrae. *Machaeroprosopus tenuis* (Camp, *ibid.*) and *Pseudopalatus pristinus* (Mehl, *ibid.*) belong here.

Skulls and/or isolated squamosals of "*Rutiodon* group A" have been collected at Blue Mesa, Long Logs, Crystal Forest, Fossil Garden, Saurian Valley, Phytosaur Basin, Blue Mesa NW, Blue Mesa SE, Point of Bluff, and Battleship West, and these are often associated with *Calyptosuchus wellesi* specimens.

Skulls and/or isolated squamosals of "*Rutiodon* group B" have been found at Black Forest, Zuni Well North, Inadvertent Hills, Billings Gap, Ramsey Slide Tank, and the Flattops, and these are commonly associated with *Typothorax coccinarum* specimens.

The aetosaur-phytosaur association can be demonstrated outside of the park. In the St. Johns area of Apache County, *Calyptosuchus, Desmatosuchus,* and "*Rutiodon* group A" (*Machaeroprosopus zunii* Camp = "*Rutiodon* group A") are found together at 4 localities (*Placerias* Quarry, Big Hollow Wash, and Blue Hills). Let us call this the C-D-RA assemblage. At Ward's Bonebed in Coconino County this assemblage is repeated (*Machaeroprosopus gregorii* in Colbert, 1947; *M. lithodendrorum* in Camp and Welles, 1956, p. 257; and possibly *M. validus* Mehl, 1916 = RA). The Dockum beds of Crosby County, Texas, yield the C-D-RA assemblage (*Leptosuchus imperfecta* Case, *L. crosbiensis* Case, and *Phytosaurus doughtyi* Case = RA). This assemblage can be seen in the Rotten Hill area of Potter County, Texas (*Leptosuchus studeri* Case and *Brachysuchus megalodon, im partem* of Case and White 1934, p. 144, = RA). In the Dockum group of Quay County, New Mexico, *Calyptosuchus* and "*Rutiodon* group A" (*Machaeroprosopus gregorii* of Gregory, 1953B, p. 12 = RA) are found together at Revuelto Creek. *Typothorax coccinarum* only occurs in one area outside of Petrified Forest National Park.* In Rio Arriba County, at and near Ghost Ranch, abundant remains of *T. coccinarum* were collected with numerous skulls of "*Rutiodon* group B" (*Rutiodon tenuis* of Lawler, 1979, and perhaps *Belodon buceros* of Cope, 1881). O'Sullivan places these beds, which are exposed above the Poleo Sandstone, in the upper unit of the Petrified Forest Member on lithologic grounds (O'Sullivan 1974). The *Typothorax*-"*Rutiodon* group B" association (T-RB assemblage) seen at Ghost Ranch supports O'Sullivan's conclusions.

Whether "*Rutiodon* groups A and B" represent two true species or clusters of species exhibiting two suites of tem-

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Typothorax or *Typothorax*-like stagonolepidids have been reported from the Pekin Formation of North Carolina (Baird and Patterson 1967); the Stubensandstein of Germany (Gregory 1953A); the Argana Formation of Morocco (Lehman 1971); the Maleri Formation of India (Huene 1940); and the Cacheuta Formation of Argentina (Rusconi 1947). None of these specimens appear to be closely related to *Typothorax* and some are not aetosaurs at all.

poral characteristics cannot be dealt with here. This question is a remarkably complex one and is well beyond the scope of this paper. Regardless of the taxonomic nightmare currently surrounding North American phytosaurs, their cranial characteristics, especially those of the temporal region, are useful as biostratigraphic tools, as has long been recognized (Camp 1930; Colbert 1947; Gregory 1957; etc.). North American stagonolepidids appear to be of equal biostratigraphic importance.

Age of the Stagonolepidid-bearing Sediments of Southwestern North America

Palynomorphs collected at Petrified Forest National Park in sediments below the Sonsela Sandstone have yielded late Carnian (Dunay 1974, Dunay and Fischer 1979) and late Carnian/early Norian (Gottesfeld 1975) ages. Plant megafossils, from the same levels, are considered to be late Carnian age (Ash 1980, Ash, Litwin and Traverse 1982). Ash has recently placed these in his *Dinophyton* floral zone (Ash, *ibid.*). Lower Petrified Forest Member micro- and megafloras compare closely with those occurring in the upper Tecovas and Trujillo Formations and their equivalents in Texas.

Fish are rare in the park, only tooth-plates of *Ceratodus* have been discovered below the Sonsela, but material (Schaeffer 1967) from the upper Chinle Formation (?Church Rock Member) of southeastern Utah and southwestern Colorado (Dolores Formation of authors), and additional fish specimens from the lower Petrified Forest Member (*Placerias* and Downs Quarries) of the St. Johns area (Jacobs and Murry 1980) correspond closely with that of the *Diplurus newarki* Zone (middle to late Carnian) of the lower Newark Supergroup (Olsen, McClure and Thomson 1982).

"*Rutiodon* group A" specimens, found below the Sonsela Sandstone in the Petrified Forest, are similar to phytosaurids (*Nicrosaurus kapffi* and *Belodon plieningeri*) occurring in the lower Stubensandstein ("*Belodon* Beds") of Württemberg, Germany (Gregory 1957, Colbert and Gregory 1957, Gregory 1962, Gregory 1969, Gregory and Westphal 1969). Indeed, these forms may well be congeneric. The probable presence of *Paratypothorax* in both regions strengthens Gregory's conclusions (Gregory 1957) that the lower Petrified Forest Member and lower Stubensandstein were approximately coeval. Therefore, tetrapod evidence suggests a slightly younger age (Norian) for the lower Petrified Forest Member than that of plants and fish. When one considers all of the evidence at hand, a late Carnian/early Norian age is suggested for the lower unit of the Petrified Forest Member and *Rutiodon*-bearing strata of the Dockum Group in Texas.

Higher levels at Petrified Forest National Park produce fossils of "*Rutiodon* group B" and *Typothorax* which are not known with certainty to occur outside of Arizona and New Mexico or in sediments other than those of the upper Petrified Forest Member and Sonsela Sandstone of the Chinle Formation. However, two upper-Dockum phytosaur skulls, perhaps representing "*Rutiodon* group B", have been found at Sloan Creek in Union County, New Mexico (Stovall and Savage 1939, p. 759-766) and in Apache Canyon in Quay County, New Mexico (Gregory 1957, p. 12; Colbert and Gregory 1957, p. 1464; Gregory 1972, p. 123). Another skull (MNA Pl. 2524), recently collected from the

Owl Rock Member of the Chinle Formation, near Moenave in Coconino County, Arizona, may also belong here. In at least the Apache Canyon specimen, the supratemporal fenestrae have undergone complete dorsal closure.

The stratigraphic position of the upper unit of the Petrified Forest Member, and the advanced nature of its phytosaurs and aetosaurs, is indicative of a probable Norian age although a more precise correlation is not possible at this time. Unfortunately, plant fossils from the upper unit are poorly known (Gottesfeld 1975; Ash 1980) and Chinle fish genera appear to have relatively wide stratigraphic ranges (Schaefer 1967).

SUMMARY

Four large (3 to 5 meters long), monotypic stagonolepidid genera are present in *Rutiodon*-bearing rocks of the Chinle Formation and the Dockum Group (late Carnian/Norian) of southwestern North America. Three genera (*Desmatosuchus, Typothorax,* and *Calyptosuchus*) are known from nearly their entire skeletons, while the fourth *(Paratypothorax)* is represented only by its integument. The former 3 genera are only known from the American Southwest. *Paratypothorax* is also present in Europe. All these reptiles are found at Petrified Forest National Park.

Calyptosuchus wellesi has a narrow carapace. Lateral horns are present on its neck, but are lacking on the body. Its scutes exhibit well-defined radiate ornamentation and bear large eminences in the posterior dorsal and caudal region. It is restricted to the lower Petrified Forest Member of the Chinle Formation at Petrified Forest National Park and only occurs in the "*Rutiodon* group A" -bearing sediments outside the Park in Arizona, Texas, and New Mexico. It is the most common, lower unit aetosaur in the Petrified Forest.

Desmatosuchus haplocerus is a massive, narrow-bodied form. It exhibits the greatest degree of spinescence among *Rutiodon*-level stagonolepidids, and possesses remarkably enlarged pectoral horns. All of its presacral, lateral scutes bear spines or knobs. Its cervical paramedian scutes are long and heavy. Scutal ornamentation is random. This reptile is restricted to the lower Petrified Forest Member at Petrified Forest National Park and is found only in "*Rutiodon* group A"-bearing rocks in other parts of northeastern Arizona and in Texas. While it is common in some regions, it is rare in the park.

Typothorax coccinarum has a flat, disk-shaped carapace. It lacks lateral body horns, although they are present on its neck. Its immense presacral, paramedian scutes are randomly pitted and lack large eminences. This aetosaur is restricted to the upper Petrified Forest Member and perhaps occurs in the uppermost Sonsela Sandstone at the Petrified Forest. It is the most common vertebrate in the upper unit of the park, where it occurs with advanced rutiodonts ("*Rutiodon* group B"). Outside of the park, it is found only with advanced rutiodonts. It is known from northeastern Arizona and northcentral New Mexico. "*Typothorax*" *meadei* is not congeneric with *T. coccinarum*.

Paratypothorax sp. has a discoidal carapace similar to that of *Typothorax*. However, the paramedian scutes of the former differ in their ornamentation which consists of radiating grooves and ridges. The posterior dorsal and caudal paramedian scutes bear large, falcate eminences. The
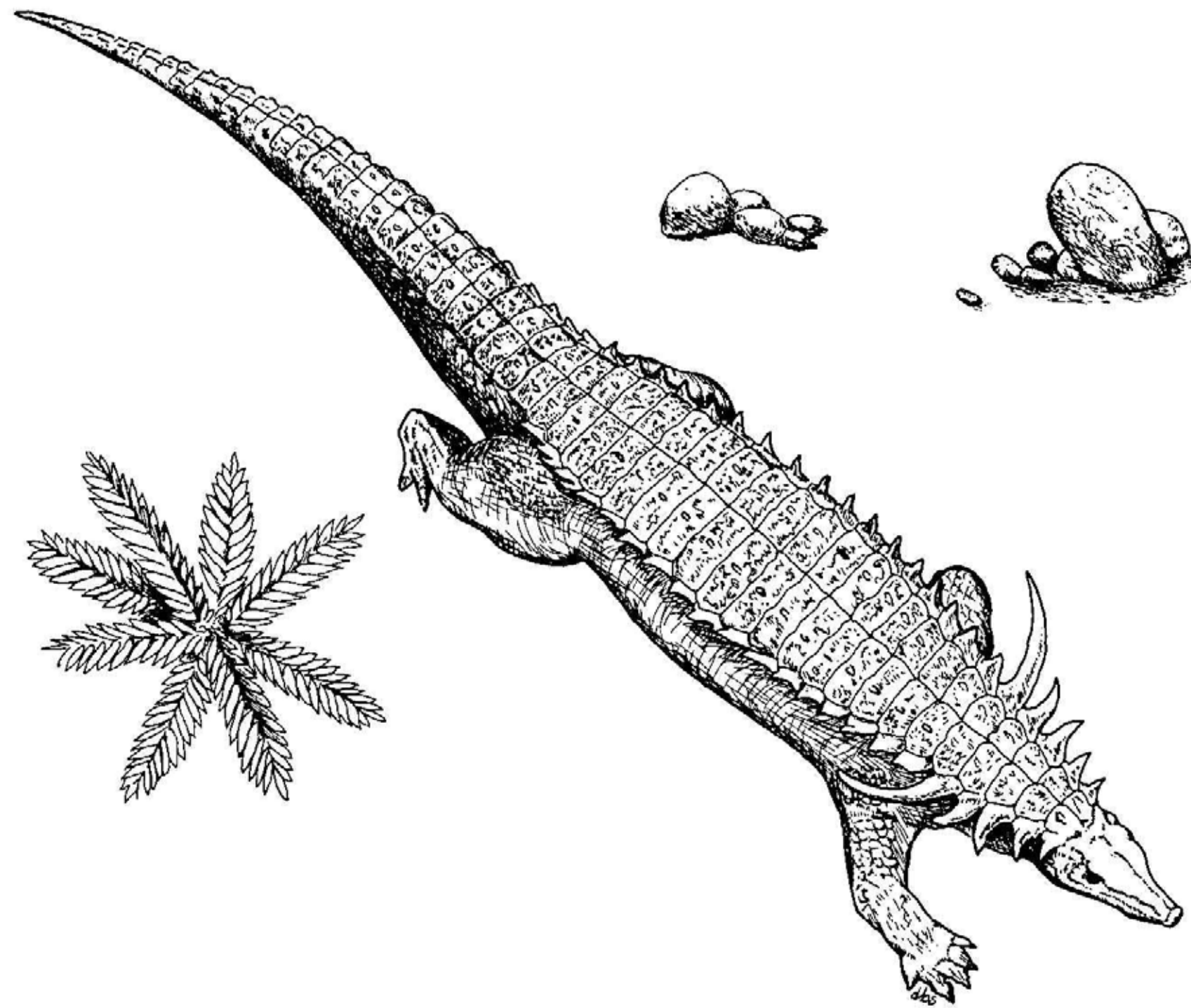
Figure 18. Reconstruction of *Desmatosuchus haploceras* as drawn by R. McCrea under the direction of Robert A. Long. (Redrawn by Dolber B. Spalding)

lateral body scutes are cornuate. This stagonolepidid is possibly restricted to the lower unit of the Petrified Forest Member at Petrified Forest National Park, and only occurs in "*Rutiodon* group A"-producing levels in Texas. The American form appears to be closely related to *Paratypothorax andressi* of the Stubensandstein of Heslach, Germany, which has often been confused with the phytosaurid, *Nicrosaurus kapffi* in the past.

POSTSCRIPT
Since this manuscript was submitted, much new stagonolepidid material has been collected from Petrified Forest National Park during the summer field seasons of 1983 and 1984. A description of this material will be presented elsewhere.

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A Synthesis of
Petrified Forest National Park
Rock Art and Ceramics

by R. J. Martynec

ABSTRACT
The PEFO region is recognized by archaeologists as a contact zone for the Anasazi and Mogollon cultures in late prehistoric times. Analysis of intrusive ceramic types indicate that a complex series of trade networks were operational within the park and that these economic systems changed through time. Chronological assessment, stylistic definition and comparison of the PEFO rock art styles permits regional assignment of this material to previously defined traditions. Where data are available, comparable results are obtained from both the rock art and ceramic analyses. Although preliminary, these results provide intriguing hints regarding the prehistoric interaction sphere operating in the four-corners region.

INTRODUCTION
Petrified Forest National Park (PEFO) is known best for its vast array of geological resources. The park is also famous for its significant cultural resource—rock art. The excellent workability of the local Moenkopi sandstone permitted the prehistoric experimentation, both stylistically and technologically, that resulted in some of the most unusual petroglyphs in the Southwest. The stark visual contrast between the unworked, heavily patinated sandstone and the almost white interior of the freshly pecked rock makes this art form all the more impressive.

Numerous sites displaying other forms of prehistoric cultural material are also located throughout the park. These vary in size from small, single family dwellings, such as pithouses, to huge, contiguous roomed complexes like the partially reconstructed Puerco Ruin (AZ Q:1:22). Data accumulated from reconnaissance surveys conducted within the park account for no less than 364 separate sites. Other than the pioneering efforts of Stewarts Overview (1980), this wealth of archaeological data has received only perfunctory examination.

The archaeology of the PEFO region is decidedly complex for the late prehistoric period—from the time of Christ until pueblo abandonment in the thirteenth century. This region has long been recognized by southwestern archaeologists as a contact zone for at least two major cultural entities, the Anasazi and the Mogollon (Fig. 1). The resultant heterogeneous mixture of cultural data acquired from the archaeological record has proved difficult to analyze. However, because PEFO is located in a contact zone it does offer archaeologists the opportunity to address the intriguing issue of temporal variation in cultural influence. It is not uncommon for PEFO sites to display artifact assemblages that reflect both temporal and spatial differences in

traits which characteristically belong to either the Anasazi or the Mogollon.

Previous studies have demonstrated that although prehistoric social interaction is difficult to discern in the archaeological record, it is not impossible (Haury 1958; Meggers and Evans 1958; Newman 1958). Specific patterns of social interaction that might be indicative of the processes of acculturation and adaptation, though of tremendous interest, are currently beyond the scope of this analysis. The purpose of this paper is to discuss several aspects of the archaeological record at PEFO to which additional research could be added. The focus of this analysis is on ceramics and rock art at PEFO.
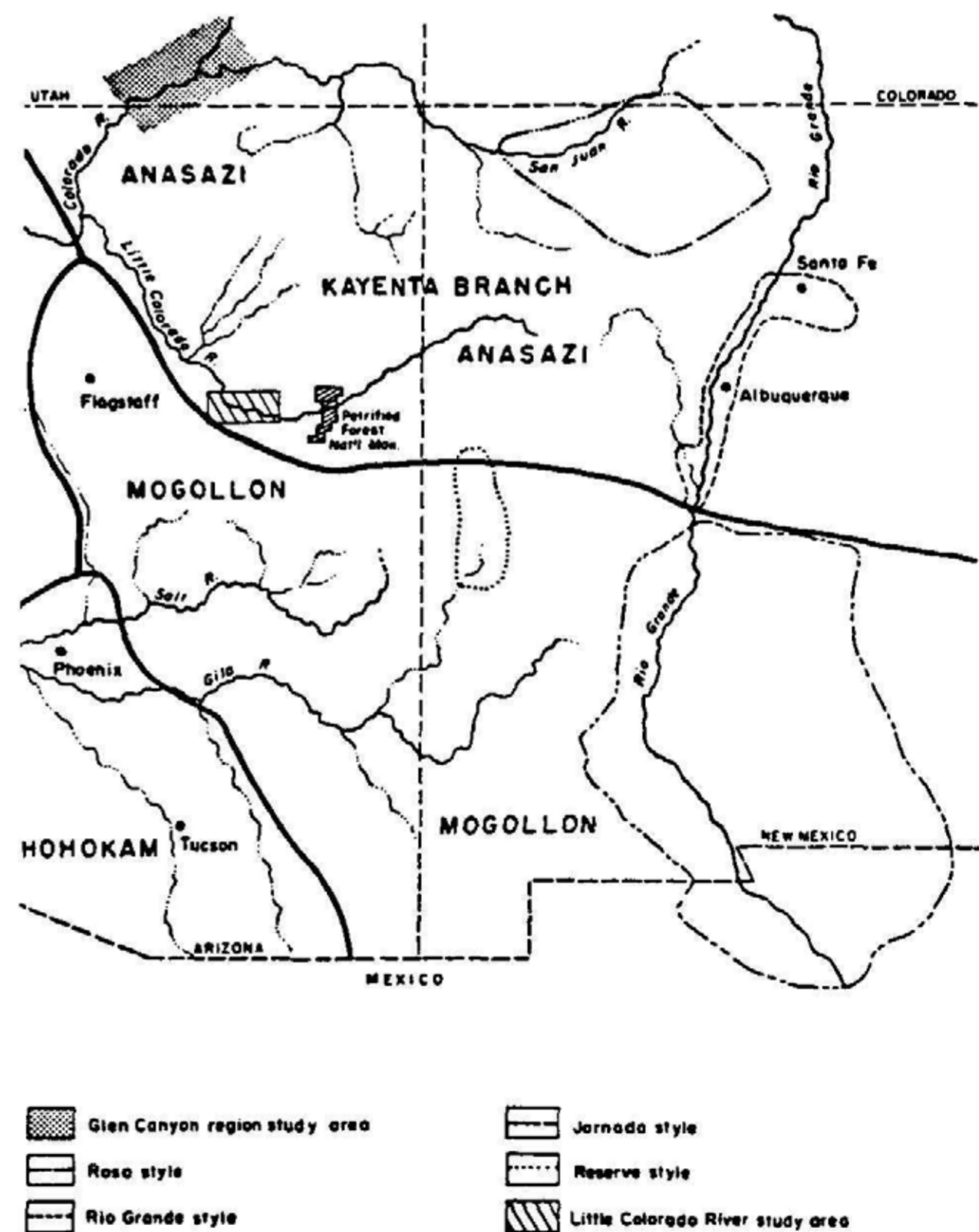

Figure 1. Cultural boundaries and rock art study areas

CERAMICS

The methodological approach to analysis of PEFO ceramic material was to identify the pottery types found at PEFO sites and then to identify which of these types were indigenous and which were manufactured outside the park. In 1947 Erik Reed, a Park Service Archaeologist, compiled an index of pottery types represented at PEFO by personally conducting extensive surveys and by reviewing previous researchers' site reports. Examination of Reed's "type list", from a current perspective, resulted in only minor revisions.

As expected, the pottery types discovered in this Anasazi-- Mogollon contact area are numerous and difficult to separate. The descriptions advanced in the literature are often ambiguous and conflicting. Examples of ambiguities are as follows:

1. Puerco Black-on-White is the same as Chambers and Gallup Black-on-White according to Reed (1947).
2. Wingate Black-on-White is the same as Gallup Black-on-White according to Gladwin (1945) and is the same as Reserve Black-on-White according to Breternitz (1966).
3. Klageto Black-on-White is the same as Pinedale Black-on-White according to Reed (1947) and may not even be a type according to Breternitz (1966).

Establishing typological validity was decidedly not the intent of the study. It was, therefore, determined that all types listed in the literature would be retained and the problematic types identified.

The methodology utilized to seriate pottery types was to establish a date range and then verify its validity with a comparative analysis of data from site reports for PEFO and adjacent areas. With a majority of the types listed, it became evident which date ranges were accurate.

To obtain a temporal perspective regarding change in ceramic cultural affiliation at PEFO, it was necessary to review PEFO site reports and attempt to quantify the data. Data comparability proved to be the single largest obstacle. In many instances (especially survey reports), only qualitative information is provided. Further, there are numerous cases where cultural differences, as seen from ceramic types, appeared to be spatial rather than temporal, i.e., prior to Pueblo III, contemporaneous Anasazi and Mogollon sites can be found within the park. In spite of these limitations, specific temporal trends in cultural influence were identified from intrusive ceramic types. The results are presented in Table 1.

For a more detailed presentation of this analysis the reader is referred to Martynec (n.d.).

ROCK ART

Analysis of how stylistic and technological changes in rock art might be indicative of temporal changes in the sphere of cultural influence necessitates a two-step approach. The first, of course, is to gain temporal control of the petroglyph design elements, i.e., to establish a chronology. The second step involves a comparison of PEFO rock art with that from surrounding areas.

The fieldwork, conducted in 1981, resulted in the recording of eleven rock art sites, with over two thousand design elements. Because it was necessary to examine intrasite, as well as intersite, variability for the relative chronometric placement of design elements, all sites were subjected to 100 percent survey.

Dating of rock art cannot be accomplished by any single dating technique currently available to archaeologists. Instead, rock art studies have had to rely on several sources of data, such as comparison of design elements with ceramics and kiva murals, patina, superimposition, comparison of petroglyph and site frequencies, and association with datable ceramic sites. Because of the reliance on these sources, rock art chronologies have been regarded with skepticism by many in the archaeological community. Considering the magnitude of currently available data and the remarkable concurrence of results from these studies, skepticism is unwarrranted.

An initial typology, or relative chronology, was defined by assigning petroglyphs to one of five classes based on the degree of patina reformation. A further subdivision of design elements, in terms of stylistic and technological at-

Table 1. Cultural affiliation of ceramic types at Petrified Forest National Park sites.

Period	Date	Number of sites	Cultural Affiliation	Discussion
Adamana Horizon	pre A. D. 500	13	Adamana	No intrusive ceramics, therefore no assignable cultural affiliation.
Adamana Horizon	A D. 500-700	2	Adamana and Mogollon	Inclusion of Woodruff Brown indicates southern influence—specific origin of this type cannot be isolated.
Lino-Woodruff Period	A. D. 650-850	46	Anasazi with some Mogollon	More Lino Gray than Woodruff Brown sites—specific origin cannot be isolated.
Pueblo I	A. D. 800-1000	14	Anasazi	Lino White, an imitation of Lino Gray at Petrified Forest, is predominant— specific origin cannot be isolated.
Holbrook Period	A. D. 950-1150	54	Anasazi with a little Mogollon	Most pottery was of local origin, i.e., Holbrook and Puerco B/W, main external influence was from the north and northeast, i.e., the people who made Chambers and Gallup B/W. Secondary influence was from the northwest (Jeddito Area) and the south (Forestdale and Showlow Areas).
Walnut Horizon	A. D. 1100-1200	33	Anasazi	Local types. Primary influence was from the northwest (Jeddito Area). Secondary influence was from the south (Kinishba and Showlow Areas).
Tularosa-St. Johns Horizon	A. D. 1200-1300	11	Mogollon with a little Anasazi	Influence is predominantly from the south (Pinedale and St. Johns Area). There is some secondary Anasazi influence from the immediate north and east of PEFO in the form of Wingate B/Red.
Homolovi Focus	1300's	2	Anasazi	Primary influence is from the Jeddito Area.

tributes, resulted in the identification of rock art traditions, which are diagnostic of specific patina classes or time periods. Statistical testing demonstrated that similarities between contemporaneous design elements and manufacturing techniques are unlikely to have resulted from chance. The results of this analysis are conclusive: specific design elements and manufacturing techniques were used in different prehistoric time periods. For a more detailed report of this rock art analysis the reader is referred to Martynec (1982).

The following stylistic and technological attributes of PEFO rock art are temporally diagnostic:

Basketmaker Period   0 (?)–A.D. 650

    Curvilinear and rectilinear design elements, especially counterclockwise spirals (measured from the center out) manufactured by direct percussion with a sharpened hammerstone.

    Anthropomorphs with small heads, long horns, and rectangular bodies containing horizontal lines. (Figure 2)

    Very few zoomorphic representations.

Early Pueblo Period   A.D. 650–1000

    Snakes, lizards, and lizard men manufactured by both direct and indirect percussion with a sharpened hammerstone.

    Mask/Kachina tradition manufactured by direct percussion with a sharpened hammerstone. (Figure 3)

    Very few curvilinear and rectilinear type design elements.

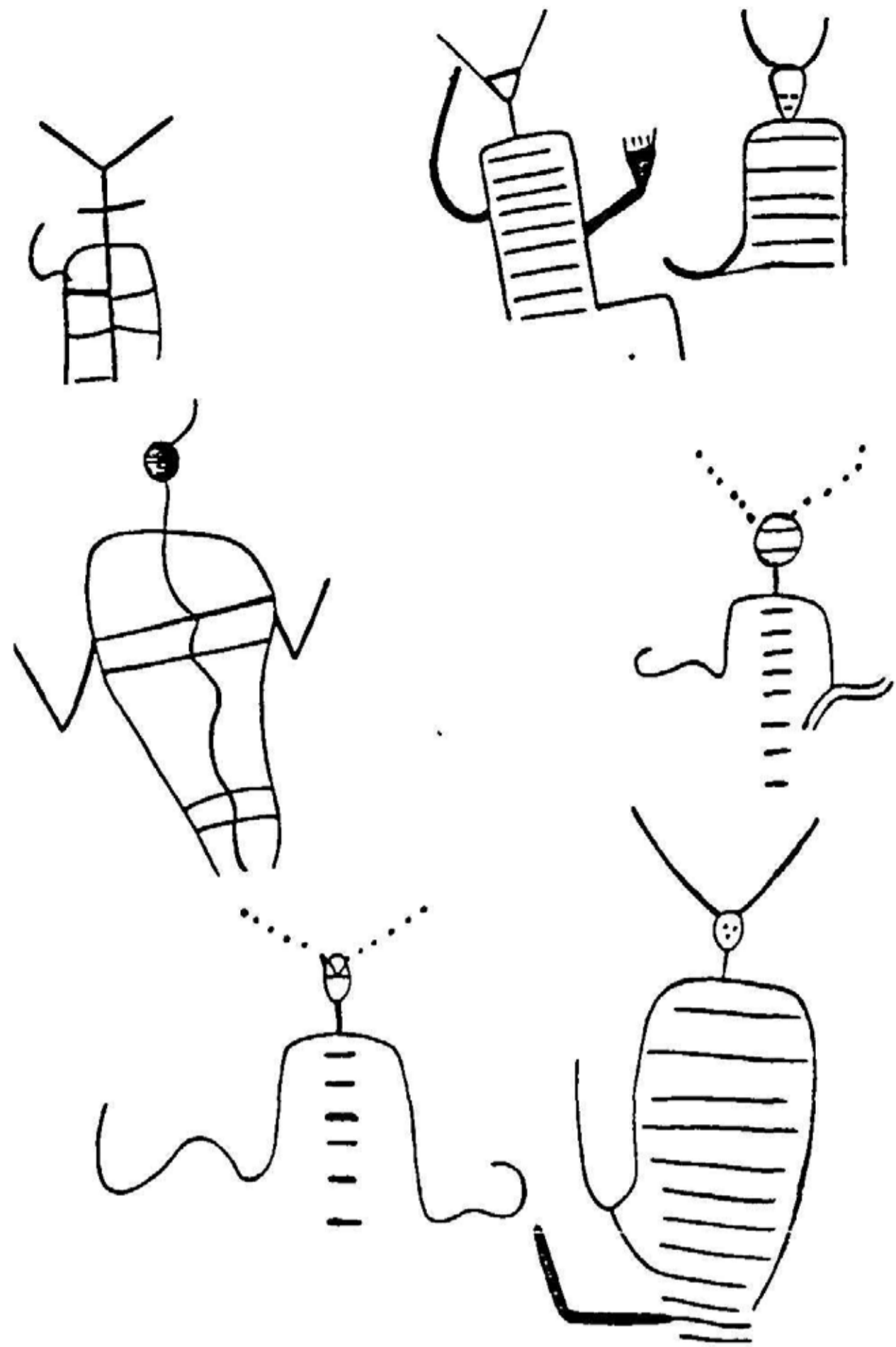   Animal tracks, singly and series, absent.

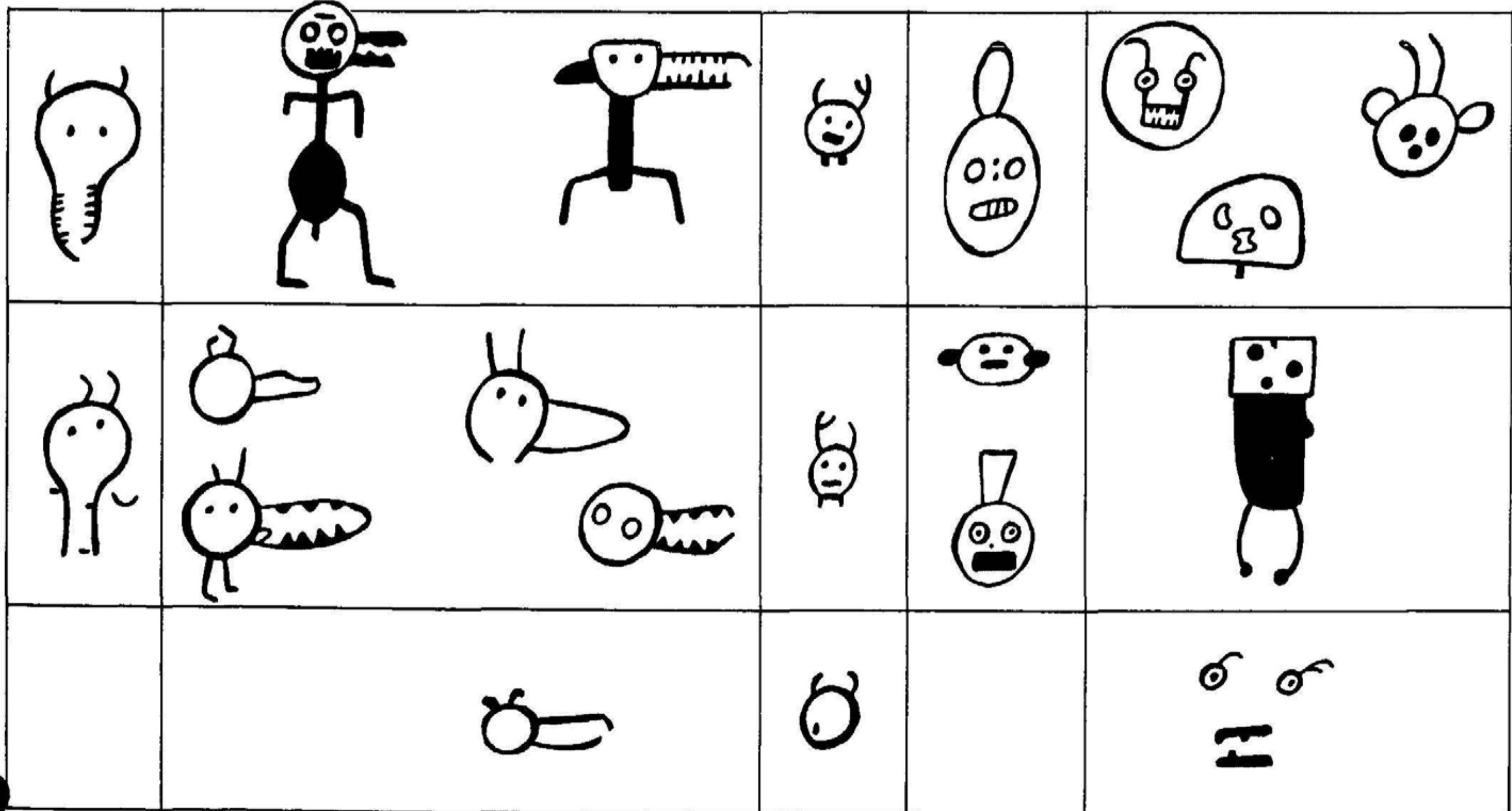Figure 2. Basketmaker Period petroglyphs at site AZ Q:1:67

Figure 3. Mask/Kachina traditions at site AZ K:13:38

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Middle Pueblo Period   A.D. 1000-1300

Anthropomorphs manufactured by direct percussion with a blunt hammerstone.

Zoomorphs and rectilinear design elements with blanket-type designs manufactured by direct percussion with a blunt hammerstone.

Variability in cultural material, that is, headdresses, flutes, bows, staffs, and ear bobs. (Figures 4 and 5)

Animated anthropomorphic and zoomorphic figures, but limited attention and carelessness with respect to detail.

Anthropomorphs with extremely large hands and feet, often depicted with genitals and possible birthing scenes. (Figure 6)

Largest number of bird and insect representations.

Multiple design element scenes. (Figures 7-9)

Techniques of grinding and incising commence. (Figure 10)

Negativism. (Figure 10)

Late Pueblo Period   A.D. 1300-1400

Curvilinear design elements manufactured by indirect percussion with a sharpened hammerstone.

Anthropomorphs with extremely large hands and feet, but without genitals.

Hunting-related subject matter (sheep and bow-and-arrow scenes).

Weak attempt to continue animation and extreme carelessness with respect to anthropomorph and zoomorph detail.

No lizards, lizard men, or birds.

Modern

Christian themes.

Vandalism.

Rock Art Styles

The past two decades have witnessed a steady increase in rock art analyses. Anasazi rock art material from the Glen Canyon (Turner 1963), Canyon de Chelly (Grant 1978), and Winslow (Pilles 1975) regions (Figure 1) are well documented. Polly Schaafsma's research in New Mexico (1972, 1980) has resulted in the definition of several Anasazi and Mogollon petroglyph styles, including the Kayenta, Reserve, Rosa, and Jornada. All of the aforementioned analyses provide data that are comparable with that from PEFO.

Table 2 identifies which rock art study areas bear stylistic and technological similarities with PEFO. An abbreviated summary of the ceramic analysis is also included for comparison.

RESULTS

Where data are available, comparable results are obtained from both the rock art and ceramic analyses. There was, however, a specific problem involving data interpretation of early material that is noteworthy. The identifiable Basketmaker rock art and ceramic traditions in the four-corners region are remarkably similar in many respects, and are therefore difficult to assign to a particular cultural entity. It is difficult to discern which concepts regarding either medium were transmitted throughout the region. Because of the developmental sequence and differences in production techniques, the early Basketmaker ceramic and rock art traditions at PEFO appear to be *in situ* developments—

Figure 4. Cultural material

Figure 5. Flute player petroglyph
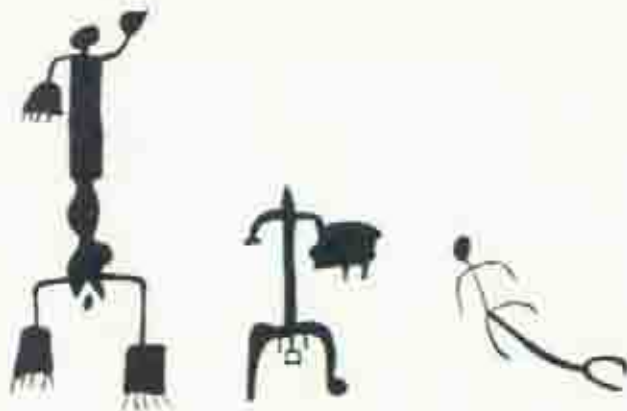
Figure 6. Possible birthing scenes at site AZ Q:1:21

Figure 7. Hunting scene petroglyph

Figure 8. Hunting scene petroglyph

Figure 9. Hunting scene petroglyph

Figure 10. Grinding and negativism

Table 2. Comparison of ceramic and rock art intrusives at Petrified Forest National Park (PEFO).

A. D. date	Areas with rock art similar to that at PEFO	Influence based on intrusive ceramics
0–500	Canyon de Chelly, Winslow, Glen Canyon	Local types only
500–650	Canyon de Chelly, Winslow, Glen Canyon	Mogollon influence
650–850	Canyon de Chelly, Winslow, Glen Canyon	Anasazi and Mogollon
850–1000	Winslow, Glen Canyon	Anasazi
1000–1150	Winslow, Glen Canyon	Western Anasazi
1100–1200	Winslow, Glen Canyon	Eastern Anasazi
1200–1300	Winslow, Glen Canyon, Jornada	Mogollon-Pinedale and St. John
1300–1400	Winslow, Glen Canyon	Anasazi-Jeddito

and yet, design element similarities manifest an undeniable link in ideology with other areas. Since definition of culturally assignable typologies for the Basketmaker II time period has proved problematic for archaeologists interested in the Western Pueblo region, regardless of the nature of their studies, and since ceramic analyses seem to have decreased in their potential for archaeological utility, future studies at PEFO should focus on dating the early petroglyphs. Separation of Basketmaker II and III petroglyphs at PEFO might be accomplished by application of the analytical techniques employed in Martynec (1982) to very early, single component, PEFO rock art sites. It is the author's opinion that absolute temporal resolution of the earliest PEFO petroglyphs, as well as all others in the Southwest, will come about by using techniques developed exclusively to date rock art. Two dating techniques have been recently developed. Bard, Asano, and Heizer (1978) have attempted to calibrate trace element buildup in desert varnish, using neutron activation measurements. Howes (1980:11) has also attempted to measure trace element buildup by X-ray fluorescence analysis. In both analyses, the time calibration of trace element variation is estimated by comparing prehistoric values with those from dates recorded by early travelers. Developmental calibration and testing could be accomplished by establishing a data base by "dating" present-day petroglyphs. Although the preliminary results of these tests are inconclusive, the analytical approach is sound and will, with continued development, provide an effective dating technique.

One result of the rock art analysis is the unexpected discovery of a lack of identifiable Mogollon-style petroglyphs from Pueblo times. Since other archaeological evidence (ceramics) at PEFO would indicate that the area was an Anasazi/Mogollon contact zone, this is indeed surprising. Studies have produced conflicting opinions regarding the degree of temporal changes in cultural influence in this region (Reed 1947; Schaafsma 1980). It was the consensus, nevertheless, that both cultures were present and that influence did change through time. For this reason, it was assumed that PEFO rock art would, at least in part, be separable into the basic stylistic and technological typologies established for the Anasazi and Mogollon in previous rock art studies (Turner 1963; Grant 1978; Schaafsma 1972; Pilles 1975). There is only one Pueblo III component at a small site (AZ K:13:39) that can be identified with Jornada Mogollon—a distant cultural branch centered far to the south and east of PEFO. There were no PEFO petroglyphs that could be assigned to any of the recorded styles for any of the local Mogollon branches. All of the remaining petroglyphs that display identifiable stylistic and technological features are comparable to those of the Glen Canyon Region (Turner 1963) and the Little Colorado River Region (Pilles 1975). The lack of local Mogollon-style petroglyphs may be more apparent than real. Unfortunately, several of the areas that might have offered the greatest insight with respect to PEFO rock art have not been studied. The ceramic analysis would indicate the need to review Mogollon rock art material from the areas immediately to the south and east of the park and Anasazi material from the Hopi Mesa area.

In spite of the gaps in the data base, the ceramic and rock art analyses produced comparable results regarding the change in cultural influence through time at PEFO (Table 2). Extensive changes in patterns of economic and ideological exchange are clearly indicated. Although preliminary, these results provide intriguing hints regarding the prehistoric interaction sphere in the four-corners region.

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Salt Cedar Study in the Petrified Forest

by George E. Johnson

ABSTRACT

A study was made at Petrified Forest National Park to determine which of two methods of eradication would show best results in the elimination of salt cedar from small isolated dry washes.

The two methods tested and compared were (1) excavation of the whole plant, as opposed to (2) treatment of the freshly cut stems with the herbicides Garlon 3A and Garlon 4.

The test results showed both were equally effective but not efficient enough to warrant further consideration.

BACKGROUND

Salt Cedar or Tamarisk *(Tamarix pentandra)* has become densely established along the Puerco River and sparsely established along minor drainages within Petrified Forest National Park. The merits of salt cedar have been lauded and the demerits decried since its introduction and need no discussion here, but the problem involved is based on the fact that salt cedar is an exotic plant that some feel should be eradicated. Here again, the subject is open to controversy.

In the past, Park Service policy decreed that exotic plants and animals should be removed, but in 1975 after numerous public hearings regarding the elimination of feral burros from the Grand Canyon National Park, park management policies were revised to state:

Control or eradication of exotic plant and animal species will be undertaken when they are undesirable in terms of public health, recreational use and enjoyment, or when their presence threaten the faithful presentation of the historic scene or the perpetuation of sigificant scientific features, ecological communities and native species.

Here again, there are points to ponder.

During 1968 and 1969 attempts were made to eradicate salt cedar from the Lithodendron drainage in the Painted Desert by the application of 2,4,5T and 2,4D. Subsequent studies showed negligible results, and further attempts were dropped for several years (Johnson 1970).

In 1975, the National Park Service entered into a contract with the Office of Arid Lands Studies, University of Arizona, to do a vegetative study on Petrified Forest. Part of the program involved management recommendations developed during an environmental workshop held May 6, 1977, at the University of Arizona and attended by specialists in the fields of land management. After lengthy discussion, three alternatives were offered: (1) a simple passive approach of waiting for better technology, (2) an active policy of eradication, and (3) a research phase followed by either

an active or passive policy. Petrified Forest has endorsed the third approach, which is discussed in this paper.

OBJECTIVE

The primary objective is to put into action a research project listed in the Natural Resources Management Plan of Petrified Forest National Park as Salt Cedar Study (PEFO-N-2).

Results Expected

This study is expected to produce knowledge as to the efficacy of two different methods of eradicating salt cedar.

Selection of Test Areas

During September 1978, two study plots were selected in areas precluding reinfestation from outside sources after treatment with the methods of eradication being tested. The two sites were dry washes as nearly identical as possible in length, width, and degree of infestation.

The area selected for Test #1 (West Branch of Jim Camp Wash) is a tributary draining the E ½ of Section 2, T 16 N, R 23 E. The actual area involved that part of the wash south from the bridge on West Old U. S. 180 to its confluence with Jim Camp Wash in Section 11, same Township and Range.

The area selected for Test #2 (North Jim Camp Wash) is the upper end of Jim Camp Wash from its source in the N ½ of Section 31, T 17 N, R 23 E, and extending southwestward across the SE corner of Section 36, T 17 N, R 23 E, into Section 1, T 16 N, R 23 E, as far as the Jim Camp Bridge on the main park road.

Findings

A survey and census of the plot for Test #1 ascertained that there were approximately twenty-five large clumps of salt cedar and a few smaller ones. By "large" is meant clumps with root crowns three to six feet in diameter. The infestation was mapped as to size and location.

A survey and census of plot for Test #2 ascertained that there were twenty-four large and approximately the same number of small clumps of salt cedar. The infestation at this plot was also mapped as to size and its location.

METHODS TO BE USED

The method to be used at Test Plot #1 involved physically removing as much of the plants as possible with a backhoe and handtools. The excavated debris was to be taken from the site to prevent any reinfestation by the sprouting root

fragments that might be left after the removal operation.

The method to be used at Test Plot #2 involved cutting the plants off at ground level and then painting the exposed severed stems with 2,4,5T.

Procedures

On March 2, 1979, a pesticide application proposal was forwarded to the Western Regional Office of National Park Service, requesting approval for the purchase and use of 2,4,5T (SILVEX). A local source of the pesticide was also located. Within a few days word was received from the source that the sale of SILVEX was prohibited. A few days later word was received from NPS that the request had been disapproved. This terminated plans for the eradication of salt cedar at Test Plot #2 by the use of any available herbicide.

On March 12, 1979, plans went ahead despite the setback, and a crew of four men with the aid of a backhoe and handtools excavated the salt cedar plants from the area planned for Test #1. Following the excavation, several days were spent hauling the debris from the plant sites. After a lapse of several months, periodic inspections of the test area were made to note any signs of regrowth or recovery since the excavation. Observations were as follows:

June 7, 1979 —No visible sprouts were observed.

May 29, 1980 —10 to 12 wand sprouts noted.

October 1, 1980 —13 medium-sized shoots were visible.

September 2, 1981—One year following removal the shoots appeared to be springing from six old root systems and from sources adjacent to them.

October 15, 1981 —Of the shoots found growing at the above six sites, three appeared to be springing from roots having no visible plants on the date of excavation.

August 20, 1982 —Thirteen healthy plants were observed at Test Plot #1. Approximately half appeared to be springing from the old root crowns while half appeared to be growing from trailing roots which may have been inadvertently left at the time of excavation.

SUMMARY

Number of plants excavated at Test Plot #1 28
Number of plants dead as of August 20, 1982 15
Kill efficiency by excavation 54%

Background on Test #2

Following the ban on the use of the herbicide 2,4,5T (SILVEX), other alternatives were being explored in order to complete the step involving eradication of salt cedar at Test Plot #2. On October 1, 1980, word was received from the Western Regional Office that there might be a chance of acquiring a newly developed herbicide being tested by University of Utah staff.

Shortly thereafter, the park staff was able to enlist the assistance of Dr. Clyde Hurst, CPSU Unit Leader, at the University of Utah in the acquisition and use of the herbicides GARLON 3A and GARLON 4 for test Plot #2. Dr. Hurst arrived at Petrified Forest on October 27, and plans were made to complete the third step of the Salt Cedar Study.

Procedure at Test Plot #2

On October 28, 1980, a crew of YACC youths removed the above-ground salt cedar bushes at fifteen sites on Upper Jim Camp Wash. Handtools were used such as axes, brushhooks, and even bolt cutters. None of these tools performed well on this species of brush because of the hardness, toughness, and density of stem clusters.

Dr. Hurst and Resource Management Specialist Johnson applied the herbicide, alternating between GARLON 3A and GARLON 4, in a random pattern. Occasionally, a plant was left untreated although it was cut off. These were marked as controls. The application of the herbicide GARLON 3A was made by spray bottles or paintbrush, undiluted, to each cut stem selected for that agent. The application of GARLON 4 in a fifty-fifty mixture with diesel oil was made in the same manner.

Each plant or clump of plants in the immediate vicinity was included and identified as a separate site. Stakes were planted for temporary identification of site and type of treatment. Upon completion of the treatment, permanent markers were set, and a map of the sites with a legend of the agents used was prepared.

This concluded the third step of the Salt Cedar Study (PEFO-N-2).

Follow-up on Test #2

The February 1981 revision of the park's management program called for an evaluation of the project by a contract researcher in Fiscal Year 1983, as the fourth and final step of the project. Because of budget limitations, it was proposed that the park's on-site Resource Management Specialist evaluate and thereby complete the project. Thus, in August of 1982, a final evaluation was made of Test #2, and a report submitted.

Findings at Test Plot #2

Number of plants cut but left untreated as controls 13
Number of control plants dead as of 8/22/82 3
Rate of kill by cutting only 23%

Number of plants cut and treated with GARLON 3A 17
Number of GARLON 3A-treated plants dead as of 8/22/82 13
Rate of kill by GARLON 3A 76%

Number of plants cut and treated with GARLON 4 . . 19
Number of GARLON 4-treated plants dead as of 8/22/82 15
Rate of kill by GARLON 4 . . . . 79%

Combined number of herbicide-treated plants 36
Combined number of herbicide-killed plants 28
Average rate of kill of both GARLON 3A and 4 . . 77%

CONCLUSIONS

Since twenty-three percent of the plants that were cut at ground level were killed, as compared to fifty-four percent that were killed by excavation, it is evident that the latter method is better although still not efficient enough to warrant its use in control of salt cedar.

Also, since seventy-seven percent of the plants treated with the herbicide GARLON were killed, as compared to fifty-four percent killed by excavation, it may appear that the herbicide GARLON is a more efficient means of eradication than is excavation; but since the use of GARLON requires that the plants *first be cut before applying the herb-* *icide,* and it was earlier shown that twenty-three percent of the plants cut and left untreated had been killed *without the aid of herbicides,* it presents the possiblity that GARLON alone was fifty-four percent efficient, or as effective as excavation alone. The forty-six percent of the salt cedar that survived both treatments would necessitate a continuing program of eradication.

Therefore, it is proposed that further attempts to eradicate salt cedar in small dry washes within Petrified Forest National Park be discontinued until such time as better methods are available.

Visibility and Air Quality
at the Petrified Forest National Park

by Edwin M. Roberts

ABSTRACT

Visibility at the Petrified Forest National Park is typically quite good, but it is highly variable. Data collected photographically in five studies between 1973 and 1982 show that visual range nominally is 70 miles and varies between 15 miles and 150 miles. Visual range fluctuates in the mean from year to year and season to season, but no long-term trend is evident from the data. Visibility is typically lowest in the morning and highest in the afternoon. Air quality is also good. Sulfur dioxide and nitrogen dioxide concentrations in the air are always low, being present at no more than a few percent (less than 10%) of the standards that protect human health and welfare. Suspended particulate matter can be high on occasion, depending on the wind speed and soil conditions in the region. High winds are invariably associated with high concentrations of suspended particulate matter.

PROLOGUE

The physical and climatic features of the Painted Desert are peculiar and striking, and result in the production of an environment hostile to diurnal forms of animal life and to the person who traverses it. The explorer is impressed with the unusual aspects of nature—the strange forms of the hills, and the long ranges of red and yellow cliffs, the curiously buttressed and turreted buttes and mesas, the fantastic shapes of the rocks carved by the sandblast and rendered still more weird by the hazy atmosphere and steady glare of the southern sun, the sandwhirls moving swiftly across the desert, the extraordinary combination of colors exposed by erosion, the broad clayey flats whitened by patches of alkali and bare vegetation, the abundance of fossil-wood, the extensive beds of shining pebbles, the unnatural appearance of the distant mountains sharply outlined against the yellow sky, the vast stretches of burning sand, the total absence of trees, the scarcity of water, the alluring mirage, the dearth of animal life, and the intense heat from which there is no escape.

— *C. Hart Merriam*
North American Fauna #3 (1890)

INTRODUCTION

The passage quoted above is an observation made by a well known natural scientist who explored the general area known as the Painted Desert in the late nineteenth century. It is interesting in the present context because it records the existence of hazy conditions in the area when the activities of man were significantly less than they are now. We do not have quantitative measures of haze in the late nineteenth century, but we may assume that the haze was due primarily to natural causes. It is important to remember, with present-day concern over visibility degradation, that natural as well as anthropogenic factors are responsible for changes in visibility.

Arizona Public Service Company (APS) has operated the Cholla Generating Station since 1962. Originally the station consisted of a single generating unit of 115 megawatt capacity. In or about 1970, APS foresaw the need for an additional 500 megawatts in their system. Two more units of 250 megawatts each were planned—Unit 2 to become operational in June 1978 and Unit 3 to become operational in May of 1980.

Before the station could be expanded, however, Arizona State law required APS to obtain a Certificate of Environmental Compatibility from the State Power Plant and Transission Line Siting Committee. (Arizona Revised Statutes, §40-360.03 and §40-360.06). The Committee granted the certificate in 1973 with several conditions of which one required APS to document visibility in the Painted Desert before and after each new unit became operational. Later, in 1975 and in 1979, APS applied for and was granted certificates for Units 4 and 5, each to have a generating capacity of 350 megawatts. The requirement for visibility documentation was incorporated in each Certificate. Unit 4 became operational in June, 1981. Construction of Unit 5 has been postponed; the unit will not become operational before 1989.

In conformance with the requirement to document visibility, APS began measuring visibility at the Petrified Forest National Park in the Summer of 1973. Since then, five studies, each conducted within a one-year period, have been completed. Each study consisted of four 30-day periods, each central to a season of the year. The schedule of measurement allowed the collection of a practicable data base, representative of each year of study and of seasonal variations within the year.

Visibility conditions were studied prior to construction, during construction, and following initial operation of each unit:

1. First study—Summer of 1973 to Spring 1974
2. Second study—Winter of 1977 to Fall 1977
3. Third study—Spring 1979 to Winter 1980
4. Fourth study—Summer 1980 to Spring 1981
5. Fifth study—Summer 1981 to Spring 1982

In addition to documenting visibility at the park, APS has operated a network of air quality monitoring stations in the vicinity of the Cholla Generating Station. One of the monitoring stations is located within the park; its operation was begun in 1975.

Recently, visibility has received national interest because of its importance as an indicator of air quality. In the Clean Air Act Amendment of 1977, Congress expressly declares the goals of preventing future impairment of visibility and remedying existing impairment of visibility in areas desig-

nated as Class I under the Prevention of Significant Deterioration section of the Act. The Petrified Forest National Park is a Class I area. The requirement, however, for APS to document visibility in the Painted Desert is a State of Arizona requirement and is not related to the 1977 Amendments.

This paper reviews the visibility and air quality studies that APS has performed at the Petrified Forest National Park.

VISIBILITY

General

Objects are visually perceived as a result of contrasts in brightness among the several images in a scene. For example, the contrast between print and paper allows the images of letters to be perceived. Since interest here, however, is visibility through the atmosphere, reference will be made to the perception of objects contrasted against the horizon sky at distances of several miles. Before making a more precise working definition of visibility, brief consideration should be given to how the intervening atmosphere, between object and eye, affects contrast.

The alteration of contrast between the object and the horizon sky is caused by the scattering of light toward the observer by air molecules and particles of solid matter suspended in the atmosphere (Middleton, 1952). The additional light scattered into the viewing (or optical) path has the effect of brightening the object. The number of scattering centers (molecules and particles) is greater for longer viewing paths, therefore the object appears brighter the greater its distance from the observer. The effect has been observed by viewers of western scenery who often notice the changing shades of gray in successively more distant mountain ranges.

Of the two types of scattering centers, a particle is much more efficient at altering contrast than is an air molecule. Near the surface of the earth (within a few thousand feet), particulate matter is present in sufficient concentration (number of particles per unit volume) to be the dominant factor—even in air that is considered to be very clean. There are rare times, especially in the western part of the nation, that objects (e.g., mountains) can be seen at distances of 150 miles or more. Such high values of visibility are still less than would occur in an atmosphere of pure air.

Until this point, the term "visibility" has been used imprecisely, connoting only a general state of atmospheric clarity. A common measure of visibility is visual range, the maximum distance that a *black* object can be seen through the atmosphere. The theory that relates contrast to visual range is considerably simplified by reference to a black object. For then the total light intensity in the optical path is due only to light scattered by intervening molecules and suspended particles. If the object is not black, the light intensity in the optical path is enhanced by light reflected from the object, and the maximum distance at which the object can be seen is less than that of a black object. Visual range defined in terms of a black object is, therefore, the least ambiguous measure of visibility and depends only on the properties of the atmosphere and on the limitations of the human eye to detect contrasts.

There is for each of us a minimum detectable brightness

contrast. This contrast threshold varies from person to person and varies for each person, depending, for example, on eye fatigue and age. Visual range is by definition the greatest distance at which the contrast between a black object and the horizon sky can be detected. Visual range, therefore, depends on contrast threshold and will differ from person to person. Confusion is avoided by further defining visual range in relation to a specified contrast threshold. A choice of two percent is common and is selected for this paper. It may be noted parenthetically that a two percent contrast threshold seems to be very consistent with the subjective (visually estimated) observations of visual range made by the photographers throughout the five studies.

Experimental Method

Several methods are known for measuring visual range. One method that has received considerable attention is that of photometry (Middleton, 1952; APCA, 1979). With photometry, measurements are made of brightness contrast between a distant object and its background horizon. These measurements can be made from photographic images recorded by camera and film or by direct measurement with an instrument called a telephotometer (APCA, 1979). Visual range is then related to contrast through an assumption regarding the ability of the human eye to detect contrasts.

For the studies presented here, photographic photometry was selected. Steffens (1949) was perhaps the first to use photographic photometry for visibility measurements. A camera has certain advantages over the human eye: (1) a film provides a permanent record; (2) relative light intensities can be measured accurately; (3) the film can be calibrated for its reaction to light; (4) the camera, if maintained in good condition, does not experience focus changes, fatigue or deterioration in its repeatability; and (5) a telephoto lens allows measurement through long atmospheric path lengths and a magnification of images to a size sufficient to facilitate contrast measurements.

In practice, the objects chosen for targets need not be truly black. Dark objects such as hills or ridges, either composed of dark soils or rock or covered with vegetation, provide good targets for measuring visual range. The objects available in this study are sufficiently dark that only minor corrections for their brightness were necessary to obtain visual range. These corrections have been explained elsewhere (Roberts, 1976).

Data Collection

The site chosen for conducting visibility observations was located on a hill near Pintado Point within the Petrified Forest National Park. Data were obtained by photographing two objects in each of three views, which scanned the Painted Desert and Petrified Forest National Park. Three views originally were chosen so that directional variations in visibility could be investigated. Throughout each data period, photographs were taken daily of each view every hour for eight hours beginning at 0800 MST. The three views are located and described in Figure 1. The insets are photographs of the objects. In the second and subsequent studies, three more views were added. The results in this paper incorporate data taken only from the original three views so that all studies can be consistently presented and compared.
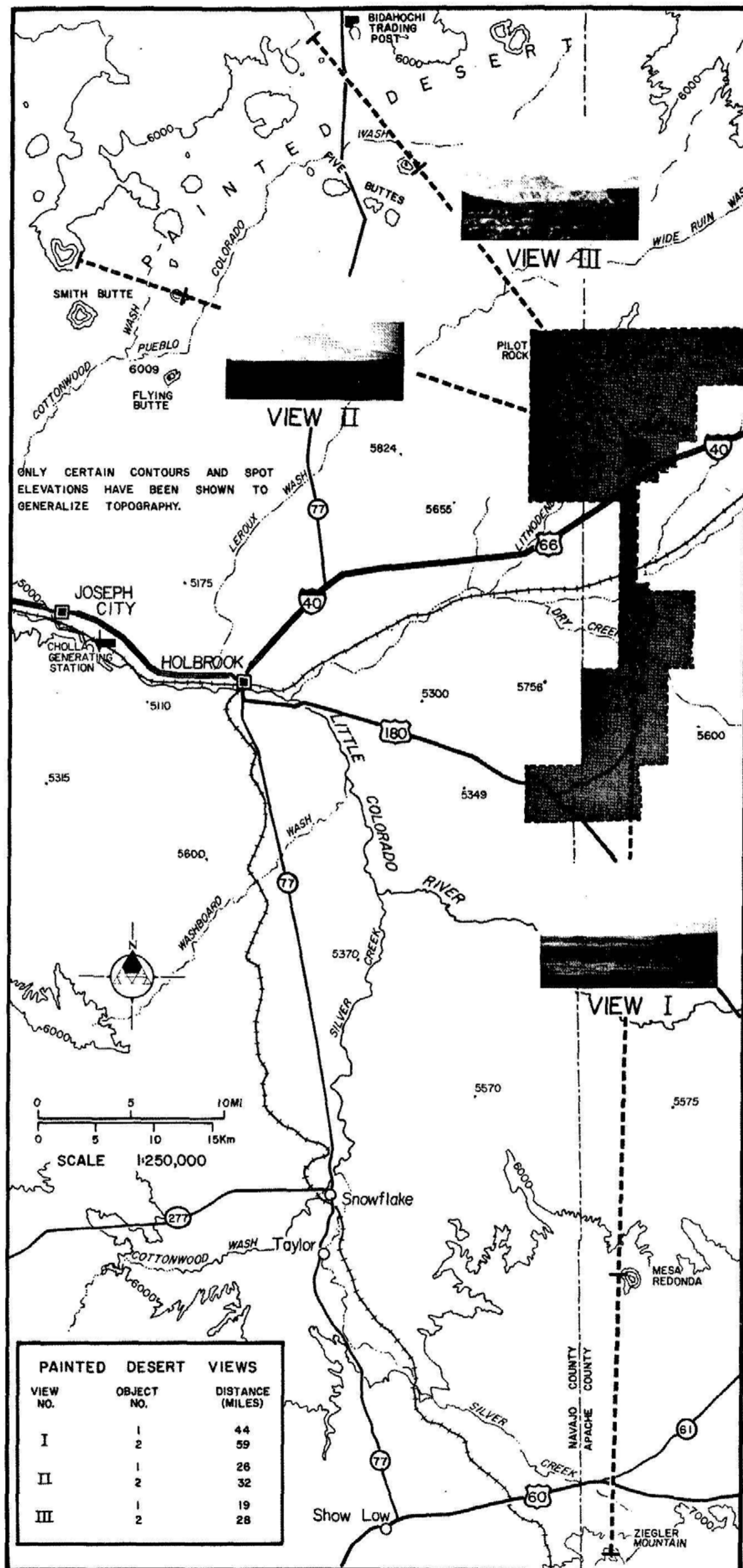
Figure 1. Location and views of visibility studies at Petrified Forest National Park

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The use of two objects in each view provided assurance that, regardless of most existing atmospheric conditions, data could be collected for each view. If conditions existed that obscured the far object, the object nearer the camera would provide data for the visual range. Proper identification and location of each object in the three views were of utmost importance if accurate measurements of visual range were to be obtained. To verify object identities and distances, an aircraft was used to conduct line-of-sight flights between each object and the location of the camera.

Photographs were taken each hour in the three views. Two 35mm cameras were used with 1000mm and 85mm lenses. Black and white panchromatic film was used in conjunction with the 1000mm lens to collect visual range data. At the same time panoramic views were photographed in color using an 85mm lens for a visual record of sky and weather conditions.

To ensure consistency of operation in the field, the photographer followed a standard operating procedure. He maintained an operational log, recording routine field data and information regarding local weather conditions; such data are needed for proper interpretation of results and for identifying situations in which the photographs would not be truly representative of visibility. For example, isolated clouds on the horizon behind the object in an otherwise clear sky, shadows on the object, or any other condition that might prevent accurate visual range measurements were noted on the observer's log. The color photographs also were very useful for this purpose.

Film and Data Processing

Processing of the film was conducted under closely controlled conditions. Each roll of film was carefully calibrated to eliminate errors caused by variations in exposure and developing. The calibration consisted of exposing a small portion of each film strip to a series of eleven known light intensities prior to the development of the film. After the film was developed, a densitometer was used to obtain the densities of each of the calibrated exposures of the film. These densities were plotted against the logarithm of exposure to determine a characteristic curve for each roll of film. In Figure 2, a typical example of a characteristic curve is presented. This curve provides the functional relation between exposure and image density. Care was taken during photography and development to ensure that the image densities lay in the upper linear portion of the curve.

In any photographic negative, the presence of an image is due to light entering the camera and sensitizing the film. The image on the film is created by an exposure, E, of the film proportional to the intensity of light from the direction of the object. The contrast between two objects in the same frame can be obtained from the measured densities of the two images and properties of the film incorporated in the characteristic curve. For example, suppose D_1 and D_2 are the image densities of two objects in the same frame. From the characteristic curve, values can be read for $\log E_1$ and $\log E_2$ corresponding to the image densities D_1 and D_2. The contrast, C, between the two objects is: $C = (E_1/E_2) - 1$.

Steffen's (1949) method of computing visual range consists of choosing the horizon sky as the second object. In this application, distant ridges and mountains are the first object. Then, in the manner described above, contrast between object and sky is measured. For each observation, visual range is computed from the measured contrasts between objects and sky, the distance to the objects, and a
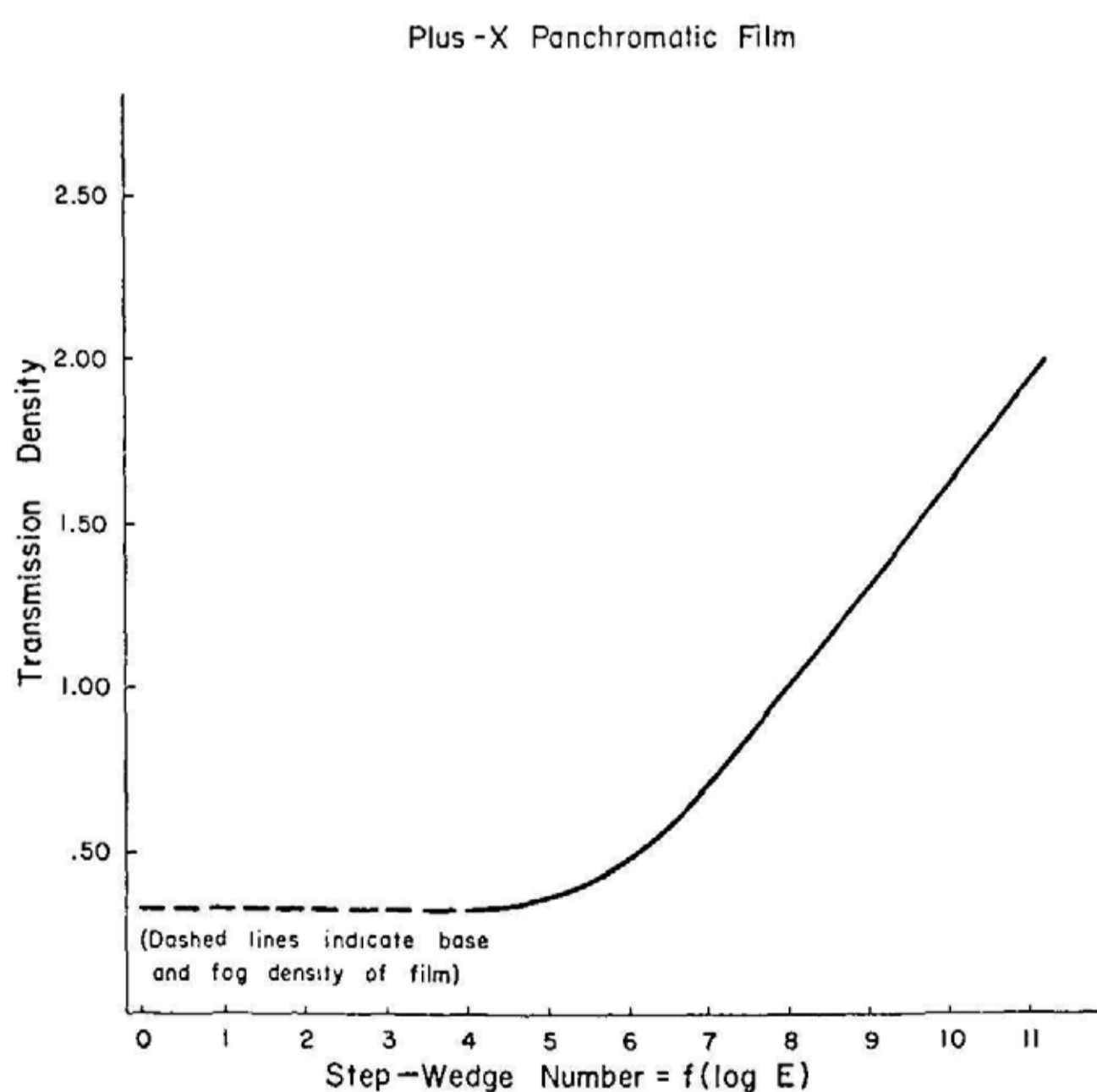

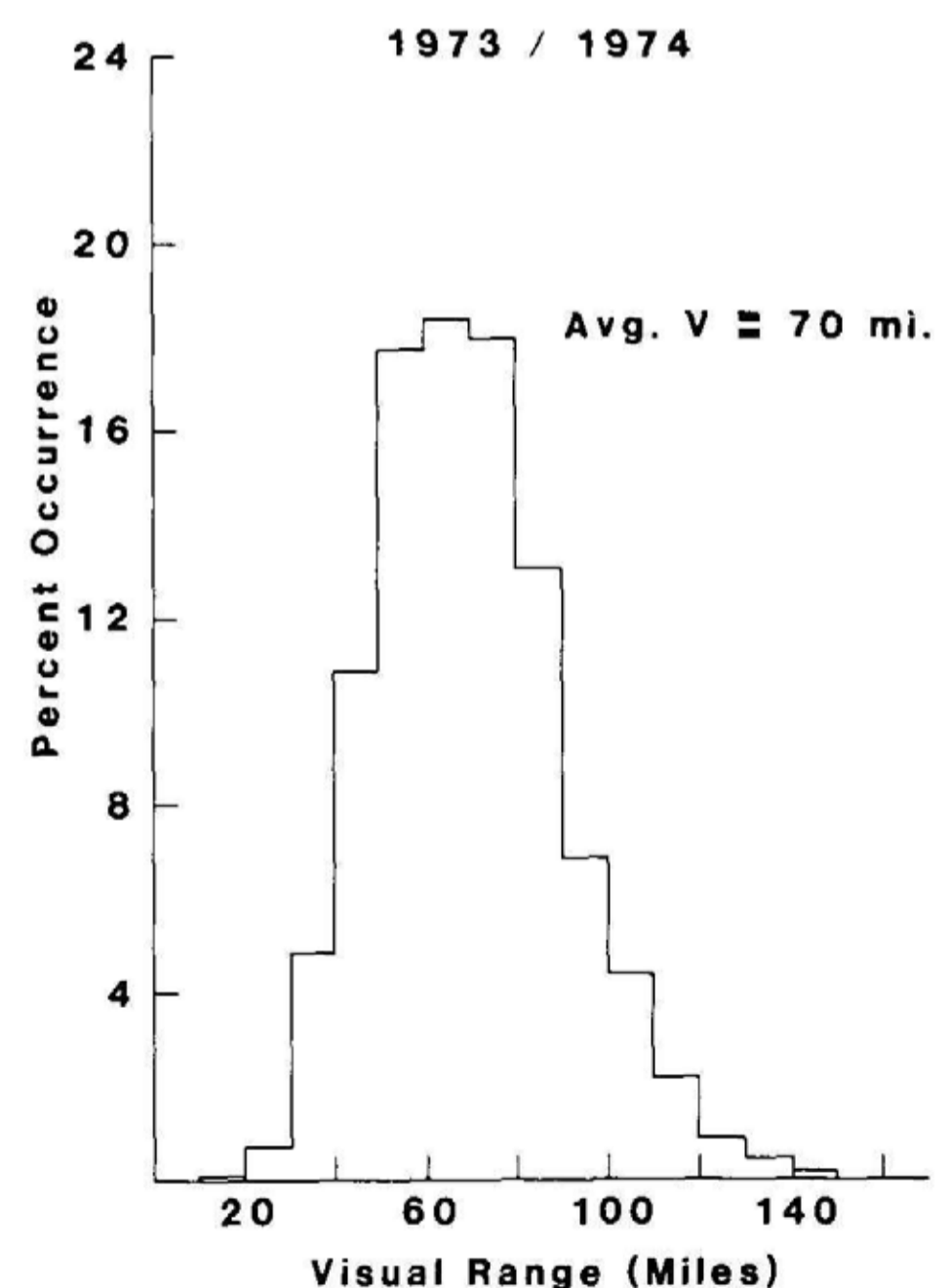Figure 2. Typical characteristic curve for calibration of photographic film

Figure 3. Frequency distribution of hourly visual range observations obtained in the 1973/1974 study at Petrified Forest National Park

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specified contrast threshold of two percent. The mathematical formulation of the calculation has been given elsewhere (Middleton, 1952; Roberts, 1976; Steffens, 1949).

Results

Space limitations preclude the detailed presentation of results from all five studies. The first study, however, has been reported in detail elsewhere by Roberts et al. (1976). The results of the five studies, while they differ numerically, have several general features in common. These common features and their implications will be reviewed and illustrated with results from the first study. Then, a brief summary and a comparison of the five studies will be given.

General Behavior

Visibility at the Park is typically very good but highly variable. Figure 3 shows a distribution of visual range values observed during the first study. For example:

The average visual range was 70 miles;

The minimum visual range was 19 miles; and

The maximum visual range was 140 miles.

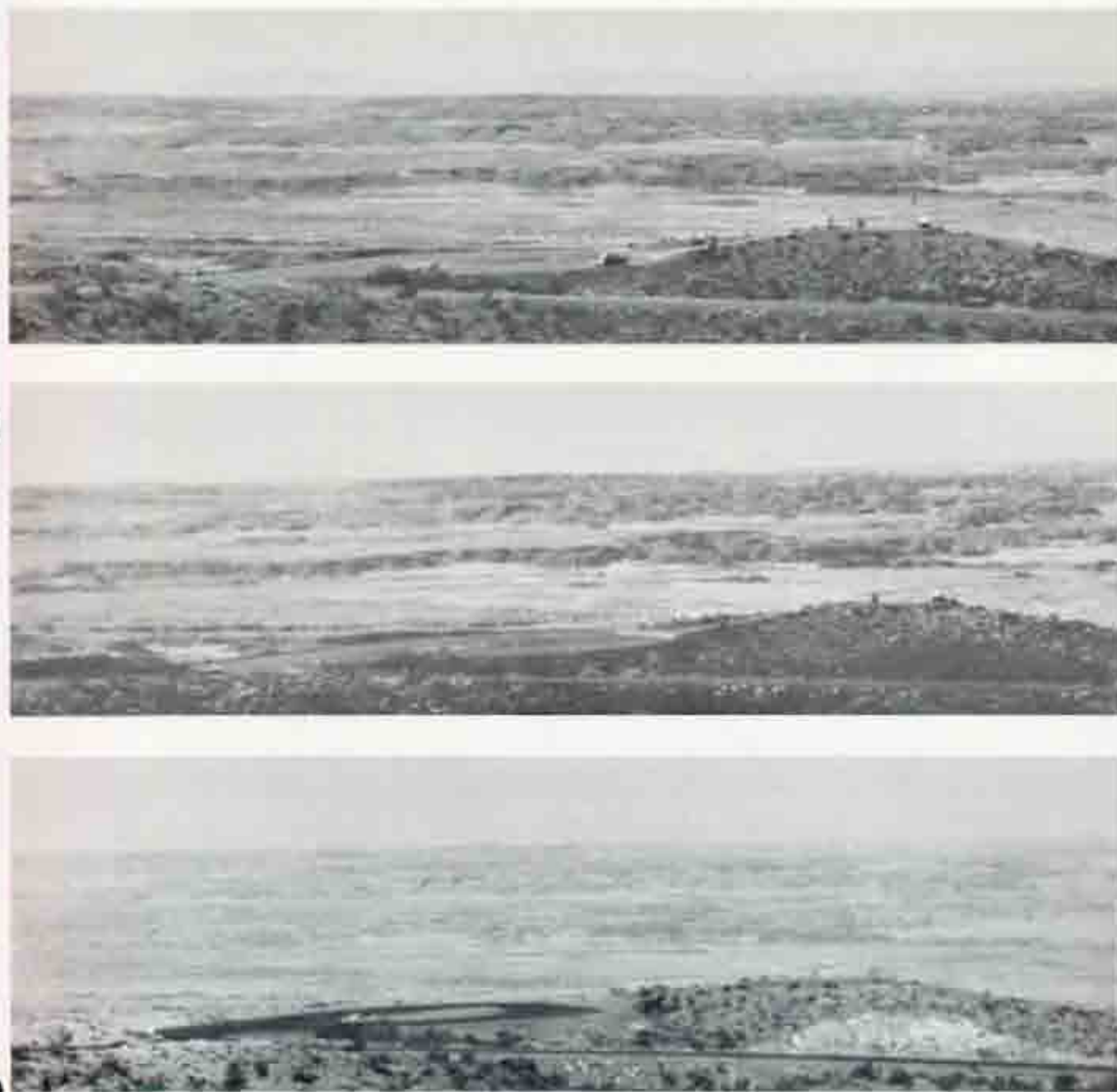Figure 4 illustrates what one could expect to observe

Figure 4. View II under three different visibility conditions, Petrified Forest National Park (1973/1974). Visual Range: *top*, 105 miles, *center*, 70 miles, *bottom*, 34 miles

under various visibility conditions. The figure shows View II, with a ridge 32 miles distant, under three different conditions of visibility. At a visual range of 105 miles, *top,* the ridge is clearly seen contrasted against the sky. At 70 miles' visual range, *center,* a reduction in contrast between ridge and sky is evident. Finally, at a visual range of 34 miles, *bottom,* the ridge is barely visible.

Directional Correlations

Visibility at any time generally varies from view to view. If, however, visual range is high in one direction, it tends to be high in all directions. Likewise, if visual range is low in one direction it tends to be low in all directions. This general tendency for the visual range among views to be highly correlated is illustrated in Figure 5 showing daily average visual range in each season of the first study. The other studies exhibit similar high correlations among the views.

The high correlation among views in daily mean visual range implies that the factors influencing visibility are widespread and somewhat uniform in their actions. One such factor is meteorology. From the noted tendency, one may infer that the atmospheric processes that control the concentration of suspended particulate matter act approximately uniformly over the large area encompassed by the three views. Another factor is the distribution of sources of particulate matter. In the locality of Petrified Forest National Park, a significant source is related to meteorological and climatological factors. The climate is arid and the vegetative cover is sparse. Under dry, windy conditions, soil particles become airborne. While there are other sources of particulate matter in the area, the observed correlation of fluctuations among the three views indicates a uniform, widely spread source—as would be afforded by the arid soil of this region. Other sources of particulate matter, noted during the studies, are forest fires, controlled burns, and dirt roads. These sources, while not as regionally pervasive as the arid soil source, occur often over wide areas and can certainly affect visibility in the entire region. Hall (1981) has also commented on visibility reductions from soil dust generated by action of wind, agricultural operations, transportation, and dust devils.

Sources of particulate matter need not be within the region to affect visibility. Pollutants emitted from point sources or urban areas spread horizontally as the air mass carrying them proceeds along its course. After a transport of several hundred miles, particulate matter will be uniformly distributed over a broad region. It has been shown, for example, that photochemical smog advected from southern California on one occasion and smoke from fires in the
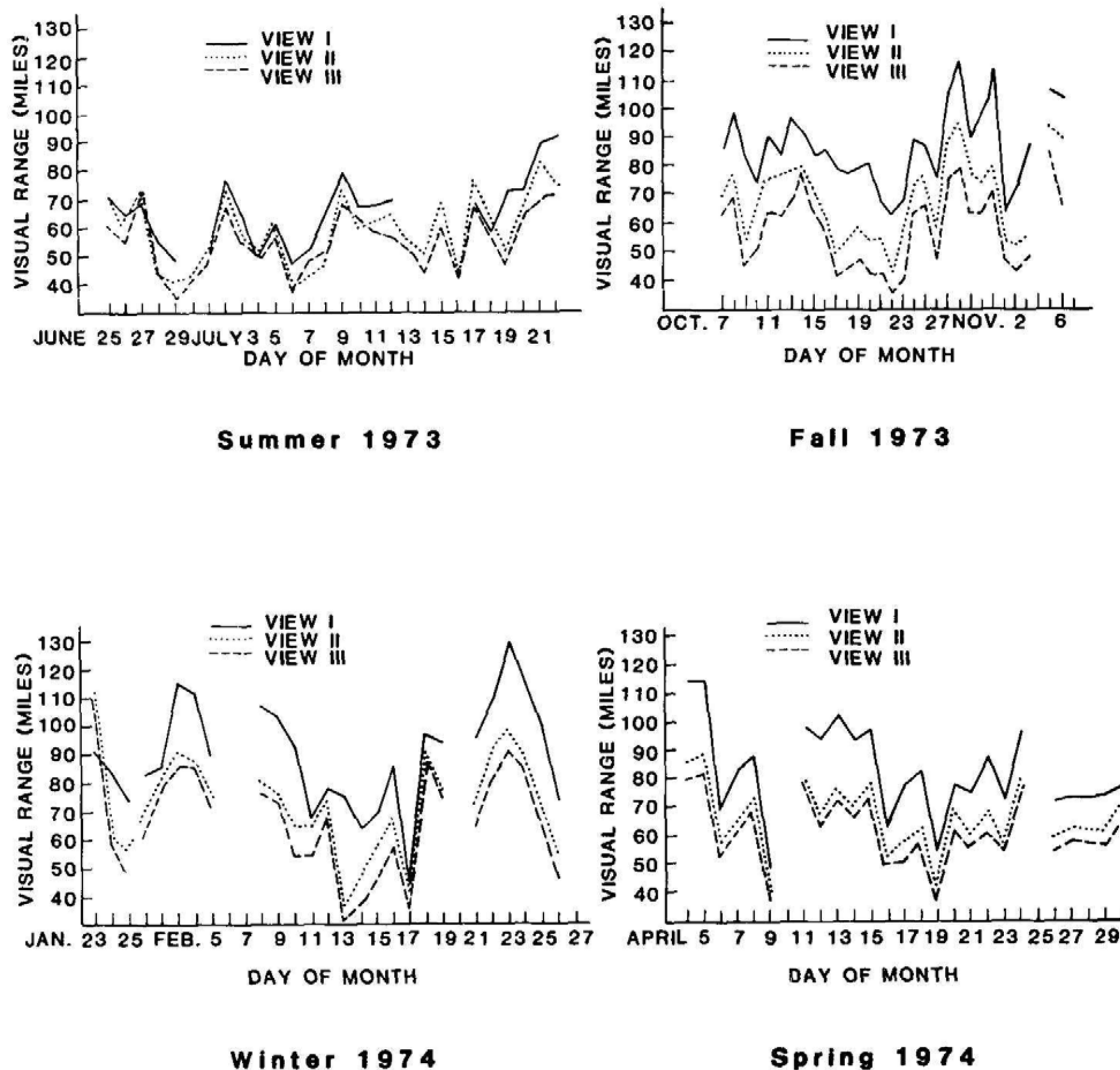

Figure 5. Daily mean visual range of three views at Petrified Forest National Park. Illustration of high correlation of visual range among views

Prescott and Tonto National Forests on another occasion had significant impacts on the clarity of air over northern Arizona (Macias, 1981).

Macias describes three distinct episodes of pollution incursion into northern Arizona. The first episode began on June 27 and persisted through July 3, 1979. The second episode, overlapping the first, covered the period July 2-6, 1979. The third episode occurred in the period July 7-10, 1979. The 1979 summer visibility study at the park was conducted coincidentally with these episodes. The results of that summer session showed a visibility pattern very similar to the pattern observed by Macias but following in time by about two days. No air mass trajectory analysis has been made, however, for the 1979 episodes noted at the park. Consequently, correspondence with the episodes studied by Macias can only be implied at this time. Likewise, no identification of particulate matter sources during the episodes observed at the park can be made without analyses of air mass trajectories and chemical composition of airborne particulate matter.

Diurnal Trends

Visibility tends to be lowest in the morning and highest in the afternoon. A plot of the mean hourly visual range against the hour of the day is indicative of the diurnal variation of visibility. Figure 6 is such a plot of data from the first study. The noted behavior is related primarily to two factors: first—the breakup of groundbased inversions that trap particulate matter; second—the changing position of the sun through the day.

A groundbased inversion is a stable, i.e., relatively non-turbulent, layer of air near the earth's surface. The inversion effectively confines particulate matter to a relatively thin layer, approximately 500 to 1000 feet thick. These inversions, occurring almost daily, cause the concentrations of particulate matter to be higher in the morning. As the solar heating progresses throughout the day the inversion is destroyed, allowing the suspended particules to be dispersed vertically within progressively deeper mixing layers;

as a result, visibility becomes better as the day progresses.

The position of the sun can affect visibility. First, visibility through a light scattering medium depends on whether the sun is behind or in front of the observer. Given a constant atmospheric condition, an observer looking toward the west would experience a different visibility in the morning from that experienced in the afternoon. Second, the visibility of a non-black object depends on the intensity of solar radiation on its surface (Roberts, 1979). The second of these solar angle effects is small in the present study because the objects are fairly dark.

Summary of All Studies

Figures 3 and 7 show histograms, or frequency distributions, of visual range observations for the five studies. If, in any of the years, an observer were to look along views chosen randomly at random times, he would experience visibility conditions described by the histogram. In the 1973/1974 study, for example, a visual range of 80 to 90 miles was observed approximately 13 percent of the time in one view or another.

On the average, it appears that there was a slight increase in visual range between 1973 and 1981. A decrease to slightly below the 1973 value is noted for 1981-1982. Visibility, however, is a climatological variable; as such it may be expected to vary from year to year and, in fact, show short-term trends. For the future it may be expected that downward and upward short-term trends will alternate. Short-term trends such as observed here are extremely difficult if not almost impossible to explain.

Table 1 summarizes the seasonal and annual averages of visual range for all studies. There are many natural factors that affect visibility to varying degrees. Among them are wind speed, wind direction, precipitation, atmospheric moisture, temperature, and turbulence. These factors vary from season to season and year to year; if we could explain changes in these climatological factors, we possibly could explain the observed changes in visual range from year to year.
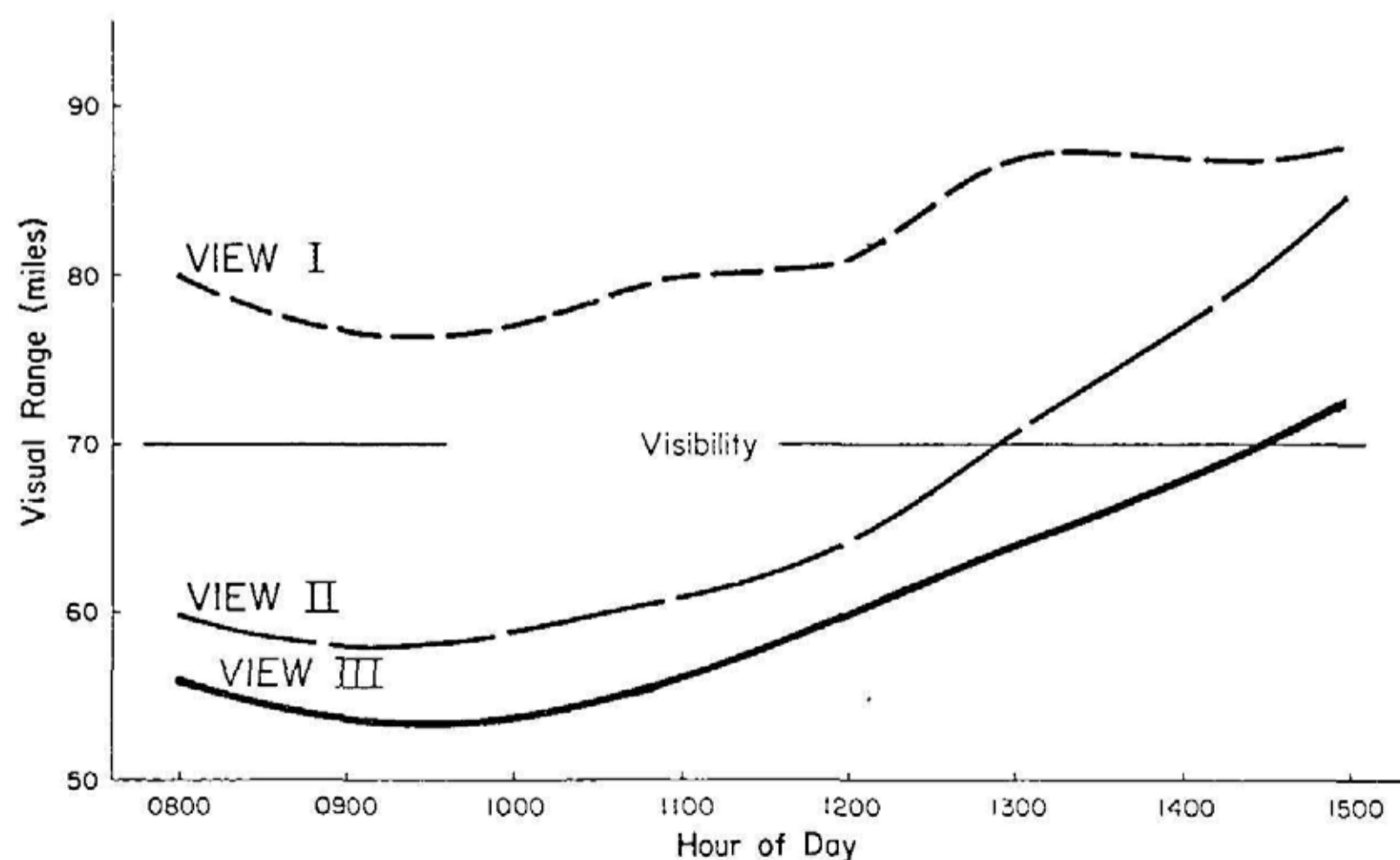

Figure 6. Mean hourly visual range illustrating diurnal trends at Petrified Forest National Park (1973/1974)
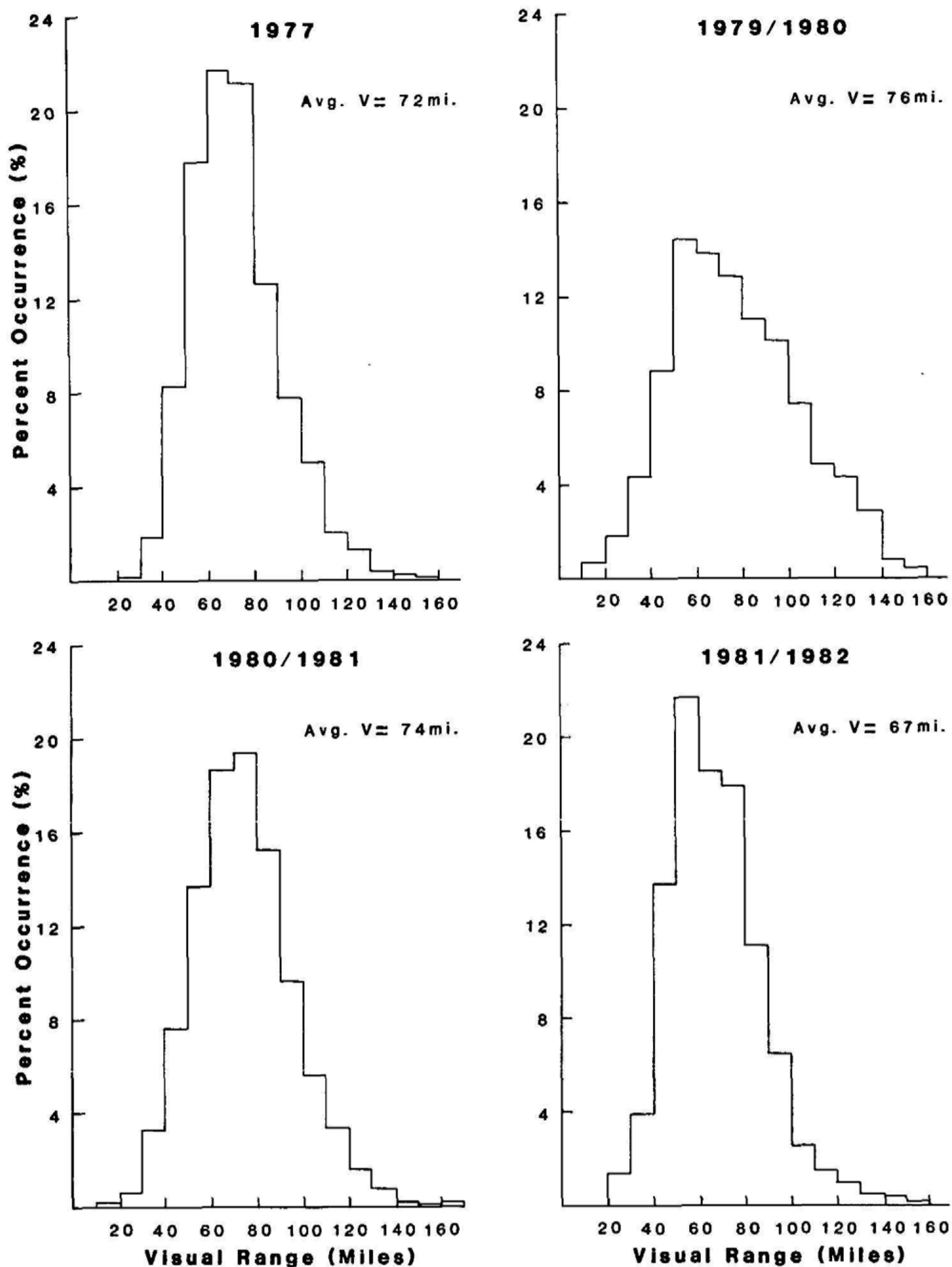
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Figure 7. Frequency distributions of hourly visual range observations for visibility studies at Petrified Forest National Park

Another factor that affects visibility is air pollution. Natural air pollution arising from arid soil and forest fire already has been mentioned. Man also contributes to air pollution. A few examples are: controlled burning; travel along dirt roads; fuel-burning in transportation, space heating, and power production; smelting and refining; and wood processing. As implied previously, APS is documenting visibility at the park because the expansion of the Cholla Generating Station would result in emissions of air pollutants. Table 1 shows the time of initial operation of each new generating unit relative to the several visibility studies. Clearly, no effect on visual range can be extracted

from the data. Any effect of the additional generating capacity on visibility is hidden by the vicissitudes of both climate and sources of particulate matter.

AIR QUALITY
Arizona Public Service Company has operated an air quality monitoring site at the park since 1975. The monitoring program includes measurements of sulfur dioxide (SO_2), nitrogen dioxide (NO_2), and total suspended particulate matter (TSP). Details of the program need not be described in detail here; each constituent was measured with either a reference method or an equivalent method approved in

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each case by the U.S. Environmental Protection Agency.

The results are summarized in Table 2 in terms of the percentage of the National Ambient Air Quality Standards (NAAQS) for each pollutant. The standards need not be given here. Suffice it to say that NAAQS were established, in accordance with the Clean Air Act of 1970, to protect with an adequate margin of safety the public health and welfare. The standards for each pollutant are associated with specified time periods. For example, TSP has two types of standards—a 24-hour standard and an annual standard. Compliance with the standards is determined by averaging the measured pollutant concentrations at a receptor over each of the specified time periods and comparing the result with the standards.

It is seen from Table 2 that SO_2 and NO_2 concentrations have been low at the park. The maximum observed levels of SO_2 have been very low, on the fringe of detectability. Nitrogen dioxide concentrations were slightly higher but, nevertheless, quite low. Concentrations of TSP were usually low as evidenced by the annual averages. On occasions, however, daily values of TSP can be high, as noted in 1975 and 1977.

The high TSP levels that have been observed at the park have all been associated with high winds. Table 3 gives the TSP levels, and corresponding wind data, that are in excess of or comparable to the 24-hour standard limit for particulate matter. A major source of airborne particulate matter is the arid, sparsely vegetated soil so prevalent in the area. Such soils are eroded by wind if the wind speed is great enough and if the soil conditions are conducive to wind erosion. Winds of speed less than about 12 miles per hour are not effective in eroding soil (Chepil, 1945). Higher winds, however, need not be erosive if soil conditions are not conducive to soil erosion; moisture content, vegetation cover, and soil packing and texture are examples of factors that can affect the potential for soil erosion. The wind speeds shown in Table 3 are higher in each case than the 12 miles per hour threshold value. Although the soil conditions on the days of high TSP levels are not known, we may be reasonably confident that high winds acting to erode the soil were responsible for the high TSP measurements.

CONCLUSION

Visibility and air quality have been documented at Petrified Forest National Park for several years. Several general conclusions can be made from these studies:

A. Visibility is typically quite good, averaging a little more than 70 miles.
B. Visibility is highly variable, ranging from 15 miles to 150 miles.
C. Visibility is typically lowest in the morning and best in the afternoon.
D. Factors that affect visibility are regional and are largely climatological.
E. Air quality is very good.
   —SO_2 and NO_2 concentrations are always low.
   —TSP levels are generally low, but can be high on some days.
   —High TSP measurements are invariably associated with high winds and quite often with lower visibility.

Table 1. Seasonal and annual visual range, Petrified Forest National Park

	Visual Range (miles)				
Year	Winter	Spring	Summer	Fall	Annual
1973	—	—	60	70	—
1974	78	70	—	—	—
1973/1974	—	—	—	—	70
1977	73	67	69	77	72
1978	—	—	a	—	—
1979	—	83	69	79	—
1980	70	b	—	—	—
1979/1980	—	—	—	—	76
1980	—	—	74	68	—
1981	85	68	c	—	—
1980/1981	—	—	—	—	74
1981	—	—	57	67	—
1982	78	65	—	—	—
1981/1982	—	—	—	—	67

a Initial operation of Unit 2
b Initial operation of Unit 3
c Initial operation of Unit 4

Table 2. Air quality at Petrified Forest National Park (percentage of National Ambient Air Quality Standards)

	SO_2			NO_2	TSP	
Year	3-hour[a]	24-hour[a]	Annual Average	Annual Average	24-hour[a]	Annual Average
1975	2	4	2	7	99	40
1976	2	3	2	3	69	40
1977	2	2	2	1	193	42
1978	2	1	2	2	40	27
1979	2	1	2	4	47	28
1980	2	1	2	4	48	25
1981	2	1	1	5	49	25

[a]The second largest value per year is compared here with NAAQS standard limits. The NAAQS are written so that two or more incidents exceeding the standard limits constitute a violation; one such incident is not a violation.

Table 3. High TSP concentrations and associated wind speeds

		Wind Speed (mph)[b]	
Date	TSP[a]	Average	Maximum
5/20/75	338	33	52
6/18/75	149	21	35
3/25/76	178	24	37
3/11/77	296	17	26
3/25/77	289	22	32
5/9/82	188	17	33

[a]The 24-hour standard is 150 micrograms per cubic meter, not to be exceeded more than once per year.
[b]Wind data recorded at Winslow, Arizona, by National Weather Service, U.S. Department of Commerce.

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Plague in Arizona
and Petrified Forest National Park

by John M. Doll and Michael E. Wright

ABSTRACT

Since its introduction into the United States, apparently at San Francisco in 1900, plague has gone from being an urban disease carried by domestic rats and their fleas that caused frequent epidemics in man to a widespread zoonosis among wild rodents, rabbits, and their fleas causing only sporadic human cases in seventeen western states. The first evidence of plague in Arizona was in 1938 when the bacterium was isolated from fleas taken from a prairie dog south of St. Johns. The first reported human case in the state occurred at Ganado in 1950. Since then, twenty-three additional human cases have been reported in Arizona; the only fatality was a Navajo sheepherder at Houck in 1963. The Vector-Borne and Zoonotic Diseases Program of the Arizona Department of Health Services began a cooperative plague surveillance and control program in 1974, in cooperation with the Centers for Disease Control, Fish and Wildlife Service, and the Indian Health Service, to determine the distribution and abundance of plague in Arizona and to control the disease.

INTRODUCTION

Plague is a bacterial disease of rodents and rabbits that is transmitted from animal to animal by fleas. The etiological agent is *Yersinia pestis*, a gram-negative bacillus. Plague is a self-limiting disease because it sweeps through animal populations killing many of the susceptible animals. Some animals are refractory (resistant to the disease), and these resistant animals may be the reservoir of infection for further epizootics.

Plague is a zoonosis because infected fleas occasionally bite and transmit the bacteria to man. The disease in humans is acute with sudden onset, and it usually produces lymphadenitis in nodes situated between the site of entry of the bacteria (from a flea bite or cut in the skin) and the body trunk. This form of the disease is known as Bubonic Plague, "bubo" meaning inflammatory swelling of a lymph gland. Other clinical forms of the disease are Septicemic Plague, with dissemination of bacteria throughout the body, and Pneumonic Plague with involvement of the lungs. The latter forms often arise from the bubonic form of the disease. Pneumonic Plague may be contracted directly from a person with plague pneumonia.

HISTORY

Plague apparently was introduced into the United States around the turn of the present century by infected rats infested with fleas. The rats were on ships entering American ports. There they left the ships and entered the cities.

The first human cases of plague reported in the United States occurred in San Francisco, California, in 1900. Over 118 people reportedly died in this first epidemic by the time it was controlled. Human cases of plague occurred also in Seattle, Washington, in 1907 and in Los Angeles, California, in 1908. The early cases of plague often were fatal. They began as Bubonic Plague initiated by the bite of an infected flea; but, in the absence of antibotics such as streptomycin and tetracycline, the disease progressed to Septicemic or Pneumonic Plague, or both. The 1924 Los Angeles outbreak began with a single bubonic infection that became pneumonic; person-to-person transmission then occurred. This epidemic resulted in thirty-one deaths (Link, 1955).

A commonly held hypothesis of how plague spread is that the domestic (commensal) rats, *Rattus norvegicus* and *R. rattus*, came into close contact with native rodents, such as the California ground squirrel *(Spermophilus beecheyi)*; the bacteria then spread enzootically (animal to animal) by fleas in the native fauna. Domestic rats also spread inland and may have been instrumental in spreading plague.

Following the San Francisco outbreak, considerable effort was made for several decades to eradicate plague in California. It was concluded in 1910 that, though remote, there was a danger of plague spreading to other portions of the United States. In 1915, after several years of intensive squirrel eradication to combat the disease, one officer in the campaign made a prediction that all plague in California would soon be eradicated and that there would no longer be any danger of its further spread. This optimism soon vanished, however, as more plague-infected rodents were found in the state.

On May 21, 1934, a human death from plague occurred at Lakeview, Oregon, about fifteen miles north of the California state line. It was the first case of plague outside of California that was attributable to association with wild animals. During 1935, two more foci of plague were found in Oregon, and in July 1935, a plague-infected rodent was found in Beaverhead County, Montana. In 1936, plague was found in Bonneville County, Idaho, and Elko County, Nevada. Plague was first isolated from wild animals outside California in 1935; it has since been found in seventeen western states, roughly as far east as the 100th Meridian.

The first record of plague in Arizona was a positive pool of ninety-eight fleas from a prairie dog *(Cynomys gunnisoni)* collected seven miles south of St. Johns in 1938. In 1950, there was a report (laboratory unconfirmed) of the first case of plague in a human being in Arizona (at Ganado). The first and only human death from plague—a Navajo sheep-

herder—occcurred thirteen years later at Houck, Arizona (Barnes, unpublished data).

METHODS

Information about the distribution and abundance of plague is obtained in four ways: 1) follow-up of human cases; 2) testing of carnivore sera for antibodies to plague; 3) surveillance of prairie dog towns, including swabbing the rodent burrows for fleas; and 4) trapping rodents for serological testing for antibodies to plague and isolation of plague bacilli from their fleas.

Of the four methods, surveillance of carnivore sera is the most cost effective. During programs of routine reduction of coyotes and other predators, trappers are requested to submit blood samples from twenty-five animals of each species from selected areas each year. The blood samples are taken by immersing small strips of filter paper (called Nobuto Strips) in blood, drying the strips, and submitting them to the Arizona Department of Health Services. The Nobuto Strips are forwarded to the Plague Branch, Centers for Disease Control, Ft. Collins, Colorado, where serum is extracted from the strips in saline and tested for antibodies to plague, using the Passive Hemagglutination test.

Fleas from prairie dog burrows and animals are pooled by flea and host species and location, are triturated (ground up), and are then inoculated into mice. In mice, saprophytic bacteria and nonpathogens are destroyed by the animal's immune system. Pathogens such as *Yersinia pestis* multiply and kill the mice, leaving a pathogen-specific population of bacteria in the dead animals.

ACKNOWLEDGEMENTS

RESULTS

There were twenty-four human cases of plague with one fatality reported in Arizona as of 7 November 1981. Cases were reported from five counties: Navajo (eight), Coconino (eight), Apache (five), Yavapai (two), and Gila (one). All cases were located in the northern half of the state (Figure 1). Before 1972, all human plague cases in Arizona were Navajo Indians (Table 1). Since 1972, however, there have been twelve Indian (eleven Navajo and one Hopi) and eight non-Indian cases. More females than male Indians contracted plague. The cases among non-Indians were equally distributed between sexes.

Males in the 15-19 year category contracted plague most often, regardless of ethnicity (Table 2). The only cases in persons thirty years or older and less than five were female Indians.

Surveillance for evidence of plague in animals was conducted in Arizona from 1974-1981. In that period, blood
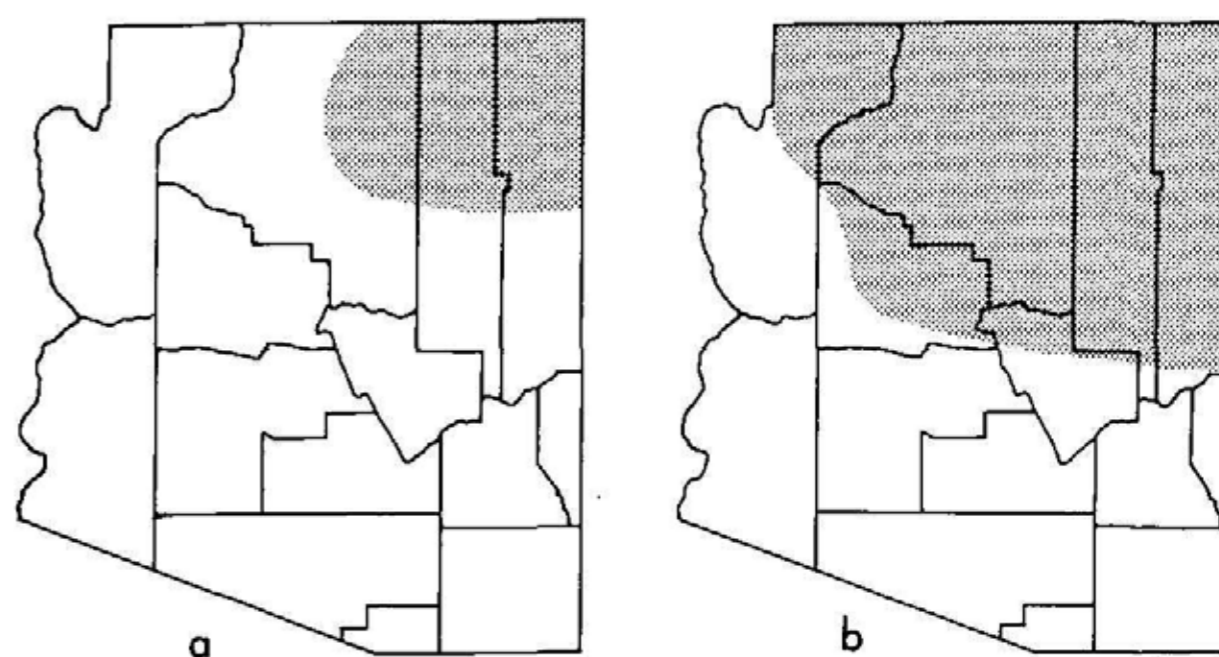

Figure 1. Known distribution of plague in Arizona (a) prior to 1972 and (b) as of 1979. (Data from records of Arizona Department of Health Services.)

Table 1. Number of human cases of plague by ethnic group in 5-year periods, Arizona, 1947-1981 (ending 7 November 1981)

Period	Indian			Non-Indian			Totals by sex		Total
	M	F	Total	M	F	Total	M	F	
1947–1951	1	1	1				0	1	1
1952–1956							0	0	0
1957–1961							0	0	0
1962–1966	1[a]		1				1[a]	0	1[a]
1967–1971	1	1	2				1	1	2
1972–1976	2	4	6	2	1	3	4	5	9
1977–1981	2	4	6	2	3	5	4	7	11
Total	6	10	16	4	4	8	10	14	24

[a]Fatal

Table 2. Human cases of plague in Arizona by age group, sex, and ethnicity, 1947-1981 (ending 7 November 1981)

Age	Indian			Non-Indian			All cases		
	Male	Female	Total	Male	Female	Total	Male	Female	Total
<5	0	2	2	0	0	0	0	2	2
5–9	2	2	4	0	1	1	2	3	5
10–14	0	2	2	0	1	1	0	3	3
15–19	3	1	4	3	0	3	6	1	7
20–24	0	0	0	1	2	3	1	2	3
25–29	1[a]	0	1[a]	0	0	0	1	0	1[a]
≥30	0	3	3	0	0	0	0	3	3
Total	6	10	16	4	4	8	10	14	24

[a]Fatal

samples from 1,612 animals of eight species were tested; 270 (17%) had antibodies to *Y. pestis* (Table 3). Serologically positive carnivores were identified in six counties, the five counties where human cases occurred, and Mohave County, the northwestern-most county in Arizona; human cases of plague have not been reported in Mohave County.

The carnivores infected were the bobcat (46%), coyote (22%), fox (15%), badger (15%), feral cat (11%), and dog (9%).

Rodents and rabbits were rarely positive with antibodies to plague or plague bacteria. Most bacterial isolations were

Table 3. Animals examined serologically for evidence of infection with plague and the percentage positive[a] in 14 counties, Arizona, 1974–1981

County	Species								Total
	Coyote	Dog	Fox	Badger	Bobcat	Cat	Skunk	Raccoon	
Apache	0/9	14/257(5)	0/2	0/1		1/3(33)			15/272(6)
Cochise	0/12						0/3		0/15
Coconino	171/298(57)	12/58(21)	5/20(25)	3/6(50)	9/15(60)	1/5(20)	0/5		201/407(49)
Gila	1/3(33)		2/3(67)				0/7	0/2	3/15(20)
Graham	0/37			0/1					0/38
Greenlee	0/11		0/2	0/1			0/1		0/15
Maricopa	0/103			0/7	0/2	0/2	0/4	0/3	0/121
Mohave	6/106(6)	3/58(9)	0/3		0/2		0/1		9/170(5)
Navajo	3/112(3)	15/175(9)	0/5	1/4(25)	1/2(50)	0/2			20/300(7)
Pima	0/11		0/5				0/1		0/17
Pinal	0/103		0/5	0/4	0/2	0/5	0/2	0/1	0/122
Santa Cruz	0/13		0/1	0/1					0/15
Yavapai	16/79(20)	4/7(57)	1/6(17)	0/1	1/1(100)	0/2	0/3	0/1	22/100(22)
Yuma	0/4						0/1		0/5
Total	197/901(22)	48/555(9)	8/52(15)	4/26(15)	11/24(46)	2/19(11)	0/28	0/7	270/1612(17)

[a] $\dfrac{\text{No. positive}}{\text{No. collected}}$ (per cent positive)

Note: Specimens collected by Animal Damage Control Division, Fish and Wildlife Service; Indian Health Service; and Arizona Department of Game and Fish. Tested by Plague Branch, Centers for Disease Control, Ft. Collins, Colorado

from fleas, usually taken from prairie dog burrows. In six years, only eight (1%) of the 666 rodents tested were serologically positive, while twenty-six flea pools (one to fifty fleas per pool) were positive. Fleas were sometimes positive on serologically negative rodents. *Y. pestis* was isolated from a spotted ground squirrel *(Spermophilus spilosoma)* found dead at Keam's Canyon following a human case in 1981.

DISCUSSION

Plague in Arizona
Data presented in this paper supports the hypothesis that plague entered Arizona from the northeast into Apache County and gradually spread westward and southward. Although the first isolation of plague bacteria was seven miles south of St. Johns in 1938, the first reported human cases were Navajo Indians on the reservation. The human death at Houck in 1963 prompted extensive surveillance on the Navajo Reservation by CDC and IHS.

The ADHS started a plague program in 1974 and initiated active surveillance at that time. Since then, plague has been found over most of the northern one-half of the state in the pinion-juniper zone (5,500-7,200 ft. elevation; Lowe, 1972) but has not been found in southern Arizona, even in mountain settings (Doll et al. 1979).

Plague in Petrified Forest National Park
During 1977, an apparently inactive prairie dog town was found just east of the Route 180 entrance to the Petrified Forest National Park (PFNP). Flea samples were collected from this prairie dog town and submitted for plague bacteria isolation; they were negative.

On May 9, 1978, two pools of *Opisocrostis hirsutis* (prairie dog fleas and two pools of *Thrassis bacchi* (antelope-ground squirrel fleas) were collected just south of I-40 on PFNP property; all four of these pools were positive for *Y. pestis.* Positive fleas *(O. hirsutis)* were also collected in 1978 from a prairie dog burrow near Sun Valley, 16 miles west of PFNP.

Protective measures taken at PFNP included warning the residents that plague was in that area, confinement of pets, and restriction of travel on the park grounds.

In 1979, residents of a dwelling on the park grounds complained of flea bites. Two of the fleas were collected at the dwelling and sent to Plague Branch, CDC. The pool of fleas, *Hoplopsyllus affinis* (rabbit fleas), were positive for *Y. pestis.* Park personnel eradicated fleas in the dwelling without waiting for laboratory confirmation. A later investigation revealed nests under the floor of one house, indicating past residence by rodents (probably *Neotoma* sp.) although rodents and fleas were not found in the nests.

ADHS gave a seminar in August 1979 to staff members of the facility at the request of the superintendent of PFNP to explain the findings and to instruct on precautions for avoiding (preventing) plague.

Another seminar was given to the Holbrook Rotary Club in February 1980 for the same purpose. Further investigations in the area revealed no further plague activity.

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