Part 3. Synthesis

Chapter 10
Paleoecology of Lake Ciniza

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INTRODUCTION

This chapter contains a concise description of various aspects of the paleoecology of Lake Ciniza. It includes a discussion of the location, age, physical characteristics, and origin of the lake; the Late Triassic paleogeography and life of the Lake Ciniza area; and some inferences about the climate of the region when the lake existed. Most statements are based on evidence presented in chapters 1-9; sources of additional data are credited here.

AGE AND LOCATION OF LAKE CINIZA

Lake Ciniza existed during Late Triassic time as materials deposited in it (the Ciniza Lake Beds) are surrounded by the Chinle Formation, which is generally considered to be of Late Triassic age (Reeside and others 1957). Furthermore, fossil leaves, clam shrimps, and fish scales in the lake beds are most closely related to forms of Late Triassic age. The palynomorphs from the lake beds are even more diagnostic and suggest that Lake Ciniza existed in the early part of the Late Triassic, the Carnian of the German Triassic.

Lake Ciniza occupied a small, elongate depression in what are now the Zuni Mountains of western New Mexico. The site is about 19.3 km southeast of Gallup, New Mexico (chap. 1, fig. 1) and is located at about 35°30' N latitude. According to recent reconstructions of Pangaea, however, it was at about 15°N latitude during the time that the lake existed (Creer 1973, Robinson 1973).

ORIGIN OF LAKE CINIZA

The depression in which the Ciniza Lake Beds were deposited formed after about a fifth of the total thickness of the Chinle Formation had accumulated in western New Mexico. At that time, flat-lying and partly lithified strata of the Chinle Formation were deformed, in a narrow zone in what are now the northern Zuni Mountains, by faulting and possibly by folding. Deformation was probably caused by a small amount of movement of the Zuni uplift. As a consequence of the deformation, an elongate northwest-southeast trending depression formed. Subsequently the depression may have become the channel of a stream that deeply eroded the upturned edges of the deformed beds of the Chinle Formation. Eventually the stream began to aggrade, and limestone pebbles and sand were deposited on the floor of the channel. Later the channel was blocked, or the stream changed its course, and Lake Ciniza began to form.

The presence of fish in the Ciniza Lake Beds indicates that the lake was open at least during its early development. The lithology of the lake beds is fairly homogenous, and there is no evidence along the lake margins to indicate that large streams emptied into the lake. Consequently, water in the lake probably came mainly from rainfall and surface water. During its early stage of development, Lake Ciniza may have lost water by seepage as the underlying rocks are porous. Eventually a continuous layer of mud was deposited on the basin floor forming a clay seal. Thereafter water was lost chiefly by evaporation and possibly by overflow into a stream channel.

PALEOGEOGRAPHY

During the time that Lake Ciniza existed, western New Mexico with adjacent areas was the site of a gently rolling plain of low relief. Highland areas composed of volcanic and sedimentary rocks were present on the southern border of the plain. Sluggish streams that originated in the highlands flowed northward across the plain, which probably had a reasonably well-integrated drainage pattern as the same genus of fish that occurs in the Ciniza Lake Beds has been found elsewhere in the Southwest in equivalent strata (Schaeffer 1967).

The channel deposit of one of the streams that was contemporaneous with Lake Ciniza is exposed in the badlands on the east side of the Spur (chap. 1, fig. 4). Several lines of evidence suggest that the stream was sluggish. Material in the deposit consists of structureless claystone. The deposit contains delicate leaves at locality FW8 which are not particularly broken or distorted and appear to have been gently rafted to the site of deposition (Ash 1970a). Several stumps, .6-1 m in diameter, occur in the position of growth near the top of the channel deposit.

The plain surrounding Lake Ciniza was underlain by slightly calcareous claystones and siltstones of the Chinle Formation. These materials originated from both volcanic and nonvolcanic debris brought into the area from sources in southern New Mexico. During transportation, the debris was greatly altered as it was subjected to several cycles of weathering, erosion, and redeposition (Schultz 1963).

CHARACTERISTICS OF LAKE CINIZA

If it is assumed that the exposures of the lake beds generally reflect the outline of Lake Ciniza, some of the characteristics of the lake, such as size and shape at its maximum development, can be inferred. The distribution of the Ciniza Lake Beds (chap. 1, fig. 4) suggest that the lake was at least 550 m long (in a northwest-southwest direction). The occurrence of steeply dipping beds and flat-lying conglomerate north of the outcrops of the lake beds suggests that the lake, or the depression in which it accumulated, might have extended as much as 183 m farther north. Conceivably the lake could have been even longer as the lake beds may extend farther north under the valley containing Fort Wingate, and they might also extend south of their exposures, but the evidence is covered by younger rocks in both places.

Judging by the distribution of lake beds (chap. 1, fig. 4), Lake Ciniza had a minimum width of 250 m measured in a northeast-southwest direction. This figure may be close to the actual width of the lake. No lake beds are exposed on either side of the Spur (chap. 1, fig. 5), so the lake clearly did not extend that far. In addition, lake beds in the vicinity of locality FW5 in Eastern Wash (chap. 1, fig. 16) appear to terminate against the underlying steeply dipping beds. Lake beds are not present on the western wall of Western Wash about 304 m west of locality FW7. Thus it appears that Lake Ciniza was between 250 m and 300 m wide.

The approximate area and ellipticity or ratio of width to length (Reeves 1968, p. 24) may be calculated for Lake Ciniza using the figures given above. If the lake was 550 m long and 250 m wide, it would have had an area of about 35–40 acres and an ellipticity of 0.55. If it was 732 m long and 304 m wide, it would have had an area of about 60–70 acres and an ellipticity of 0.58. Shoreline irregularities and possible islands have been disregarded in these calculations, but these figures are probably reasonably accurate. Lake Ciniza probably had fairly straight sides, because it occupied a fault block depression which may have been slightly modified by stream erosion. Thus the lake would have been somewhat rectangular in shape.

The floor of the basin in which Lake Ciniza accumulated is represented by the upper surface of the flat-lying conglomerate and in places by the truncated ends of the steeply dipping beds. The floor is exposed in a few places (chap. 1, fig. 9). These exposures indicate that the floor was somewhat irregular with possibly 1–2 m of relief. East of locality FW6 the eastern slope of the basin floor is exposed. It is underlain by steeply dipping beds composed of soft, silty sandstone. Here the top of the slope is about 6.7 m above the floor of the basin (cross-section A-A′ in chap. 1, fig. 4).

There could have been islands and shoals in Lake Ciniza. Tombstonelike projections of steeply dipping beds along the western bank of Eastern Wash may be the remains of an island, and the exposures of steeply dipping beds and flat-lying conglomerate near locality FW3 may represent a shoal area.

Lake Ciniza probably was not deeper than 6.7 m at its maximum extent, or it would have spilled out of the basin near locality FW6, if not elsewhere. Actually the lake probably was considerably less than 6 m deep as lake beds are not present on some high areas of the basin floor. One of these highs is exposed between localities FW4 and FW5 in Eastern Wash. As shown in the geologic map (fig. 4), there are no lake beds between the steeply dipping beds and the flat-lying rocks in the main body of the Monitor Butte Member of the Chinle. Yet 15.2 m north near locality FW5 there is a 1.5-m-thick section of lake beds. There are about 2.1 m of relief on the basin floor and slope between the two places. A similar situation has been noted about 30 m northeast of locality FW1 in the headwaters of Western Wash where a high area of steeply dipping beds is overlain directly by flat-lying rocks of the Monitor Butte Member. At locality FW1 there is a thick section of lake beds exposed on the side of a hill. Here there may be 2.5–3 m of relief. Thus the lake apparently did not exceed 2.1 m in depth and may have been less.

According to Tasch (chap. 6) the level of the lake shrank periodically leaving relict pools on the margins. In turn, these clam-shrimp-bearing pools evaporated seasonally. The lake probably never dried up completely, or at least complete drying did not not occur very often as the lake beds contain a comparatively large amount of organic matter and many fossils of several types. It has been noted that the sediments in modern playa lakes, which dry up frequently, are light colored and contain few fossils and little organic matter (e.g., Cross and Martinez-Hernandez 1974).

The floor of Lake Ciniza was composed of mud rich in organic matter during all but its initial phases, when the floor consisted of sand and limestone pebbles. The nonorganic fraction was derived from the soft sandstone, siltstone, and claystone that underlay the surrounding area. Some of the organic matter was derived from branch and leaf debris that covered the land surface, but most organic matter probably was derived from the primary producers—algae—in the lake waters. Prior to transportation the land plant debris had been partially broken down by microorganisms of various types and consisted chiefly of small bits of stems and leaves when it entered the lake. The debris also included a few larger fragments of leaves and some leafy coniferous shoots. This material was washed into the lake principally by sheet flow because there is no evidence of large streams flowing into Lake Ciniza. Coarse-grained plant and rock debris that was washed towards the lake may have been generally strained out by the shoreline vegetation and deposited along the strandline. The debris was broken down still further in the lake but was not attacked by benthonic organisms as large fragments of plant material and other fossils in the lake beds do not appear to have been disturbed by organisms after entering the lake. Some exposures of the lake beds contain continuous laminations that do not show any indications of burrowing and reworking (chap. 1, figs. 10, 11).

The presence of only a small amount of calcite in the lake beds suggests that the waters were neither very alkaline nor very acidic. The absence of primary gypsum and the small amount of calcium and magnesium in the lake beds indicate that the lake probably was not hard. There is the possibility that the lake was acidic and hard, and that the bottom waters were so anoxic that both gypsum and calcite which precipitated were destroyed, the calcite by solution in acid bottom waters and the gypsum by sulfate reducing bacteria. That, however, does not seem likely as the surrounding strata of the Chinle Formation which would have been the source of these substances does not contain very much calcium, as Dean has shown (chap. 2). Also there is no bedded gypsum in the adjacent rocks. In addition clam shrimps, which occur in such great abundance in the lake beds, typically live in a slightly alkaline environment (Tasch 1969). Thus, it appears that Lake Ciniza was probably slightly alkaline and soft.

Several lines of evidence suggest that Lake Ciniza was stratified. The amount of organic matter in the lake beds is relatively high and suggests that there could not have been much free oxygen in the bottom waters during most of the history of the lake. If there had been, decomposition would have proceeded at a high rate, and most, if not all, the organic matter would have been destroyed. As it was, much organic matter was not destroyed so anaerobic reducing conditions must have prevailed in the bottom waters during most of the time the lake was in existence. Bacteria and allied microorganisms create reducing conditions in the presence of organic matter (Zobell 1946). Undisturbed laminations in the lake beds and the absence of any evidence of higher benthonic animals (like worms) seem to substantiate the idea that the bottom waters did not contain much free oxygen. Except in a few unusual cases, higher benthonic organisms cannot live in anaerobic conditions on modern lake bottoms (Ruttner 1963).

On the other hand, clam shrimp and fish fossils indicate that there was also in the lake a layer of water containing large quantities of free oxygen. Thus Lake Ciniza undoubtedly was stratified and had an upper layer (epilimnion) containing large quantities of oxygen where the fish and clam shrimps lived. The lower layer (hypolimnion) contained little free oxygen and was stagnant during most of the history of the lake.

The hypolimnion of Lake Ciniza probably contained large quantities of H_2S which was formed by sulfate reducers as they destroyed the organic matter in the bottom sediments. Several lines of evidence suggest that sulfate reducers were present in the bottom sediments of Lake Ciniza. Weber and Lawler have shown (chap. 9) that the samples they studied contained native sulfur, and sulfate reducers contribute to the formation of sedimentary deposits of sulfur (Zobell 1958). Limonite crusts and nodules (chap. 1, fig. 12c) in the lake beds were probably formed from oxidation of pyrite which originally precipitated when H_2S came in contact with ferrous ions in the lake waters. According to Zobell (1958), H_2S produced by sulfate reducers unites with oxygen to form sulfur. The H_2S also inhibits the growth of aerobic organisms, and as a result more organic matter is available for the sulfate reducers which then produce more H_2S. This cycle is limited by the organic matter or sulfate available or by the introduction of oxygen by water movements (Zobell 1958).

Krumbein and Garrels (1952) studied the origin of sediments in relation to Eh and pH. According to their findings the presence of pyrite and absence of calcite in highly organic shale indicates that the deposit was laid down under strongly reducing conditions and at a pH of less than 7.8. The Ciniza Lake Beds were thus probably deposited in such an environment because they contain pyrite and abundant organic matter but no calcite.

The lithology and stratification of the lake beds suggest that Lake Ciniza had poor general circulation during most of its history. If streams large enough to cause currents had entered the lake, they would have brought in such coarse-grained materials as sand. The lake beds, however, consist entirely of silt- and clay-size particles, not only in the central part of the basin (locality FW2), but along the margins (locality FW6) as well. Laminations in the gray shale that forms the bulk of the lake beds (chap. 1, figs. 10, 11), although they are not regular, support the idea that there were no strong currents in Lake Ciniza because laminations are destroyed by even slight bottom currents (Pettijohn 1975).

Elongated fossils in the lake beds, such as leaves and stems, do not show any preferred orientation and indicate that Lake Ciniza did not contain strong currents. This condition is substantiated by the carapaces of the clam shrimps which are randomly oriented (chap. 6, figs. 1a–1c). Large fragments of leaves such as *Nilssoniopteris* and the leafy shoots of *Pagiophyllum* and *Dinophyton* are not distorted or fragmented (chap. 4, figs. 2f, 2g, 12a, 15a, 17a) as one would expect if there had been strong currents in the lake. The coprolites undoubtedly were quite soft and barely coherent when they were deposited in the lake. Of all the organic remains in the lake, they would have been most susceptible to disturbance by subsurface currents. Yet they are not distorted in any manner (chap. 8, figs. 1, 2, 3). It is possible, of course, that coprolites sank into the mud on the floor of the lake beyond the effects of any bottom currents.

The comparatively large amount of organic matter in the lake beds implies that there was little general circulation in Lake Ciniza. If there had been good general circulation, the bottom waters would have been supplied with oxygen, and the organic matter would have been destroyed. According to Twenhofel and McKelvey (1941), poor circulation permits organic matter to accumulate.

Anderson and Kirkland (1969) point out that a chemically stratified lake can be considered as two lakes, one above the other. Shallow currents may develop in the upper waters. In the case of Lake Ciniza they were set in motion chiefly by wind blowing across the lake and by evaporation. Shallow currents could have formed at the mouths of any streams that entered the lake. This stream water would have been warmer than the lake water and thus less dense. Therefore the stream water would not have sunk and caused general circulation. The limited amount of water that entered the lake as sheet flow after rainstorms probably was not appreciable and would not have caused strong currents. The bottom waters of Lake Ciniza may have contained slow-moving currents, but the fossils in the lake beds show no evidence of it.

Overturn probably did not occur frequently in Lake Ciniza. If it had, most, if not all, of the organic matter on the lake bottom would have been destroyed. Overturn allows bottom waters and sediments to be inhabited by aerobic organisms for considerable time with the result that organic matter is destroyed (Twenhofel and McKelvey 1941). The Ciniza Lake Beds, however, contain a comparatively large amount of organic matter. Thus it is apparent that microbial decomposition proceeded at a slow rate while anaerobic conditions prevailed during the greater part of the lake's history. Overturn may have occurred occasionally, and for a time thereafter decomposition proceeded at a rapid rate. Eventually the oxygen became exhausted, carbon dioxide accumulated, and the waters again became poisonous. As a result the aerobic organisms were killed, and the anaerobic organisms continued the destruction but at a much slower rate.

When and if it did occur overturn was probably generated in Lake Ciniza principally by cooling of the surface waters. In the tropics overturn can occur without any wind action. There is only a small amount of annual variation of air and water temperature in tropical regions. As a result tropical lakes are characterized by small differences in temperature between the surface and the bottom and by slight seasonal variation in the temperature (Ruttner 1963). The slightest cooling in a tropical lake usually sets up convection currents which may result in rapid overturn. According to Ruttner (1963) such cooling occurs infrequently except in those few tropical areas where there are strong seasonal variations. Overturn occurs fairly regularly, for example, in Java where rainy seasons alternate with very dry ones.

Data assembled here indicate that Lake Ciniza was a stratified lake that had rare periods of overturn at irregular intervals. Such a lake is termed oligomictic by Hutchinson and Loffler (1956).

LIFE OF LAKE CINIZA AND ENVIRONS

The widely varied plant and animal fossils in the Ciniza Lake Beds and adjacent strata represent a number of distinctive communities which lived in several diverse habitats (table 1). They include the following:

1. waters of the lake,
2. swampy margins of the lake,

3. swampy margins and deltas of any streams that may have entered the lake,
4. dry land within the drainage basin of the lake, and
5. dry land beyond the drainage basin of the lake.

Animal fossils in the lake beds were derived principally from the communities that lived in Lake Ciniza. A few could represent communities living in streams that entered the lake, and some may be the remains of animals that wandered into the lake from communities in adjacent swampy and dry land areas.

Three members of the community that occupied the waters of Lake Ciniza have been identified in the lake beds: the clam shrimp *Cyzicus,* the fish *Chinlea,* and the amphibian *Metoposaurus.* Clam shrimps were primary consumers in Lake Ciniza and were near the base of its food pyramid. They were probably detritus-feeders as their living descendents are. Clam shrimps were eaten by the larger organisms as the coprolite containing a specimen of *Cyzicus* shows (chap. 8, fig. 1c). Presumably there were other small animals in the lake which consumed microscopic organisms (such as algae) but were too soft to be preserved in the lake beds.

The fish *Chinlea* was near the top of the food pyramid in the lake and streams of the area. Schaeffer (1967), who has studied *Chinlea* in some detail, believes it fed mainly on smaller fish. None of these smaller fish were found in the Ciniza Lake Beds, but they are known from contemporaneous strata at four localities in the Southwest (Schaeffer 1967). Presumably small fish which could have fed on *Cyzicus* were present in Lake Ciniza. *Chinlea* may have supplemented its diet with baby amphibians and reptiles that lived in and near the lake.

It might be argued that fish did not live in Lake Ciniza since only a few scales of only one type of fish, *Chinlea,* were found in the lake beds. According to this argument, *Chinlea* lived in streams in the area, and their dead bodies were carried into Lake Ciniza where they disintegrated. Although this argument has some merit, the wide distribution of the scales at three localities in the lake beds strongly suggests that *Chinlea* and possibly other fish actually lived in the lake.

Metoposaurus (*Eupelor*) presumably lived in the lake and its margins as its remains were found on the surface of the lake beds (Ash 1970). *Metoposaurus* has been described as being a "thoroughly aquatic" fish eater that lived in the Chinle streams and lakes (Colbert 1972). It was near the top of the food pyramid in the lake and probably preyed on *Chinlea* and other fish. According to Colbert, *Metoposaurus* probably never ventured far from streams and lakes.

The coprolites recovered from the lake beds suggest that a variety of animals of several sizes lived in and adjacent to Lake Ciniza. Fossils preserved in the coprolites indicate that some of these animals were carnivorous, and some were probably herbivorous. Possibly some were omnivorous because some of the coprolites contain both plant and animal remains.

Plant fossils were derived principally from the communities that inhabited the swampy margins and possibly the swampy deltas and margins of streams entering Lake Ciniza. No attempt, however, has been made in this account to distinguish between representatives of lake margins community and delta and riparian communities. Some plant fossils in the lake beds also came from communities in adjacent dry land areas, possibly within just a few feet of the lake. Probably a few were washed into the lake from more distant localities in the drainage basin of Lake Ciniza. Some pollen and spores may have been carried into the lake by wind from dry land communities within and without the borders of the basin.

The lake margin plant community (and possibly the riparian communities) is represented by stems of the Arthrophyte *Equisetites* and leaves of the fern *Phlebopteris* and of the bennettitalean *Nilssoniopteris.* They may have been restricted to a lake margin habitat because none of these fossils occur in the nearby contemporaneous steam deposit at locality FW8 (table 2). This is especially true of *Nilssoniopteris* which elsewhere in the Chinle always occurs in shale rich in compressed leaves and organic matter. The lake margin plant community is also represented by the fern spores *Dictyophyllidites* and *Verrucosisporites.* It could also be represented by the Cycadophytic pollen *Cycadopites* or *Granomonocolpites* as Stone suggests that one of them may have affinities with *Nilssoniopteris.*

The lake margin plant community showed some vertical stratification. The lowest level consisted of ferns, such as *Phlebopteris.* Protruding through the understory of ferns was the Arthrophyte *Equisetites.* A somewhat higher level may have included the plant that bore the leaf *Nilssoniopteris* as it is thought to have been a shrub or possibly a tree.

The swampy margin of Lake Ciniza was occupied by the carnivorous reptile *Phytosaurus* as its teeth have been found in and on the lake beds and in adjacent strata (Ash 1970). Ecologically, according to Colbert (1972), phytosaurs were similar to modern crocodiles and would have frequented both the swampy shore areas and the waters of Lake Ciniza. Perhaps these reptiles even ventured from the immediate lake area to nearby streams. The phytosaurs were at the top of the Chinle food pyramid and probably preyed on fish such as *Chinlea,* on the amphibian *Metoposaurus,* and on any reptiles they could catch.

TABLE 1

SUMMARY OF THE HABITATS IN AND ADJACENT TO LAKE CINIZA AND OF THE ORGANISMS THAT PROBABLY LIVED IN EACH.

Habitats	Organisms
Lake waters	
Upper waters (epilimnion)	*Metoposaurus, Chinlea, Cyzicus,* presumably small fish and ? algae
Lower waters (hypolimnion)	None recognized–presumably bacteria
Swampy lake margins (possibly including the margins of deltas and streams that entered the lake)	*Equisetites, Phlebopteris, Nilssoniopteris, Dictyophyllidites, Verrucosisporites,* and *Phytosaurus*; also possibly *Cycadopites* and *Granomocolpites*
Dry land in drainage basin of Lake Ciniza	*Pagiophyllum, Dinophyton, Alisporites, Pityosporites, Minutosaccus, Klausipollenites, Granosaccus, Vitreisporites, Platysaccus,* and tall undescribed trees, and *Phytosaurus* and *Acomposaurus*
Swampy margins of streams outside Lake Ciniza drainage basin	*Neocalamites, Phytosaurus*
Dry land, near streams outside Lake Ciniza drainage basin	*Todites, Cynepteris, Cladophlebis, Pelourdea, Zamites, Williamsonia, Dinophyton,* and *Acomposaurus*

The dry land plant community in the drainage basin of Lake Ciniza is represented in the lake beds by leafy shoots of the conifers *Pagiophyllum readiana, P. zuniana, P. duttonia,* and *P. navajoensis.* It is also represented by the leafy shoots and pinwheel structures of the enigmatic gymnospermous plant *Dinophyton.* Some of the undescribed leaves listed in chapter 4 by Ash may represent plants that also lived in the drainage basin. The bisaccate pollen grains *Alisporites, Pityosporites, Minutosaccus, Klausipollenites, Granosaccus, Vitreisporites,* and *Platysaccus* are thought to be wind dispersed, and at least some of them probably came from members of the nearby dry land community. It is conceivable that some of the grains were derived from plants that lived in dry land areas beyond the Lake Ciniza drainage basin, but this possibility has not been verified.

As noted earlier, stumps of large coniferous trees occur both in the nearby channel deposit and in the main body of the Monitor Butte Member. Such large trees must have been dominating members of the dry land communities in the Lake Ciniza drainage basin and outside its boundaries. Possibly they bore some of the foliage described from the lake beds, such as *Dinophyton* or one of the species of *Pagiophyllum.*

The Arthrophyte *Neocalamites* grew along the margins of some contemporary streams in the area (Ash 1967). That plant probably had stems that were 3-7 m in height as the pith casts are nearly a foot in diameter.

The dry land plant communities in the Lake Ciniza drainage basin and surrounding areas probably were stratified, but we do know enough about their composition to draw many conclusions. There was probably an under story of ferns like *Todites* and *Clathropteris.* Protruding above the ferns were the cycadophytes like the ones that bore the leaves called *Zamites* and the female cone *Williamsonia*—all of which may have been shrubs or even tall trees. This also is probably true of the four *Pagiophyllum* species and might be true of *Dinophyton.* The large stumps known from the stream deposit at locality FW8 and elsewhere in the Monitor Butte Member in the Fort Wingate area indicate that there were at least some fairly tall coniferous trees in the area close to Lake Ciniza and to the streams in the surrounding area.

We have little evidence of the animals that lived in the dry land areas surrounding Lake Ciniza. A few remains of phytosaurs and the thecodont *Acompososaurus* are known from the main body of the Monitor Butte Member of the Chinle in the Fort Wingate area (Ash 1970). The thecodonts probably were typical inhabitants of the dry land areas whereas the phytosaurs, which lived principally along the streams and lakes, may have ventured into the dry land areas only in pursuit of their prey.

Insects also lived in the area. The wing of an insect that is related to but not ancestral to modern locusts and crickets has been described by Carpenter (in Breed 1972) from the stream deposit at locality FW8. He also reports what may be the nymphal form of an insect from the same locality.

TABLE 2
COMPARISONS OF THE PLANT MEGAFOSSILS FOUND IN THE CINIZA LAKE BEDS AND IN THE CONTEMPORANEOUS STREAM DEPOSIT AT LOCALITY FW8.

	Ciniza Lake Beds	Stream Deposit at FW8
Arthrophyta		
**Neocalamites* sp.		X
Equisetites sp.	X	
Pterophyta		
Todites fragilis		X
Cynepteris lasiophora		X
Phlebopteris smithii	X	
Cladophlebis daughertyi		X
Cycadophyta		
Zamites powelli	?	X
Nilssoniopteris ciniza	X	X
Williamsonia nizhonia		X
Coniferophyta		
Pelourdea poleoensis		X
Pagiophyllum readiana	X	
P. zuniana	X	
P. duttonia	X	
P. navajoensis	X	
Order uncertain		
Dinophyton spinosus	X	X
Large seeds		X
Small seeds		X

*Contemporaneous stream deposit west of Lake Ciniza (chap. 1, fig. 4)

DURATION

Although the lake beds do not contain varves or material which can be dated by radiometric means, it is possible to determine how long Lake Ciniza existed by using a technique that Tasch described in chapter 6. His method employs successive generations of clam shrimps, the smallest sedimentary increment between any two generations in a given bed, and total thickness of the conchostracan-bearing beds. By this approach Tasch determined that 0.9 ± 0.3 mm of sediment was deposited on the lake bottom each year. Dividing the maximum thickness of the lake beds (1.5 m) by the annual increment suggests that Lake Ciniza existed for approximately 1500 years if we assume that the lake beds do not contain any minor unconformities.

CLIMATIC IMPLICATIONS

The Ciniza Lake Beds imply that there was sufficient moisture to establish and maintain a lake in western New Mexico for possibly 1500 years during the Upper Triassic. The absence of bedded deposits of gypsum and limestone in the lake beds and adjacent strata in the Chinle Formation suggests that the climate was moist at the time the lake existed. The presence of abundant organic matter in the lake beds suggests that regular overturn did not occur in Lake Ciniza, which indicates that the climate was warm. Ruttner (1963) reports that overturn of lake waters at irregular and infrequent intervals of time is characteristic of tropical lakes.

The absence of sand in the lake beds, even along the lake margins, indicates that the surrounding area was not a desert. Had it been a desert, windstorms would have blown fine sand into Lake Ciniza. Thus, there must have been enough moisture to support a vegetative cover on the surrounding areas and to keep the surface materials so moist that they were not susceptible to transportation by wind.

The climatic implications of the fossils in the Upper Triassic Chinle Formation in the Southwest have been discussed by several authors (see summary in Gottesfeld 1972). For example, Daugherty (1941) and Ash (1967, 1970, 1972) considered the evidence offered by plant megafossils, and Colbert (1972) discussed the evidence provided by vertebrates. Climatic interpretations were also made by Gottesfeld (1972) who drew most of his conclusions from palynomorphs in the Chinle Formation. Daugherty, Ash, and Colbert agree that the fossils they have studied indicate that the climate was generally moist and warm and more or less equivalent to present-day humid subtropics or tropics. Gottesfeld (1972), on the other hand, believes that the climate was generally dry and that the moisture-loving plants and animals studied by Daugherty, Ash, and Colbert merely inhabited mesic corridors along major stream courses.

Fossils preserved in the lake beds and adjacent strata appear to substantiate the theory that the climate was generally moist and warm in the Lake Ciniza region. This is especially true of the plants as the leaves of all but the conifers are fairly large (megaphylls) and appear to have been relatively thin while living. Also they have the following characteristics which are consistent with a moist, warm climate:

1. relatively thin cuticles ($<3\mu$),
2. stomata on both upper and lower surfaces (often stomata as common on upper surfaces as on lower),
3. surficial or only slightly sunken stomata,
4. stomata either unprotected by overlapping hairs or papillae or protected by small papillae.

Furthermore, none of the other plant fossils in the Chinle have obvious xerophytic characters.

Although swamp and dry land communities have been recognized in the lake area, the division of two communities was probably due to only slight differences in elevation and not to major climatic disparity. In fact, we find that the climatically related structural differences between members of the two communities are slight. For example, the cuticle on *Nilssoniopteris*, a member of the swamp community, is only slightly thinner than the cuticles of *Zamites* and the several species of *Pagiophyllum*, members of the adjacent dry land community.

The occurrence of large trees in both stream deposits and contemporary strata in the Chinle Formation seems to be strong evidence supporting the idea that there was abundant moisture available in the area. At present such large trees usually do not grow in arid climates, even along water courses.

It is possible that the maximum temperature reached in western New Mexico when Lake Ciniza was in existence generally may not have exceeded about 35°C (95°F). This temperature is suggested by a chart published by Gordon, Tracy, and Ellis (1958) which shows that under swampy conditions the rate of accumulation of organic matter exceeds the rate of its destruction between about 10° and 35°C (50° and 95°F). Although the organic matter in the Ciniza Lake Beds accumulated underwater and not in a swamp, the temperature range suggested is probably generally indicative of the temperature under which it accumulated. As has been noted elsewhere (Ruttner 1963), there usually is little difference in the tropics between the average temperature of the atmosphere and of lake water so the average maximum temperature of the atmosphere was probably about 35° C near Lake Ciniza. Such a temperature would be consistent if the lake was in the tropics as paleographic reconstructions suggest (Creer 1973, Robinson 1973).

Lipid studies of Lake Ciniza coprolites performed by Weber and Lawler and described in chapter 9 seem to substantiate the theory that the temperature did not exceed 35°C (95°F). Those two authors indicate that present-day plants that grow in warm climates have longer-chain hydrocarbons in their cuticle than those that grow in cooler climates. Weber and Lawler conclude therefore, that the Chinle plants grew in a warm, but not extremely hot, environment.

SUMMARY

The data presented in this volume and summarized in table 3 show that Lake Ciniza was a small tropical, oligomictic lake which existed for a short time in what is now western New Mexico during the Late Triassic. The lake was chemically stratified, soft, and slightly alkaline. There were no strong currents in the lake, and it turned over infrequently at irregular intervals. The upper waters or epilimnion contained abundant free oxygen and supported a fauna of clam shrimps, fish, and amphibians. Presumably the epilimnion also contained abundant algae. The bottom waters (hypolimnion) were stagnant and contained little free oxygen during most of the lake's history. The hypolimnion and bottom sediments were a reducing environment except for a short time after each period of overturn. The floor of the lake was underlain by a layer of muddy sediment which contained abundant organic matter. The only life that existed on the bottom for any length of time were anaerobic bacteria

TABLE 3
SUMMARY OF PALEOECOLOGICAL INTERPRETATIONS ABOUT LAKE CINIZA

INTERPRETATIONS	EVIDENCE
1. Lake, not a stream or river, deposit (A,B,C,D,I,N).	A. Limited distribution of deposit (1).
2. Water soft (E,F,G,H).	B. Silt and clay in deposit (1,5,10).
3. Water slightly alkaline–pH 7 to 7.8 (E,I,N).	C. No sand-size particles in deposit (1,4,5,10,11).
4. No large streams entered lake (C,D,I,L,M).	D. Irregular lamina in deposit (1,4,7,9).
5. No strong currents in lake (B,C,I,J,K).	E. Low calcium and magnesium in deposit (2,3).
6. Upper waters contained large quantities of free oxygen (N,O).	F. Low calcium and magnesium in surrounding strata (2).
7. Lower waters stagnant, contained little free oxygen (D,I,J,K,L,M,P).	G. No primary gypsum in deposit (2,11).
8. Overturn infrequent (I,J,K).	H. No primary gypsum in surrounding strata (2,10,11).
9. Few burrowing organisms on lake bottom (D,I,P).	I. Abundant organic matter in strata (1,3,4,5,7,8,9,10,11,12,13)
10. Surrounding area not a desert, well vegetated (B,C,H,I,Q).	J. Abundant limonite in deposit, derived from pyrite (5,7,8).
11. Climate moist (C,G,H,I,Q,R,S,U).	K. Elemental sulfur in deposit (5,7,8).
12. Climate warm (I,Q,R,S,T,U).	L. Elongated fossils show no preferred orientation (4,7).
13. Climate not extremely hot (I,T).	M. Coprolites not disrupted (4,7).
	N. Clam shrimps present (1,3,6).
	O. Fish present (6).
	P. Worm burrows, trails, and castings not present (7,9).
	Q. Large trees growing in area (11,12).
	R. Arthrophytes and ferns growing in area (11,12).
	S. Large reptiles and amphibians living in area 11,12).
	T. Long-chain hydrocarbons (12,13).
	U. Leaves not strongly xeromorphic (11,12).

and allied microorganisms. The swampy shorelines of the lake were occupied by arthrophytes, ferns, and bennettitaleans. Other plants, such as conifers, bennettitaleans, and unclassified gymnosperms, lived in the high and drier ground beyond the immediate margins of the lake. Several types of amphibians and reptiles lived in the lake and adjacent areas.

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