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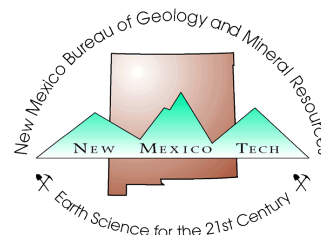
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Pliocene microfossils from the Monticello Point maar, Sierra County, New Mexico

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Abstract

Two fossil localities in the Monticello Point maar on the western shore of Elephant Butte Lake produce diatoms, charophytes, foraminiferans, ostracods, and gastropods. The stratigraphically lower locality is in charophytic limestone that represents a small pond and spring deposits in the reworked maar ejecta. It produces fossils of the charophyte *Lamprothanium*; the ostracods *Ilyocypris bradyi* and *Candona elongalactoides*; and the gastropod *Physa* sp. The stratigraphically higher locality is at the base of a diatomite that represents permanent saline lake deposition in the maar crater. It yields the charophytes *Chara*

sp. A and *Chara* sp. B; the foraminiferan *Ammonia beccarii*; the ostracods *Potamocypris unicaudata*, *Candona inopinata*, *Cyprideis salebrosa*, and *Limnocythere staplini*; and the diatoms *Campylodiscus clypeus*, *Anomoeneis sphaerophora*, *Cyclotella* sp. cf. *C. caspia*, *Denticula elegans*, and *Amphora coffaeiformis*. These microfossils are consistent with a Pliocene age assignment for the Monticello Point maar deposits, which formed in three stages. The first stage was explosive formation of the maar basin, and a second stage of erosion of the ejecta and stabilization of the maar surface soon followed. During the third and final stage, formation of a maar lake produced a saline, diatom-rich waterbody in the Monticello Point maar.

Introduction

A series of maar deposits of late Cenozoic age are present along the shores of Elephant Butte Lake, Sierra County, New Mexico (Fig. 1). Volcanological and petrological studies of these maars have been undertaken by Aubele et al. (1976), Warren (1978), and Kelly (1988); however, there has been no attempt to study the paleontology of these maars. Here, we report the results of studies of microfossils from the maar at Monticello Point. This maar produced an extensive sample of charophytes, foraminiferans, ostracods, and gastropods from two NMMNH (New Mexico Museum of Natural History and Science) localities in the SW¹/₄NE¹/₄SE¹/₄ sec. 35 T11S R4W (Fig. 1). These fossils are now in the NMMNH collection. Their paleoecological significance leads us to propose a three-stage model of maar and maar-deposit formation at Monticello Point.

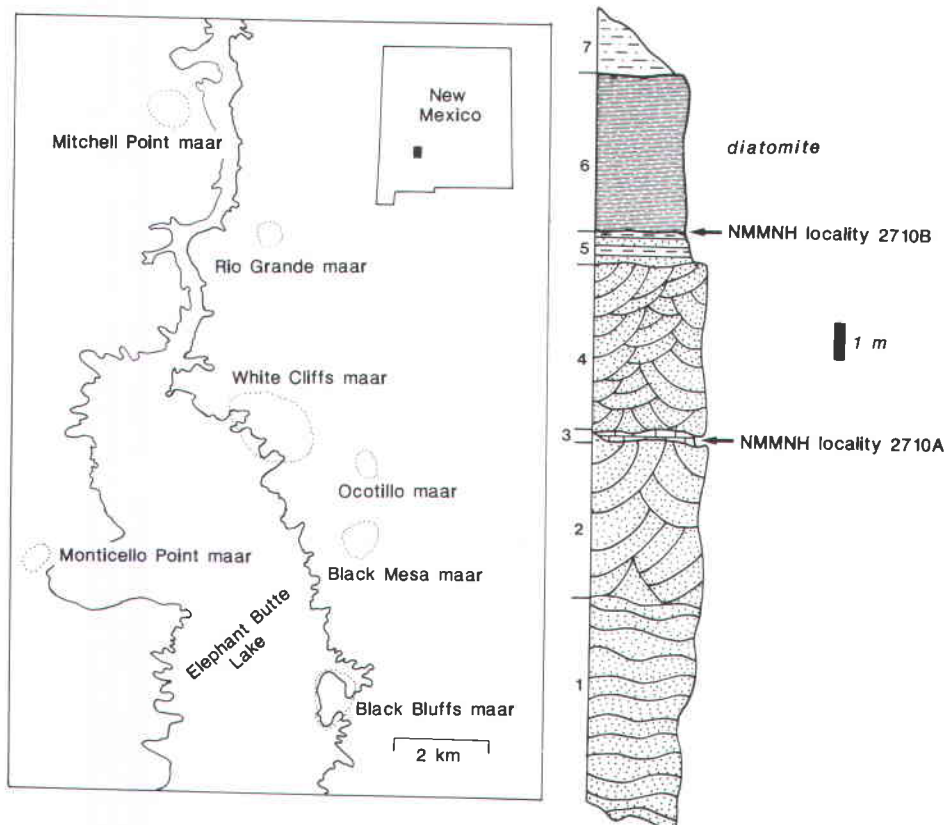


FIGURE 1—Maars near Elephant Butte Lake, including the Monticello Point maar (after Warren, 1978) and measured stratigraphic column of maar deposits at Monticello Point (see Table 1 for description).

Also in this issue

Large <i>Exogyra</i> from Dakota Sandstone	p. 49
Christina Lochman Balk honored by NMGS	p. 54
NMGS 1995 news	p. 55
NMGS 1994 abstracts	p. 56
Upcoming meetings	p. 58
Service/News	p. 62
Staff notes	p. 63

Coming soon

Climatic inferences from rock glaciers
Oil and gas discovery wells drilled in 1993

Geology and age

A maar is a volcanic crater created by a violent explosion. It is characterized by pyroclastic deposits that dip into the crater and by a lake(s) that occupies that crater (Ollier, 1967). The maars in the Elephant Butte Lake area were formed by phreatomagmatic eruptions when rising basaltic magma interacted with groundwater associated with the ancestral Rio Grande drainage (Warren, 1978).

The strata studied here are the inward-dipping maar ejecta deposits and deposits of a lake that filled the maar crater, which occupied an area of about 10 hectares (almost 25 acres). The base of the maar ejecta deposits is not exposed, and they are directly overlain by piedmont facies of the Pliocene–Pleistocene Palomas Formation (Lozinsky and Hawley, 1986). The maar deposits exposed at Monticello Point (Figs. 1, 2) are of three types:

1. Ejecta sandstones and sedimentary breccias are trough-crossbedded or wavy laminar (Fig. 2B–C). Clasts are scoriaeous basalt in a sandstone matrix. This matrix is primarily the eroded rim ejecta and in places contains volcanic bombs.

2. Lacustrine charophytic limestone (Fig. 2C) is a thin (0.1 m thick), localized unit that contains NMMNH locality 2710A. This material represents a small pond and spring deposit intercalated in the reworked maar ejecta. Fossils from this limestone are the charophyte *Lamprothanium* sp., the ostracods *Ilyocypris bradyi* and *Candona elongalactoides*, and the gastropod *Physa* sp.

3. A thick diatomite, with numerous irregular nodules of white opal and translucent quartz, forms the prominent white beds at Monticello Point (Fig. 2A, D). Warren (1978, p. 24) referred to the white

beds at White Cliffs maar, immediately east of the Monticello Point maar across Elephant Butte Reservoir, as “chalk,” but they are mostly siliceous in composition. This diatomite represents a period of permanent saline lake deposition within the stable maar lake. Fossils from the basal bed of the diatomite (NMMNH locality 2710B) are the charophytes *Lamprothanium* sp., *Chara* sp. A and *Chara* sp. B; the foraminiferan *Ammonia beccarii*; the ostracods *Potamocypris unicaudata*, *Candona inopinata*, *Cyprideis salebrosa*, and *Limnocythere stapilini*; and the diatoms *Campylodiscus clypeus*, *Anomoeneis sphaerophora*, *Cyclotella* sp. cf. *C. caspia*, *Denticula elegans*, and *Amphora coffaeiformis*.

The Monticello Point maar deposit is thought to be closely related to other maar deposits to the north, east, and southeast (across the reservoir) of Monticello Point (Fig. 1). This complex of maars is similar to what Ollier (1967) referred to as the “Red Rocks” type, caused by a number of closely spaced multiple eruptions. In Victoria, Australia, the Red Rocks maar complex contains salt lakes that have been studied ecologically and found to be characterized by very rapid and short-term changes in thermal and chemical characteristics (Walker, 1972).

The maar deposits in the Elephant Butte area are overlain by a series of basalts that erupted subsequent to maar formation. To the north of Monticello Point, the Mitchell Point maar is overlain by the Mitchell Point basalts, which have yielded a K–Ar age of 2.9 ± 0.3 Ma (Bachman and Mehnert, 1978). The White Cliffs maar, across Elephant Butte Lake, is overlain by the Black Mesa basalt, which has not been dated. However, dates of other basalts and of basaltic dikes that overlie maar deposits to the southeast of Monticello Point are

in the 2–3 Ma range (Bachman and Mehnert, 1978; Kelly, 1988). This places a minimum age of about 2 Ma on the maar deposit at Monticello Point. Fossil mammals indicate a Blancan (2–4 Ma) age for the axial facies of the Palomas Formation southwest of the Monticello Point maar (Lucas and Oakes, 1986; Repenning and May, 1986). Mack et al. (1993), using magnetostratigraphy, bracketed the Palomas Formation south of Truth or Consequences, New Mexico at 0.73 to 0.80 Ma for the top of the formation and 2.9 to 3.1 Ma for the formation base. We therefore conclude the Monticello Point maar is of late Pliocene age, an age assignment consistent with the fossils reported here.

Paleontology

Lamprothanium sp.

This charophyte (Fig. 3A–B) has elongate gyrogonites, a rounded base, five spiral cells meeting around a pentagonal plate, an apex with five extended and slightly inflated spiral cells forming a distinct neck, and 9–11 spirals in side view. *Lamprothanium* is by far the most abun-

TABLE 1—Measured section of strata in the Monticello Point maar, SW¹/₄NE¹/₄SE¹/₄ sec. 35 T11S R4W, Sierra County, New Mexico. See Fig. 1 for stratigraphic column.

Unit	Lithology	Thickness (m)
7.	Sandy siltstone; light-brown and reddish-brown.	Not measured
6.	Diatomite; white (N 9) and very pale orange (10 YR 8/2); clayey; calcareous; finely laminated. NMMNH locality 2710B.	4–7
5.	Sandstone and mudstone in thin interbeds; grayish-yellow (5 Y 8/4) and grayish-orange (10 YR 7/4). Sandstone is very fine grained, subrounded, well sorted, quartzose, calcareous, and clayey.	0.8
4.	Sandstone and conglomerate; same color and lithology as unit 3; trough crossbedded.	4.5
3.	Charophytic limestone; very pale orange (10 YR 8/2) to pale yellowish-orange (10 YR 8/6); weathers pale yellowish-brown (10 YR 6/2) and dusky yellowish-brown (10 YR 2/2). NMMNH locality 2710A.	0.1
2.	Sandstone and conglomerate; same color and lithology as unit 1; trough crossbedded.	4.0
1.	Sandstone and conglomerate; grayish-orange (10 YR 7/4) to yellowish-gray (5 Y 7/2) with brownish-black (5 YR 2/1) clasts of vesicular basalt. Sandstone is very fine grained, angular, poorly sorted, silty, and calcareous litharenite; laminar to wavy laminar bedded.	26.0 ⁺

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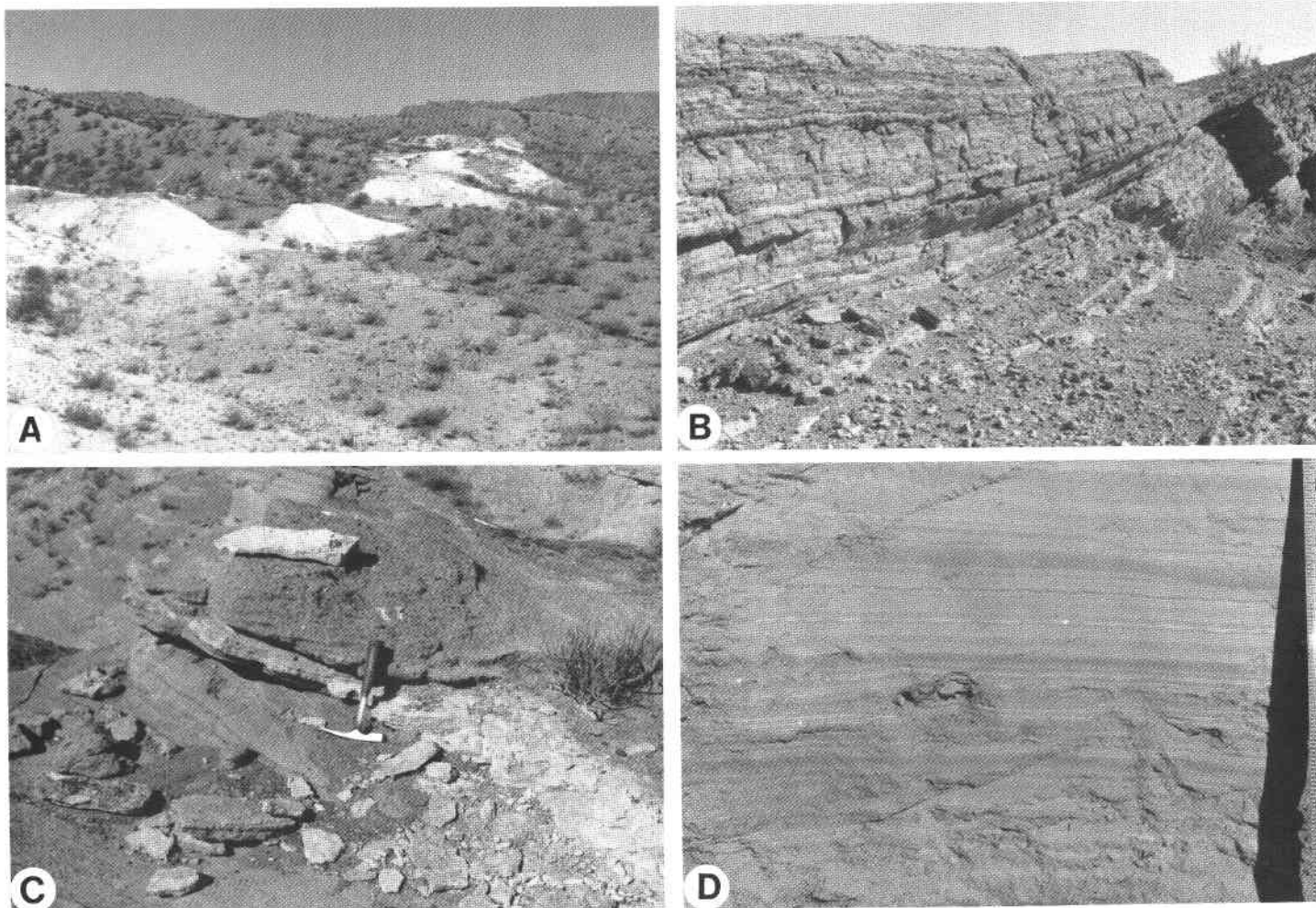


FIGURE 2—Strata exposed at the Monticello Point maar. **A**, Overview of prominent white beds of diatomite. **B**, View of wavy-bedded unit 1 (Fig. 1). **C**, View of unit 3, light-colored limestone that contains charophytes and other fossils (NMMNH locality 2710A). **D**, Close-up of finely laminar beds of diatomite, unit 6 (NMMNH locality 2710B).

dant charophyte in the Monticello Point maar sample. Studies in Australia indicate members of this genus are particularly adapted to highly saline environments (Burne et al., 1980; Brock and Lane, 1983). They have also been reported associated with foraminiferans and eusaline to metasaline ostracods and molluscs in the Holocene of Algeria (Plaziat, 1991).

Chara sp. A.

This charophyte (Fig. 3C–G) has a round to slightly oval gyrogonite, poorly developed ridges, five–six spirals in side view, a pentagonal basal plate defined by the five spiral cells, multiple pentagonal plates aborally, and a poorly developed neck. *Chara* sp. A from Monticello Point appears to be the same species illustrated by Forster (1991, fig. 9.15) from the Pliocene Glens Ferry Formation (3.1 Ma) at Sand Point, Idaho.

Chara sp. B

This charophyte (Fig. 3H–I) has an asymmetrically oval gyrogonite with 9–11

spirals in side view. The cells have strongly developed ridges, the apex has a well-developed neck made of thin extensions of the spiral cells that are often broken, and the basal-plate pentagonal is formed by the convergence of the five spiral cells. The internal structure of the gyrogonite is rounded rhombohedral platelets arranged in slightly fan-shaped patterns originating on the inner wall and spreading to the outer wall. Platelet size is reduced near the origin and along the outer wall.

Ammonia beccarri (Linnaeus, 1758)

The test of specimens of *A. beccarri* (Fig. 3J–L) is trochospiral, inflated, and has eight chambers in the outer whorl. The wall structure is calcareous and finely perforate. The wall of the Monticello Point specimens is often covered with clay rosettes of diagenetic origin (Fig. 3L).

Foraminifera are only occasionally reported in nonmarine environments of Pleistocene and Holocene age. Pleistocene occurrences in New Mexico are from pluvial/playa lakes of the Estancia Ba-

sin—*Protelphidium orbiculare* (Brady) and *Criboelphidium selseyense* (Heron-Allen and Earland) (Bachhuber and McClellan, 1977)—and the Lucero Basin—*Criboelphidium selseyense* (Kietzke, unpublished data). *Ammonia beccarri* has also been reported from several southeast California lake sediments and cores (Arnal, 1954; Smith, 1960; Patterson, 1987), usually associated with *Elphidium* spp. and other brackish to lagoonal indicator species of barnacles, ostracods, and gastropods. *Ammonia beccarri* has also been reported from Quaternary lakes in the Algerian central Sahara Desert (Conrad and Lappartient, 1991) associated with *Elphidium* and *Protelphidium* as well as various typically marine ostracods and molluscs. Foraminifera are also known from other Sahara saline lakes (Plaziat, 1991), nonmarine saline ponds in Manitoba, Canada (Patterson et al., 1990; Patterson and McKillop, 1991), wells in central Asia (Brodsky, 1928), and a lake in Hawaii (Resig, 1974). Foraminifera, including *Ammonia beccarri*, have also

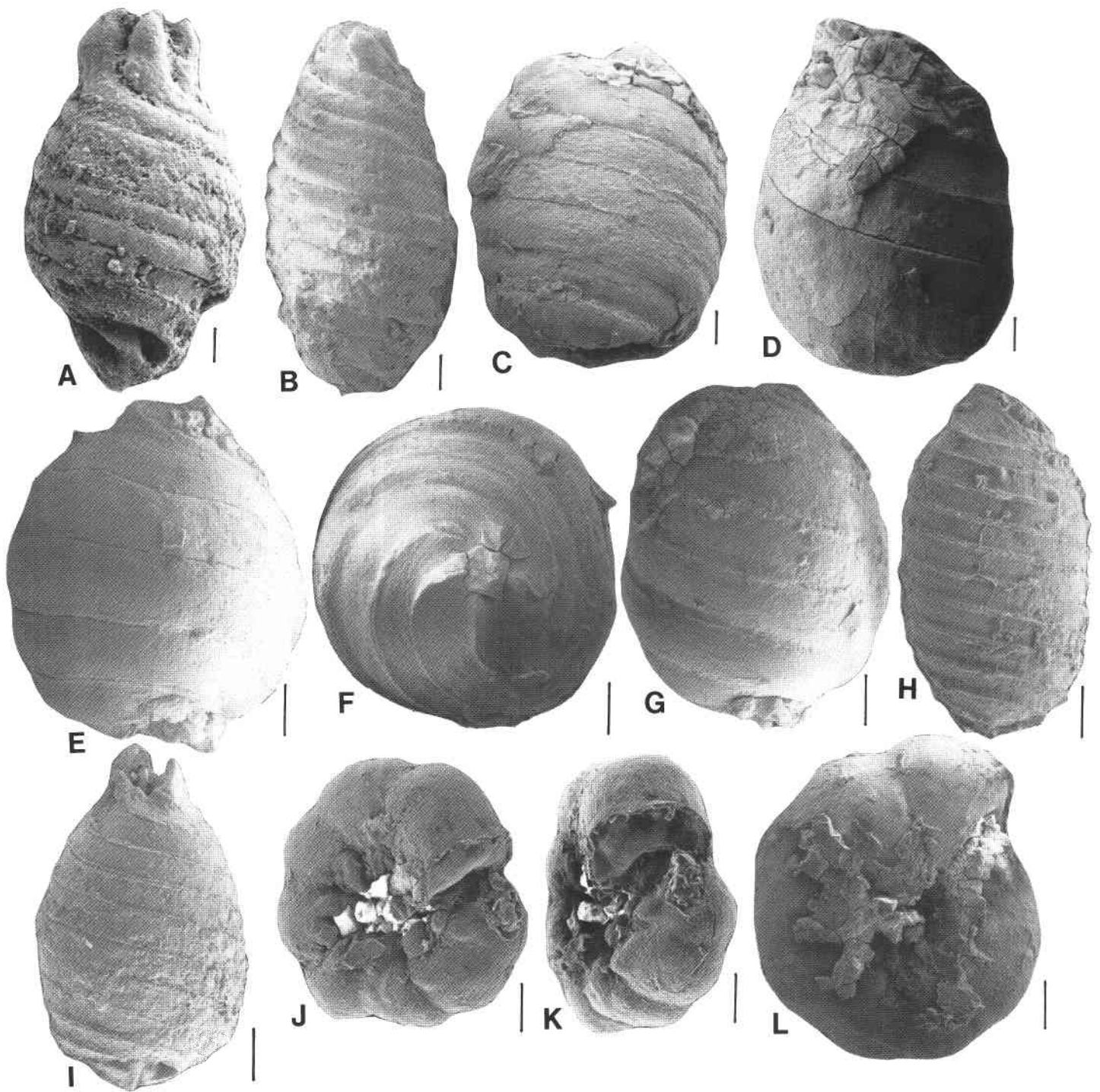


FIGURE 3—Charophytes and foraminiferans from the Monticello Point maar. A–B, *Lamphrothanium* sp., side view of upper end of worn gyrogonite with prominent apical neck (A) and side view of a more-typical elongate, flask-shaped gyrogonite (B). C–D, *Chara* sp. A, side views of gyrogonite. E–F, *Chara* sp. A, side (E) and basal (F) views of gyrogonite; note pentagonal base plate in F. G, *Chara* sp. A, side view of gyrogonite. H–I, *Chara* sp. B, side views of gyrogonite. J–K, *Ammonia beccarii*, basal (J) and side (K) views of test. L, *Ammonia beccarii*, basal view of heavily encrusted test. Bar scales = 1 micron.

been reported from several Quaternary and Recent lakes in Australia (Ludbrook, 1953, 1965; Cann and DeDecker, 1981; DeDecker et al., 1982).

A Recent New Mexico occurrence of foraminiferans has been noted in the intestinal contents of the Pecos pupfish, *Cyprinodon pecosensis* (Echelle and Echelle) from a saline spring in the lower Pecos Valley (Sublette et al., 1990). Sublette et

al. (1990) thought these foraminiferans were from marine fish introduced to nearby Red Bluff Reservoir. This is certainly possible for the extant population but does not account for the Pliocene and Pleistocene occurrences. More likely, as outlined by Bachhuber and McClellan (1977), at a critical point the playas and springs reached a salinity at which the foraminiferans are able to reproduce. At

that point a supply of foraminiferans carried by migrating waterfowl would quickly occupy the newly available niche.

Ammonia beccarii is a valuable paleosalinity indicator, particularly when reproducing populations are present. Bradshaw (1957) demonstrated that although this species can survive in salinities of 2‰ to 70‰, they can only reproduce in the range of 13‰ to 40‰.

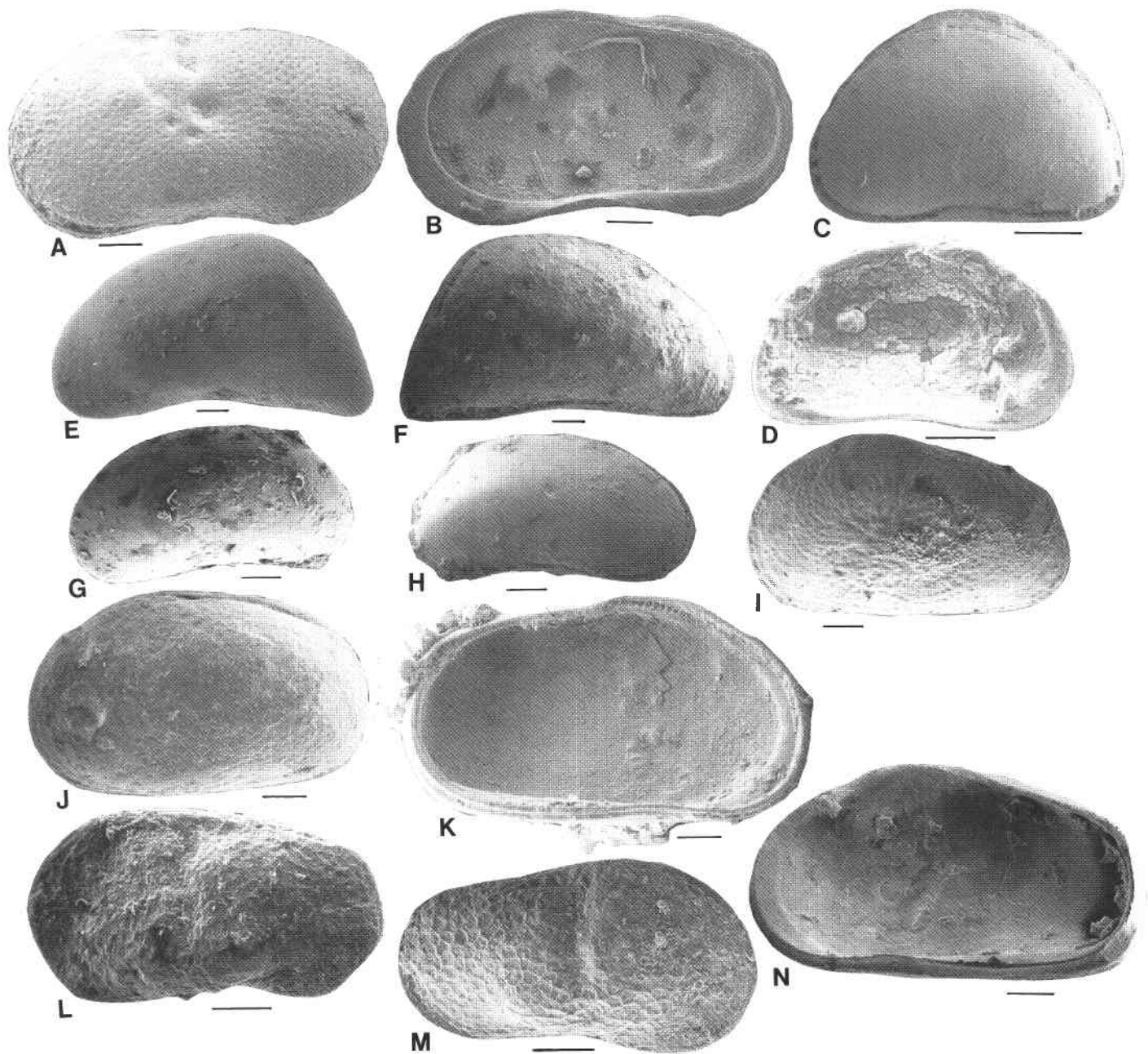


FIGURE 4—Ostracods from the Monticello Point maar. A–B, *Ilyocypris bradyi*, left side view of carapace (A) and interior view of right valve (B). C–D, *Potamocypris unicaudata*, side view of left valve (C) and interior view of left valve (D). E–F, *Candona inopinata*, left (E) and right (F) side views of adult females. G–H, *Candona elongalactoides*, left side view of adult female (G) and right side view of adult female (H). I–K, N, *Cyprideis salebrosa*, left side view of adult male (I), left side view of adult female (J), interior view of adult female right valve (K) and interior view right male valve (N). L–M, *Limnocythere staplini*, left side view adult male (L) and right side view of unusually reticulated adult male (M). Bar scales = 10 microns.

Ilyocypris bradyi Sars, 1890

This ostracod (Fig. 4A–B) has large valves that are rounded rectangular in outline and punctate. The left valve overlaps the right. The dorsal margin is straight, rounded at the ends, and has slight indentations at the sulci. The ventral margin is moderately convex near the midpoint, and the anterior and posterior margins are evenly rounded. The anterior margin is slightly larger than the posterior margin, and the greatest height is slightly (0.23 of length) posterior of the anterior margin. The valve surface is marked by two prominent sulci, the anterior one

longer than the posterior; both sulci trend about 5° posterior of vertical. The valves are also marked by three pits corresponding to the larger adductor field and two mandibular scars on the valve interior. The surface is marked by moderate but even-sized punctae, obscured and distorted slightly in the sulci and muscle scar field pits. The posterior marginal surface has many small spines, and the edge of the anterior ventral margin also has scattered spines. These spines are probably the seti tubercles of Carbonnel and Ritzkowski (1969). The interior has a well-developed inner lamella, which is widest anteriorly

and ventrally (except at the ventra), concave where it is narrow, and moderately wide along the posterior margin. The muscle scars are somewhat obscured by diagenetic recrystallization. The adductor scar field is nearly circular and is composed of four elongate scars and a larger, rounded posterior scar. The other scars are difficult to resolve, although their general shapes and positions are marked by raised areas corresponding to surface pits and sulci.

This species is large, like *Ilyocypris biplicata* (Koch), but it has posterior spines,

unlike that species. Its lack of lateral and posterior tubercles separates it from most other members of the genus. The Monticello Point specimens are slightly more angular anteriorly than is typical of most modern examples, but this may be within the variation of this species.

Hoff (1942) considered this species characteristic of running waters as well as temporary waters; he indicated that it tolerates salinities up to 4.5‰. He also noted that it prefers high-bicarbonate waters and crawls on the surface. Bronshtein (1988, p. 95) reported that in the former Soviet Union this species is "found in various types of waters: seasonal water holes, ox-bow lakes, and rivers, . . . [but] undoubtedly may be considered crenophilous, since its favorite habitat is springs." Regarding Pliocene occurrences, Forester (1991, p. 140) reported this species from the Verde Valley, Arizona (4.5–4.0 Ma) and considered it to be part of an assemblage of "taxa [living] in ground-water discharge settings." Forester (1991, p. 142) also reported this species from Flatiron Butte, Idaho (2.8 Ma), with an assemblage of "ordinary taxa [that were] eutropic, living in shallow, permanent to ephemeral, fresh to slightly saline lakes or ponds dominated by groundwater discharge."

Potamocypris unicaudata Schafer, 1943

This ostracod (Fig. 4C–D) has smooth, rounded triangular valves with a highly arched dorsal margin and ventral margin nearly straight to very slightly convex. The anterior and posterior margins are rounded. The anterior is larger, with its greatest height slightly posterior (0.26 of length) to the anterior margin and its greatest length near the ventral margin.

Potamocypris unicaudata is similar to *Potamocypris smargdina* (Vavra) but differs in being proportionally higher, especially the right valve, and in having greater dorsal and ventral overlap. It differs from modern representatives of the species in minor ways: being slightly more pointed posteriorly, being slightly more elongate, and having greater ventral overlap.

Candona inopinata

This ostracod (Fig. 4E–F) has moderately large, smooth valves. The left valve overlaps the right ventrally, and along the anterior and posterior margins. The dorsal margin is highly arched, with greatest height at 0.46 of length from the posterior margin. The ventral margin is slightly concave with its greatest concavity slightly posterior of the midpoint. The anterior margin is rounded, the posterior margin is pointed, and the anterior dorsal margin is flat. In dorsal view, the valves are inflated with their greatest width at about the same point as greatest height.

This species closely resembles *Candona truncata* Furtos, *Candona acutula* Delorme, and *Candona rawsoni* Tessler but differs from

these species in having a more highly arched dorsal margin, lower length/height ratio, and a much more pointed posterior margin. The Monticello Point specimens do not have the apparently compressed anterior seen in some of the specimens from the Verde Formation in Arizona (Forester, 1991, fig. 6.5–6). *Candona inopinata* has previously been reported from the Pliocene Verde Valley and the 111 Ranch locality, both in Arizona (Forester, 1991). Both these localities have faunas suggestive of spring or seep deposition.

Candona elongalactoides Dickinson and Swain, 1967

This species of *Candona* (Fig. 4G–H) has smooth, elongate valves that are subelliptical to slightly reniform in side view. The greatest height is slightly anterior of the midpoint. The dorsal margin is evenly, slightly convex to nearly straight, and the ventral margin is slightly concave. The anterior and posterior margins are broadly and subequally rounded. The left valve is larger than the right and overlaps all margins except the dorsal margin.

This species has been reported from a number of Pliocene localities: Hay Ranch Formation, Elko County, Nevada (Dickinson and Swain, 1967); Glens Ferry Formation, Owyhee County, Idaho (Swain, 1986a); and the Cache Valley Formation, Franklin County, Idaho (Swain, 1986b).

Cyprideis salebrosa van den Bold, 1963

The valves of this ostracod (Fig. 4I–K, N) are medium to large, subovate, and have a distinct but not deep sulcus. The left valve overlaps the right, and the dorsal margin is straight to slightly arched at its greatest height, which is slightly anterior of the adductor muscle scar field. The ventral margin is slightly convex, and the anterior and posterior margins are rounded, the anterior slightly more so than the posterior. The posterior margin of males is more pointed than that of females. The valve surface has numerous rounded pits arranged in a somewhat concentric fashion centered around the anterior hinge area and the muscle scar field. The muscle scars have a set of four adductor scars arranged in a vertical row and two antennular scars slightly above and anterior of the adductor scars. The anterior scar is larger and "u" shaped; a single, elongate mandibular scar is just anterior and ventral of the adductor field and is somewhat "," shaped. Three or four dorsal scars are above the adductor field, and one is anterior near the anterior hinge area. The hingeline has anterior and posterior dental areas of the right valve divided by a blade-like selvage area that fits into the tooth sockets and a groove in the left valve. Sexual dimorphism is distinct, with males larger, more elongate proportional to height, and with a sharper posterior angle than females.

This species has been described from many Pliocene, Pleistocene, and Holocene deposits (e.g., Gutentag and Benson, 1962; Benson, 1969; Lister, 1975; Swain, 1976; Stout, 1981; van den Bold, 1990). It is often cited as being characteristic of brackish (e.g., van den Bold, 1990) and saline conditions (e.g., Lister, 1975). The nodes sometimes seen on this species are absent on the Monticello Point specimens, and the surface ornamentation ranges from strongly reticulated to nearly smooth. Noding has been observed to vary with differences in the salinity, with higher-salinity specimens showing fewer nodes (Vesper, 1975). The total lack of node development in the Monticello Point specimens thus suggests saline conditions.

Limnocythere staplini Gutentag and Benson, 1962

This species of ostracod (Fig. 4L–M) has small, subquadrate valves with an obscure to faintly reticulated surface. It is distinctly sexually dimorphic with females proportionally shorter, more arched dorsally, and deeper valved, particularly anteriorly, than males. The dorsal margin is nearly straight in males and slightly but distinctly arched in females. The ventral margin is sinuate with a concave surface extending past the duplicature at the valve center. The anterior and posterior margins are rounded, the anterior more so than the posterior. The valves have a distinct sulcus, ending in a subcentral pit over the muscle scar area, and a small node anterior of the sulcus, followed by another faint sulcus anterior of that. The surface is marked with faint to obscure reticulations arranged in a vaguely concentric fashion centered on the muscle scar area.

Males of this species resemble males of *Limnocythere friabilis* Benson and MacDonald, but differ in being proportionally deeper valved, less distinctly reticulated, and lacking postero-marinal spines on the left valve. In New Mexico, this species has been reported from Pleistocene pluvial Lake Estancia. Lister (1975) noted that this species is often associated with *Cyprideis salebrosa* in samples from the Quaternary of the Salt Lake Basin. This species is characteristic of saline environments (Delorme, 1969, 1989). Forester (1986) found *L. staplini* particularly characteristic of alkaline-depleted saline environments. Lister (1975) suggested that variations in the prominence of reticulations in this species may be environmentally controlled.

Diatoms

We submitted a sample of the diatomite from NMMNH locality 2710B to J. Platt Bradbury of the U. S. Geological Survey for analysis. Dr. Bradbury (letter to Lucas, 13 April 1989, with permission) reports:

The Monticello Point sample has abundant diatoms, although they are not es-

pecially well preserved—as often happens in saline, alkaline aquatic environments. The sample is dominated by *Campylodiscus clypeus* and *Anomoeneis sphaerophora* (type *costata*). *Cyclotella* sp. cf. *C. caspia*, *Denticula elegans*, and *Amphora coffaeiformis* are rare. There is some fine-grained marl in the material. . . it indicates. . . salinity probably between 3 and 10‰, comparatively high pH and alkalinity, and shallow water environments at that site (the diatoms are benthic and require sunlit substrates).

Physa sp.

Silicified specimens of this gastropod, identified for us by R. Smartt, are common in the charophyte limestone (NMMNH locality 2710A).

Paleoecology

Two microfossil assemblages are found in the sediments from the Monticello Point maar. The samples immediately associated with the *Chara* beds are rich in charophyte gyrogonites but have only two species of ostracods, *Ilyocypris bradyi* and *Candona elongalactoides*. The sediments are sandy, containing poorly sorted sand grains of worn sedimentary and granitic rocks mixed with euhedral to slightly rounded basaltic volcanic rocks. This sediment is considerably coarser than that found in the clays associated with the overlying diatomites. The microfossils in this sequence suggest a moving water, possibly spring environment. This is indicated by the oriented charophyte fronds found on the limestone surfaces and the presence of *Ilyocypris bradyi*, a species frequently found in springs and other lotic environments.

The second microfossil assemblage is found in the basal clays associated with the diatomite (NMMNH locality 2710B). This assemblage contains a somewhat more diverse ostracod fauna, including several saline indicator species (i.e., *Cyprideis sal ebrosa*, *Limnocythere staplini*). The charophytes also include *Lamprothanium*, a saline-tolerant genus, and the foraminiferan *Ammonia beccarii*. This environment is interpreted as a saline lake with permanent water. A very similar association of *Ammonia beccarii* and *Cyprideis torosa* was reported by Anadon (1992) from a Miocene lacustrine sequence in the Ebro Basin of northeastern Spain. Anadon considered this fauna particularly characteristic of perennial, saline waters with a salinity range of 13‰ to 40‰ and a Cl/SO₄ ratio between 3 and 26.

Direct comparison of the fossil assemblages from the Monticello Point maar with other saline-lake faunas is hampered by the fact that most previously described assemblages of this type come from playa lakes, not maars. Their similarity to the Monticello Point assemblages, however, indicates that water chemistry is more important to a particular saline-lake biota than is the mode of formation and ge-

ometry of the lake basin. Anadon (1992, p. 6) noted that in playa lakes in Spain, ephemeral lakes lacked "marine-like organisms" even though they had favorable water chemistry. Anadon (1992, p. 6) listed five interactive factors that determine whether "marine organisms" could succeed in a particular saline lake: (1) perennial waters, (2) chloro-sulphate water composition (Cl/SO₄ ratios between 3 and 26), (3) salinity range (13‰ to 40‰), (4) possibilities of colonization, and (5) successful competition against saline-tolerant limnic biota. The Ostracoda of the Monticello Point maar are saline-tolerant limnic species. These species probably precluded successful colonization by marine ostracod species. The Foraminifera, on the other hand, apparently find in saline lakes a niche not occupied by competing limnic thalassic organisms.

Evolution of the Monticello Point maar

We envision a three-stage evolution of the Monticello Point maar and its associated deposits:

1. The first stage was explosive formation of the maar basin. Rising magma contacted ground water, producing an explosive ejection of debris, creating the maar basin. This Surtseyan stage was one in which sand wave and surge beds were built up around the maar crater. No Strombolian eruptions seem to have taken place, as no cinder cones or air-fall ash beds appear to be associated with the Monticello Point maar. This stage of the development of the Monticello Point maar is the "hydromagmatic surge" phase described in some other maar depositional models (e.g., Wohletz and Sheridan, 1979; Aranda-Gomez et al., 1992). Sand wave and surge deposits of the Monticello Point maar contain fluvial lithic material full of scoria and volcanic bombs (unit 1 in Fig. 1).

2. The second stage involved erosion of the ejecta and stabilization of the maar surface. After the explosive stage, the maar crater becomes a small sedimentary basin. Erosion of the ejecta in and around the crater tends to produce a generally upward-fining sequence of sediments in the closed drainage basin of the maar crater. Fluvial deposition in the maar basin produces crossbedded sandstones and conglomerates (units 2 and 4 in Fig. 1). Springs develop along the maar walls and provide habitats for charophytes, gastropods, and a few ostracods (NMMNH locality 2710A).

3. Maar lake formation culminates the second phase. Provided the crater rim is not ruptured or otherwise dissected during the first or second stages, a lake forms in the crater. This lake was a saline, diatom-rich waterbody in the Monticello Point maar. A diverse biota of saline-tolerant charophytes, foraminiferans, ostracods, and diatoms lived in this lake until changing paleohydrology filled in or otherwise

terminated lacustrine deposition at Monticello Point maar.

This model of the formation of Monticello Point maar may have general applicability to many or all the maars exposed near Elephant Butte Lake. However, no studies of the sedimentary deposits or fossils of these maars are available. Until such studies take place, the Monticello Point maar remains the only one of the many maars in this area for which we have documentation of the stratigraphy and paleontology.

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