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, foraminifera, 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 Lamprothamnium; the ostracods Hyacypsis bradyi and Candonina elongapectinata; 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 Chana sp. A and Chana sp. B, the foraminiferan Ammonia beccarii; the ostracods Potamocepseyris uncavusata, Candonina inquisita, Cyprideis salebrosa, and Limnocythere stiplini; and the diatoms Campylodictis cygns, Anomoeocystis sphyrahina, Cyclostephanos cf. C. cosp., Denticula elegans, and Amphora coffeiformis. 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, diatomaceous 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, foraminifera, ostracods, and gastropods from two NMMNH (New Mexico Museum of Natural History and Science) localities in the SW1/4, NE1/4 SE1/4 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.

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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 the 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 scoriaceous basalt in a sandstone matrix. This deposit at Monticello Point (Figs. 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 Lamprothamnium sp., Chara sp. A and Chara sp. B; the foraminiferan Ammonia beccari; the ostracods Potamocypris unicaudata, Canadona impervata, Cyprideis salebrosa, and Limnothyrella spatulata; and the diatoms Camypodiscus clypeus, Anomoeoneis spathiformis, Cyclotella sp. cf. C. caspia, Denticula elegans, and Amphora coffeiformis.
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 foraminifers 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 Forester (1991, fig. 9.15) from the Pliocene Glenns 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 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 Basin—*Protelphidium orbiculare* (Brady) and *Cribroelphidium selseyense* (Heron-Allen and Earland) (Bachhuber and McClellan, 1977)—and the Lucero Basin—*Cribroelphidium 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 Lapparent, 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 (Brotsky, 1928), and a lake in Hawaii (Resig, 1974). Foraminifera, including *Ammonia beccarri*, have also
been reported from several Quaternary and Recent lakes in Australia (Ludbrook, 1953, 1965; Cann and DeDeckker, 1981; DeDeckker et al., 1982).

A Recent New Mexico occurrence of foraminifers 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 foraminifers 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 foraminifers are able to reproduce. At that point a supply of foraminifers 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) 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, *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 tubercules 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 bili plicata* (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 4.3%. 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, oxbow lakes, and rivers, . . . [but] undoubt- edly 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 set- tings." Forester (1991, p. 142) also reported this species from Flatiron Butte, Idaho (2.8 Ma), with an assemblage of "ordinary taxa [that were] eutrophic, living in shallow, permanent to ephemeral, fresh to slightly saline lakes or ponds dominated by groundwater discharge."

Potamoocypris 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.

Potamoocypris unicaudata is similar to Potamoocypris smargdina (Vavra) but differs in being proportionally higher, especially 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.

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 Purton, Candona acutula DeLorme, and Candona rausoni 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 subel- liptical 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); Glenns Ferry Formation, Owyhee County, Idaho (Swain, 1986a); and the Cache Valley Formation, Franklin County, Idaho (Swain, 1986b).

Cypreides 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 an-terior 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 fe- males. 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 anterior 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 "v" 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 pos-terior dental areas of the right valve di-vided 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 propor- tional to height, and with a sharper pos-terior angle than females.

This species has been described from many Pliocene, Pleistocene, and Holo- cene deposits (e.g., Guten and Ben- son, 1962; Benson, 1969; Lister, 1975; Swain, 1976; Stout, 1981; van den Bold, 1990). It is often cited as being character- istic 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 speci- mens, 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 de-velopment in the Monticello Point speci- mens thus suggests saline conditions.

Limnothrephes staplini Guten and Benson, 1962

This species of ostracod (Fig. 4L–M) has small, subquadrate valves with an ob- sure to faintly reticulated surface. It is distinctly sexually dimorphic with fe- males proportionally shorter, more arched dorsally, and deeper valued, 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 dis- tinct 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 Limnothrephes friabilis Benson and MacDon- ald, but differ in being proportionally deeper valued, 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 Cypreides salebrosa in samples from the Quaternary of the Salt Lake Basin. This species is char- acteristic of saline environments (De- lorme, 1969, 1989). Forester (1986) found L. staplini particularly characteristic of al-kaline-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 Z710B 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 abun- dant diatoms, although they are not es-
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 charophytes, foraminiferans, ostracods, Ilyocypris bradyi, a species frequently found in springs and other lotic environments. 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 aphyric 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.  These species probably precluded successful colonization by marine ostracods species. The Foraminifera, on the other hand, apparently find in saline lakes a niche not occupied by competing limnic thalassic organisms.

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