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ARCELLACEANS AND FORAMINIFERA FROM PLEISTOCENE LAKE TECOPA, CALIFORNIA

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ABSTRACT

An assemblage of 22 foraminiferal species and a single species of Arcellacea is documented from Lake Tecopa, a dry Pleistocene lake bed in southeastern California. As the lake was never in direct contact with the ocean, the close affinity of this assemblage to the fauna inhabiting coastal marine waters off California suggests colonization via avian transport. The presence of a well developed foraminiferal fauna in Lake Tecopa augments previous paleolimnological interpretations based on fresh water ostracode and diatom data and also provided by petrographic analysis. The presence of foraminifera in Pleistocene lake sediments also provides further evidence that foraminifera are not always indicative of marine facies.

INTRODUCTION

Foraminifera have been found globally in a variety of nonmarine environments (see Cann and De Deckker, 1981, and Resig, 1974, for review of nonmarine citations in the literature). Although most studies have reported only one to five species (Daday, 1884; Howchin, 1901; Brodsky, 1928, 1929; Gauthier-Lievre, 1935; Bartenstein, 1939; Cann and De Deckker, 1981), the occurrence of larger foraminiferal assemblages is not unknown. Arnal (1955a, 1957, 1958) reported 21 species from the Salton Sea, California, and Resig (1974) reported 41 species from Salt Lake, Oahu, Hawaii. More recently, Blanc-Vernet (1982) reported *Ammonia* and *Elphidium* from Holocene lakes in the Sahara Desert, 1,700 km from the ocean, and Fontes and others (1985) noted Holocene occurrences of *Ammonia* in Daiet el Melah in the north-northwest Sahara Desert.

I examined a Pleistocene sediment sample collected from the dry bed of Lake Tecopa in southeastern California with the intent of quantifying the arcellacean assemblage; the presence of a foraminiferal fauna was unexpected. Although previous limited sampling of the Lake Tecopa beds yielded fresh water ostracodes and diatoms (Sheppard and Gude, 1968) neither arcellaceans nor foraminifera have been reported previously from the area.

GEOGRAPHIC LOCATION

Lake Tecopa is located in southeastern Inyo County, California (Fig. 1), an area of mostly isolated short mountain ranges separated by desert plains in the Basin and Range physiographic province. The sampled bed crops out in an intermontane basin bordered to the east by the southern extensions of the Resting Spring and Nopah ranges, and to the west by the southern part of the Greenwater Range, Dublin Hills, and Ibex Hills (Fig. 2). Most of these mountains range 1,000 to 1,300 m above sea level and none exceeds 1,600 m (Sheppard and Gude, 1968).

GEOLOGIC SETTING

Outcrops in the mountain ranges surrounding Lake Tecopa consist primarily of Cambrian strata, but some Tertiary sediments and volcanic rocks are also present. In addition, Precambrian sedimentary rocks crop out south of the town of Tecopa (Mason, 1948). The maximum extent of the lake is unknown because of erosion and concealment by relatively recent alluvial fans. However, the visible lacustrine deposits extend 22.5 km north-south along the Amargosa River and have a maximum east-west extent of 17.7 km, covering a total area of approximately 230 sq km (Fig. 2). The lake beds range in elevation from 425 m near Tecopa to 590 m along the flanks of the surrounding hills, with about 70 m of stratigraphic section exposed. The present lake bed is characterized by badlands in the central part of the basin and dissected gravel-capped pediments along the margins. Some pre-Lake Tecopa rocks found within the lake area probably represent islands that existed in the lake.

Tuff beds comprise 8-12% of the exposed stratigraphic section and are the most conspicuous and continuous strata. As they are the result of ash precipitation directly into the lake, tuffs provide accurate chronostratigraphic markers for determining isochro-

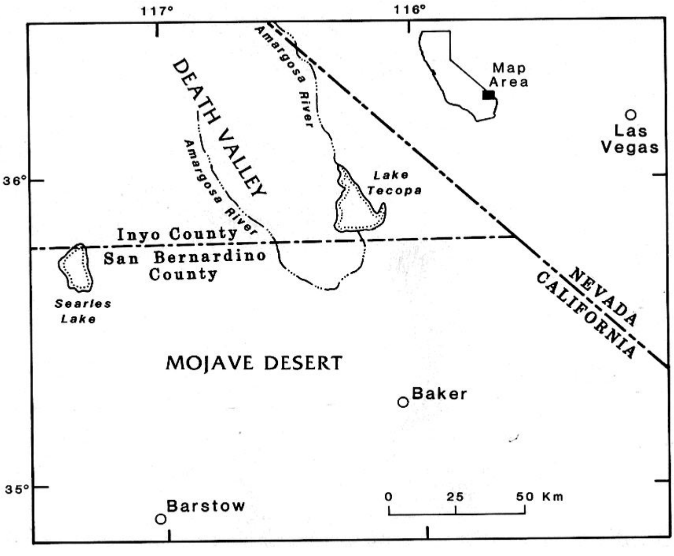


FIGURE 1. Location map of Lake Tecopa in southeastern California (after Sheppard and Gude, 1968).

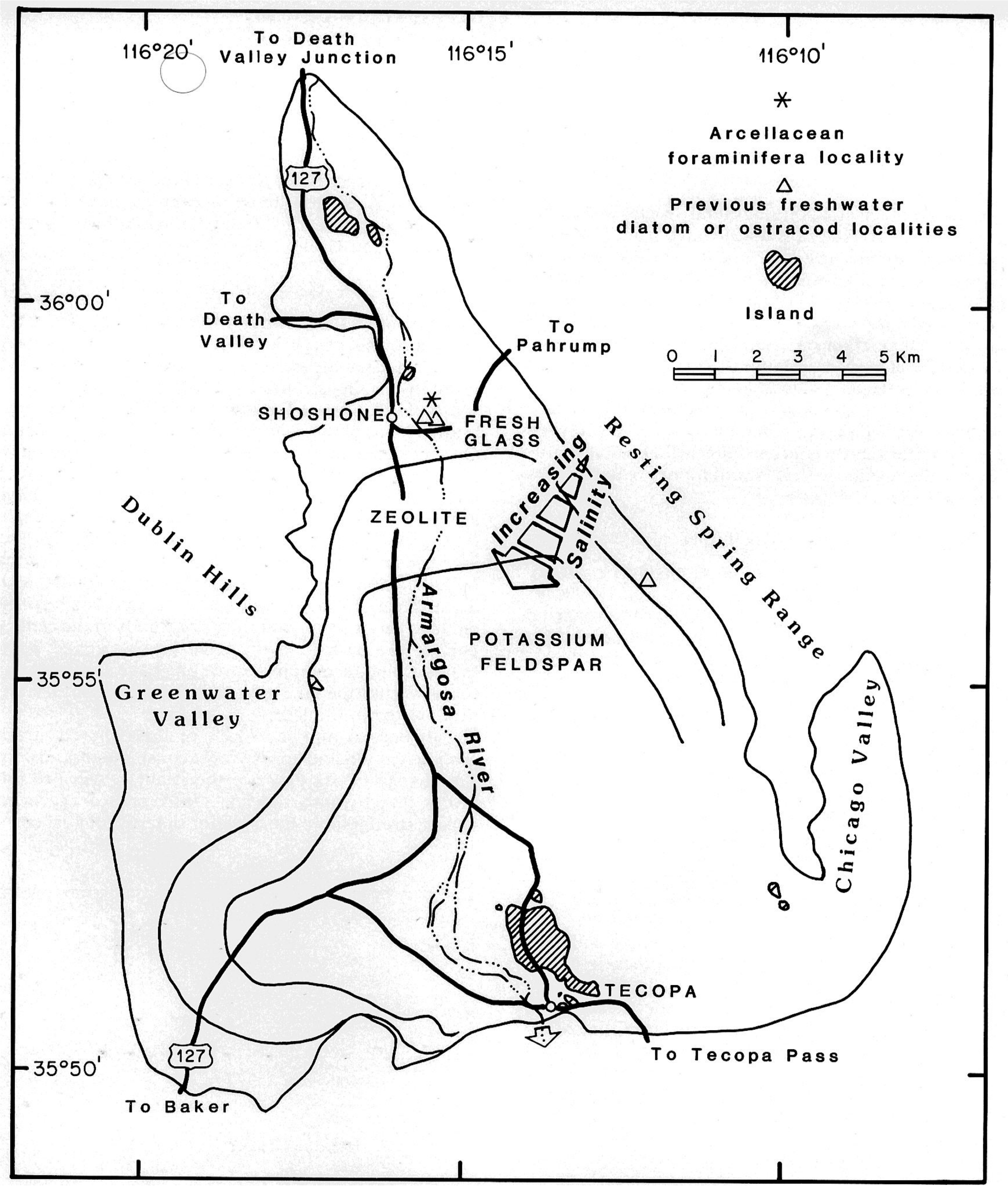


FIGURE 2. Map of Lake Tecopa showing microfossil localities and diagenetic facies (fresh glass, zeolite, and potassium feldspar) for Lava Creek Ash (modified from Sheppard and Gude, 1968).

nous events in lake deposition. Twelve tuffs are recognized in the lake sediments (Fig. 3). A well developed soil horizon above the Lava Creek Ash Tuff indicates intermittent terrestrial conditions.

AGE OF THE LAKE DEPOSITS

Mammalian bone fragments of the genera *Equus*, *Camelops*, *Mammuthus*, and *Ondatra* have been reported from Lake Tecopa by various workers (Bailey, 1902; Noble, 1926; Hay, 1927; Sheppard and Gude, 1968). Sheppard and Gude (1968) also reported the presence of fresh water ostracodes and diatoms. These fossils indicate that the deposits are of middle-late Pleistocene age.

Radiometric techniques and comparison of x-ray diffraction patterns in tuffs has provided finer resolution in dating the lake beds. In the 70 m of exposed lake beds, Sheppard and Gude (1968) and Izett and others (1970) recognized the 0.61-my Lava Creek Ash tuff 45 m above the base of the section; Izett (1981) recognized the 2.01-my old Huckleberry Ridge Ash at 15 m above the base (Fig. 3).

PHYSIOGRAPHIC CONDITIONS DURING LAKE HISTORY

Smith (1984) postulates that the lake was an ephemeral, shallow body, perhaps subject to periodic desiccation, when the present assemblage of arcellaceans and foraminifera was living. Sheppard and Gude (1968) suggested that Lake Tecopa was both saline and alkaline during most of its history; they noted the presence of trona lenses, halite, and molds of gallusite or pirssonite throughout the stratigraphic section in the central part of the basin. Bury and Redd (1933) experimentally determined that a minimum salinity of *14-21 %o* is required to form gallusite and pirssonite. In another study, Freeth (1923) suggested a minimum salinity of *22%o* for the formation of trona. Thus the central basin would have been too saline for most organisms. Further indirect evidence of high salinity in the central basin is provided by the abundant calcite deposits at the north end of the lake where the Amargosa River entered. Calcite precipitated as the inflowing calcium-bearing "fresh" fluvial water mixed with saline basin water. Additional geochemical and biostratigraphic evidence points to an areal variation in lake salinity. Tuffs deposited near shore and within inlets still contain fresh glass (Sheppard and Gude, 1968) and thus probably were deposited in fresh water (Fig. 2). Farther basinward, these same tuffs are represented by zeolite and potassium feldspar facies, respectively, indicating deposition in an environment of areally increasing salinity and alkalinity.

In addition, fossil fresh water diatoms and ostracodes have been found only in sediments near inlets of the lake or close to shore (Fig. 2), providing further evidence of the great lateral variation in salinity and alkalinity in the lake.

MATERIALS

The sample analyzed in this study was collected from a single locality east of the Amargosa River, alongside a short dirt road on the north side of the highway, about 0.8 km east of Shoshone, on the road to Pahrump; SE 1/4 SE 1/4 Sec. 30, T.22N, R.7E. It was taken from a silty bed, 9 m below the top of a dissected lake bed pediment on the northwest side of the first narrow canyon accessed by the dirt road (Fig. 2).

The foraminifera and arcellaceans of this report came from the uppermost 25 m of section (Fig. 3). Based on examination of a core from nearby Searles Lake, in a different drainage basin, Smith (1984) suggested a date of between 0.57 ± 0.12 to 0.31 ± 0.10 Ma for the upper 25 m.

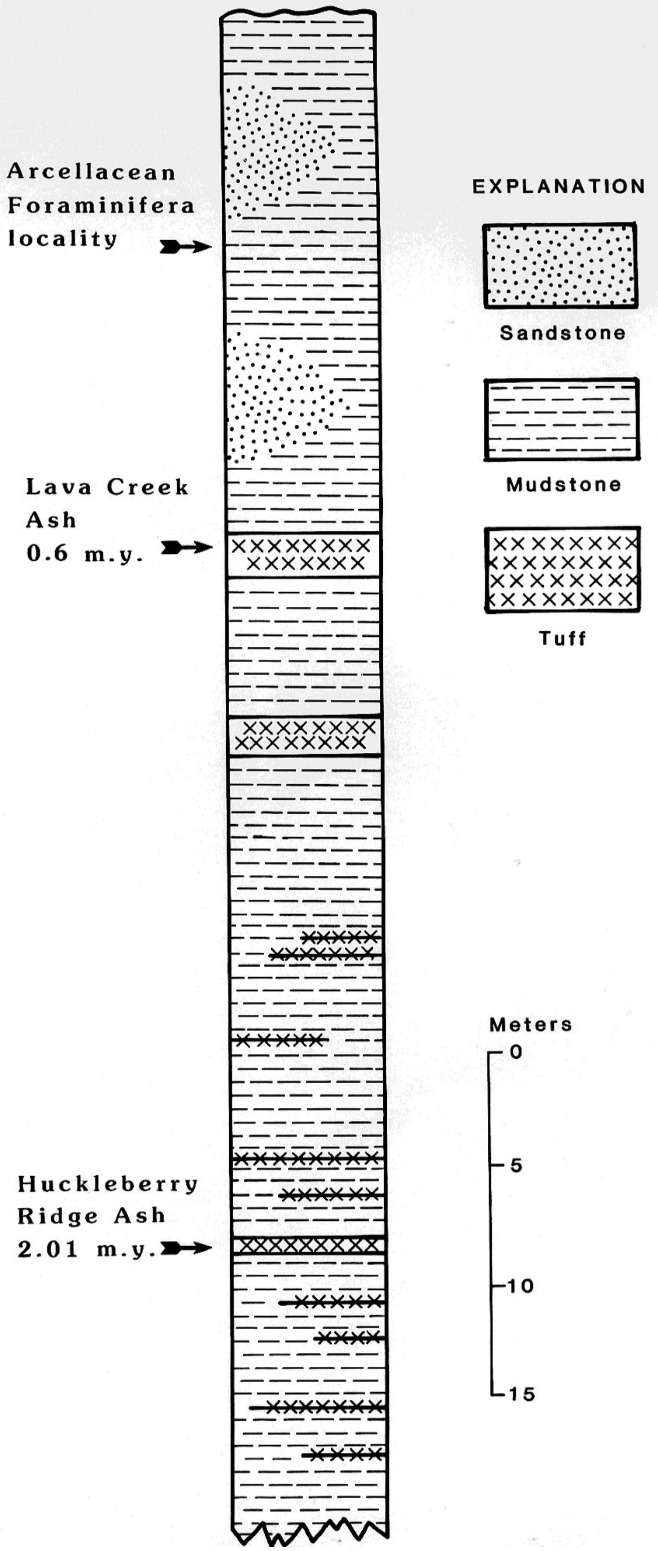


FIGURE 3. Stratigraphic column showing estimated position of the arcellacean and foraminifera sample analyzed in this study (modified from Sheppard and Gude, 1968).

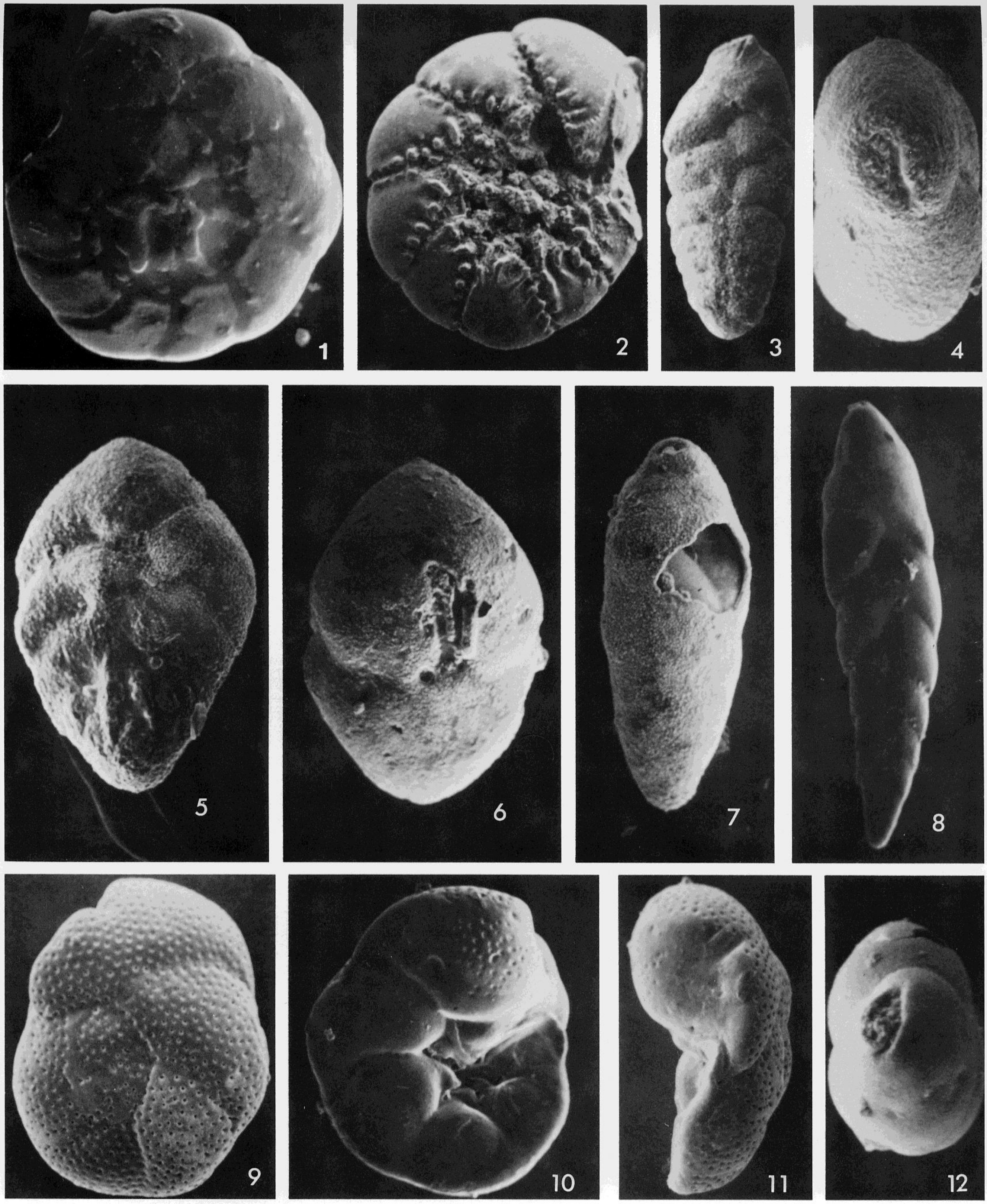


PLATE I

1,2 *Ammonia beccarii* (Linne), hypotype (USNM 383331), both x 120. **1** Spiral view; **2** umbilical view showing incised sutures. **3, 4** *Bolivina goudkoffi* Rankin. **3** Side view of hypotype (USNM 383332) showing protruding aperture, x 120; **4** apertural view showing narrow comma-shaped aperture, x 1,500. **5, 6** *Bolivina pseudoplicata* Heron-Allen and Earland, hypotype (USNM 383333), both x 180. **5** Side view showing distinctive lobate chamber margins and wedge shape; **6** apertural view showing slitlike aperture and protruding toothplate. **7** *Buliminella curta* Cushman. Side view of broken hypo type (USNM 383334) showing internal tooth plate, x 240. **8,12** *Coryphostoma* sp. 8 Side view of hypo type (USNM 383335), x200; **12** apertural view of tooth plate in rounded aperture, x420. **9-11** *Rosalina co/umbiensis* (Cushman). **9** Spiral view of hypotype (USNM 383336) showing coarsely perforate surface, x 130; **10** umbilical view showing open umbilicus, x 120; **11** edge view, x 130.

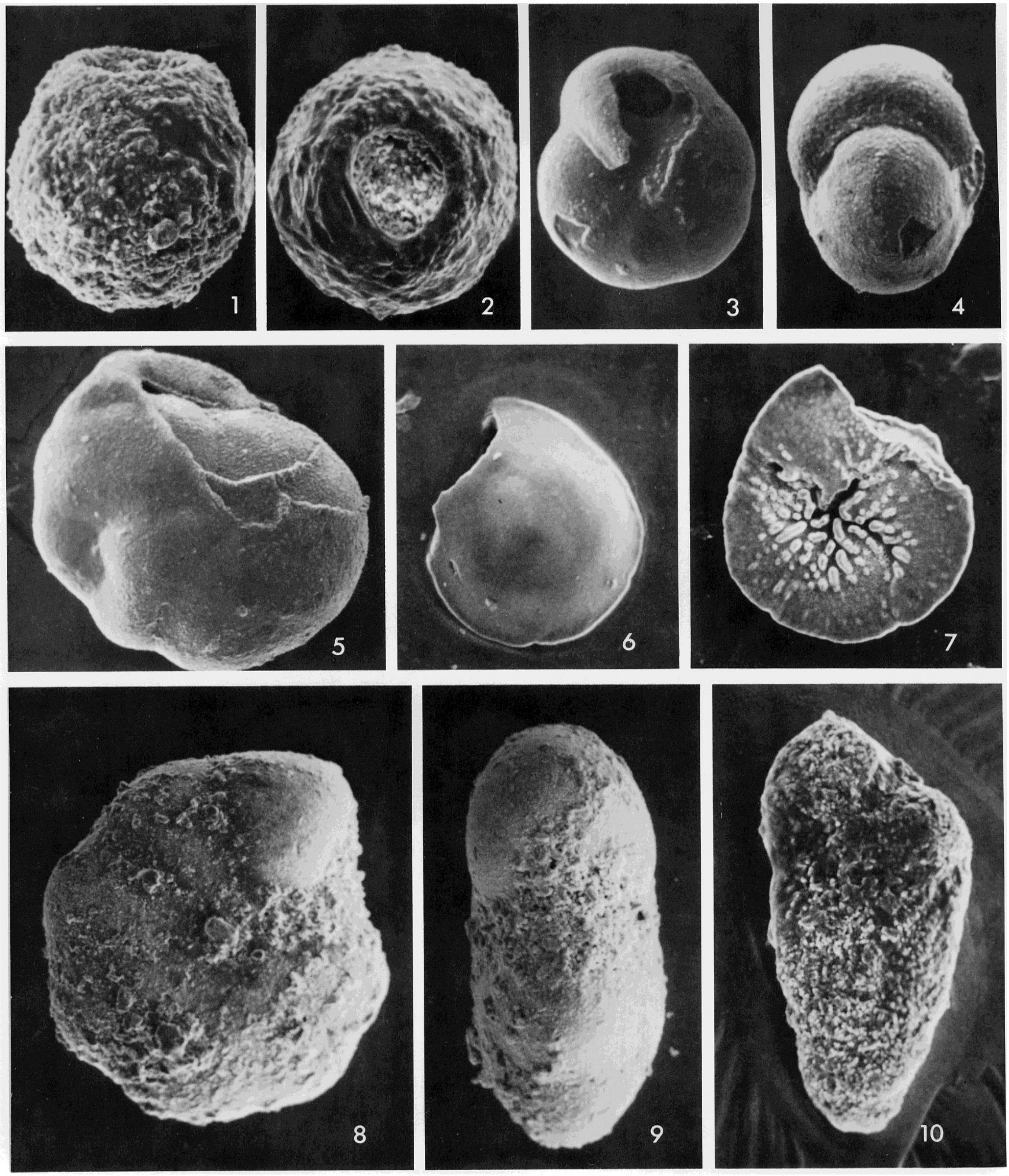


PLATE 2

1, 2 *Centropyxis constricta* (Ehrenberg). **1** Side view of hypotype (USNM 383337) showing unusually globular shape, x 500; **2** apertural view of hypotype (USNM 383338) showing simple round aperture, x 500. **3, 4** *Pullenia bulloides* (d'Orbigny), hypotype (USNM 383339). **3** Side view of damaged hypotype, x 240; **4** apertural view of same hypotype, x 240. **5** *Cassidulina* sp. 1. Side view of specimen (USNM 383340), x 100. **6,7** *Rotorbis* sp. 1. **6** Spiral view of damaged hypotype (USNM 383341), x200; **7** umbilical view showing invaginations and pustules on concave surface, x 240. **8, 9** Foraminiferal sp. 1. **8** Side view of hypotype (USNM 383355), single row of large pores along suture lines obscured, x200; **9** apertural view, x240. 10 Foraminiferal sp. 2. Side view of highly corroded specimen (USNM 383342), x455.

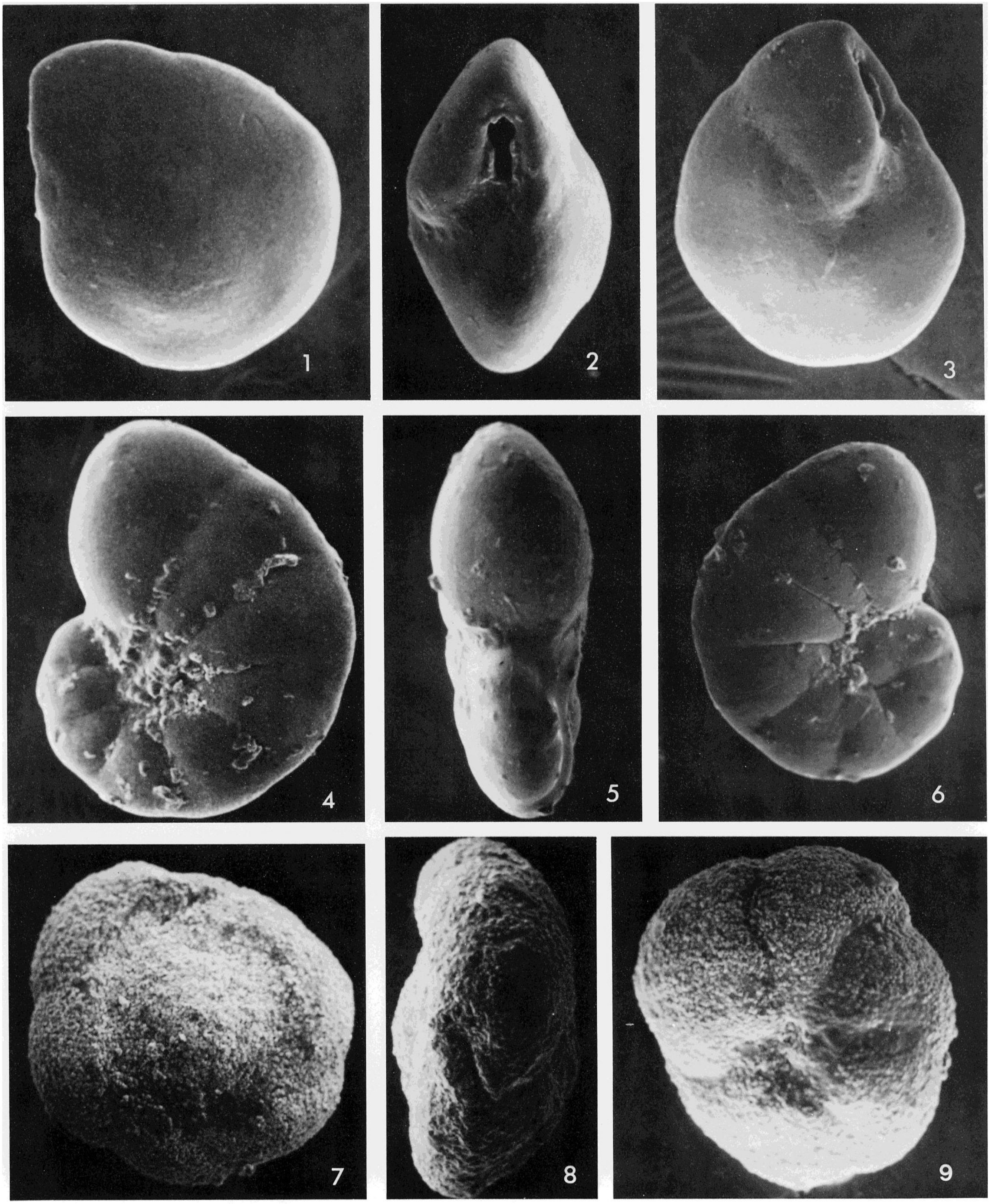


PLATE 3

1-3 *Epistominella subperuviana* (Cushman), hypotype (USNM 383343), all x 350. **1** Spiral view; **2** edge view showing large oblong, narrow lipped aperture; **3** umbilical view. **4-6** *Pseudononion atlantiea* (Cushman), hypo type (USNM 383344). **4** Umbilical view showing characteristic calcareous pustules at center of coiling axis, x 200; **5** edge view showing slight trochospiral coiling, x 240; **6** spiral view showing trochospiral coiling, x 240. **7-9** *Nuttallides* sp. 1.7 Spiral view of highly corroded specimen (USNM 383345), x 337; 8 edge view, x 350; **9** umbilical view, x 350.

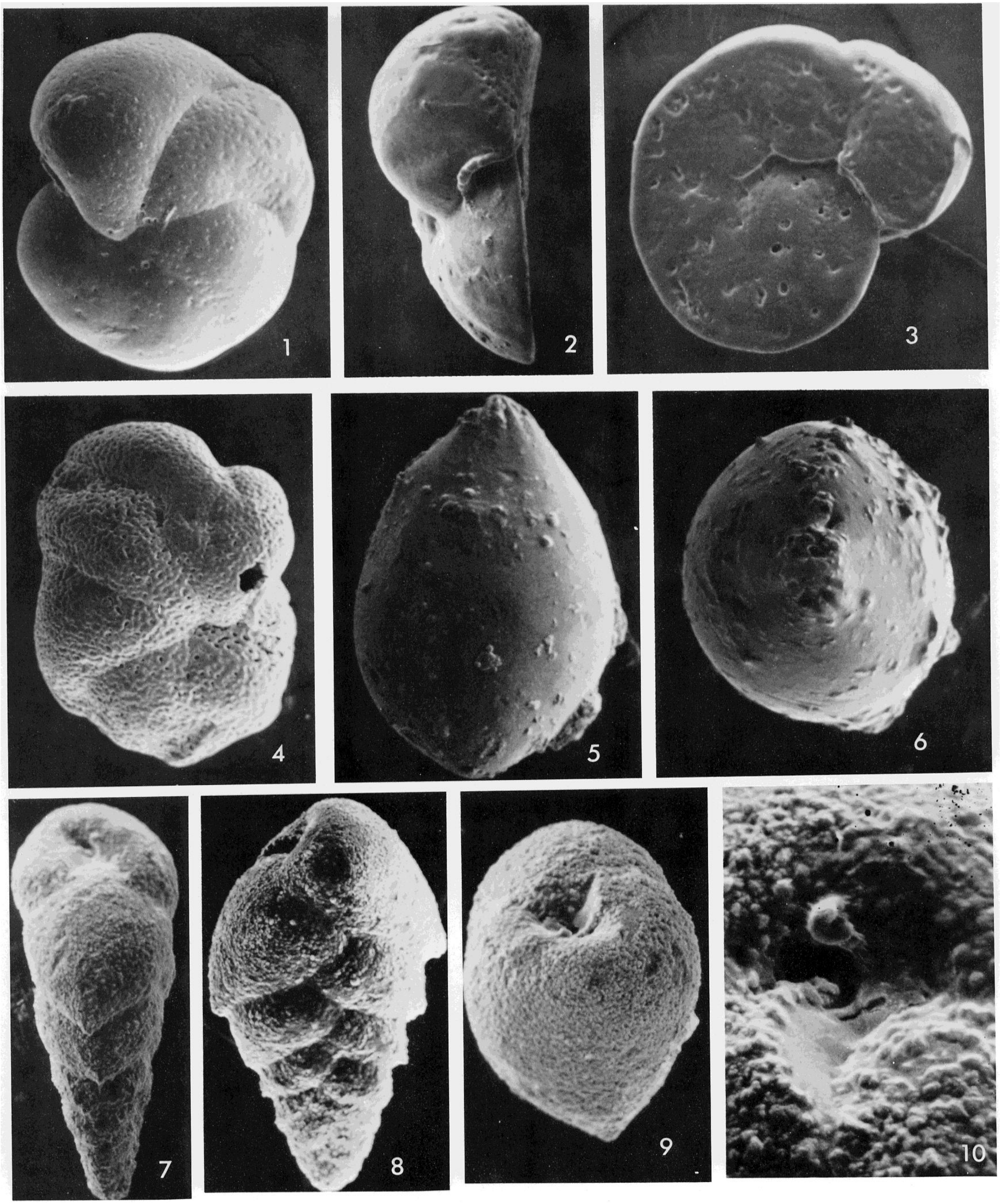
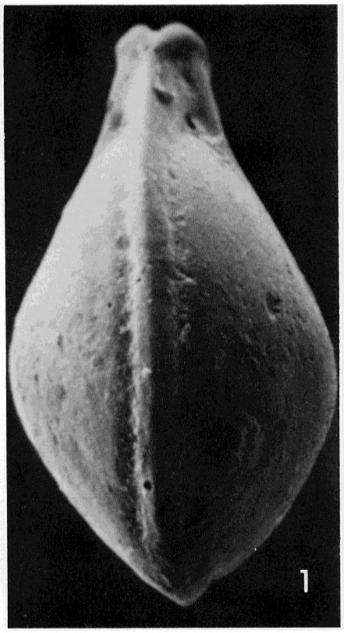
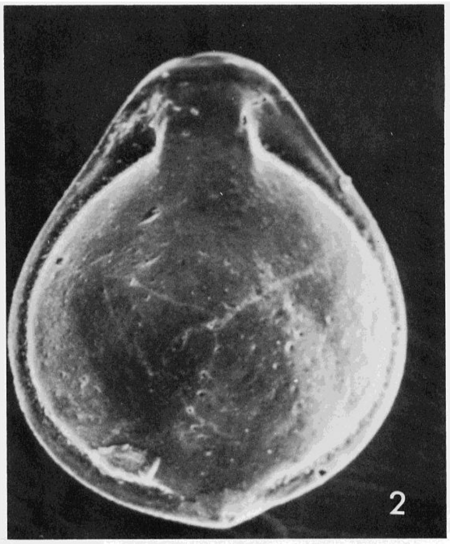
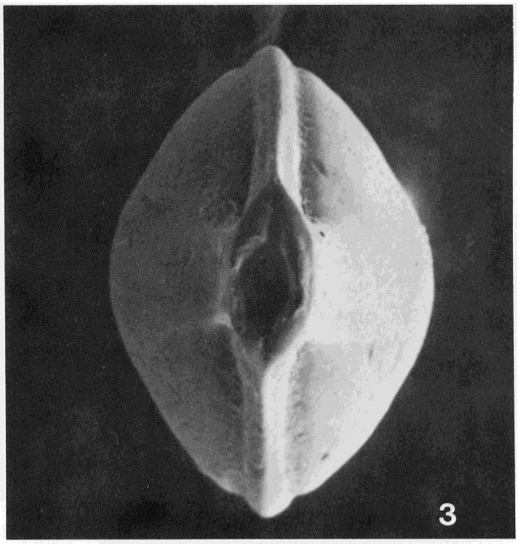


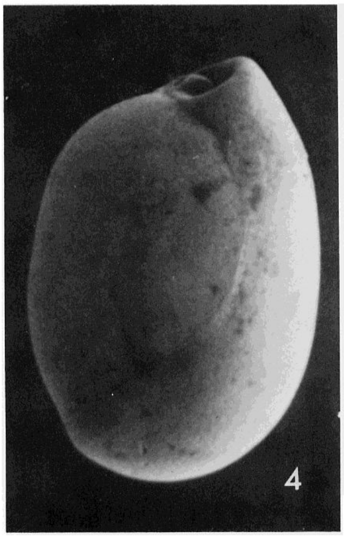
PLATE 4

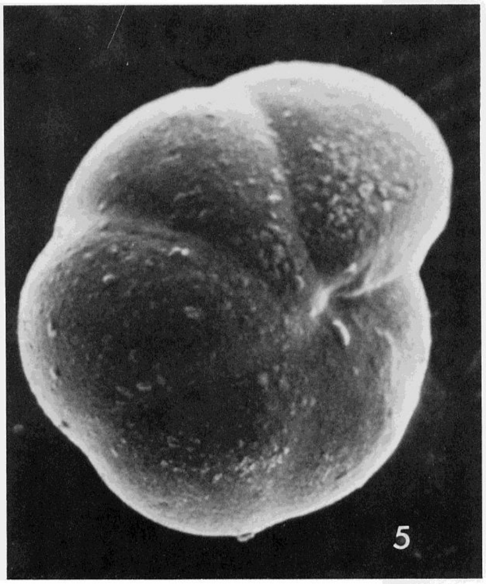
1-4 *Lobatula lobatula* (Walker and Jacob). **1** Umbilical view of hypo type (USNM 383346), x 130; **2** edge view of hypo type (USNM 383347) showing flat spiral side and rimmed aperture, x 130; **3** spiral view of hypotype (USNM 383348) showing apertural groove extending back along the margin several chambers, x 160; **4** umbilical view of a more irregular morphotype, x 100. **5, 6** *Guttulina problema* (d'Orbigny), hypotype (USNM 383349), both x 160.5 Edge view; **6** apertural view. **7-10** *Suggrunda eckisi* Natland, hypo type (USNM 383350). **7** Edge view showing pointed and overlapping chambers, x 350; **8** side view, x 358; **9** apertural view, showing slightly compressed test, x 500; **10** enlargement of aperture, x 1,500.

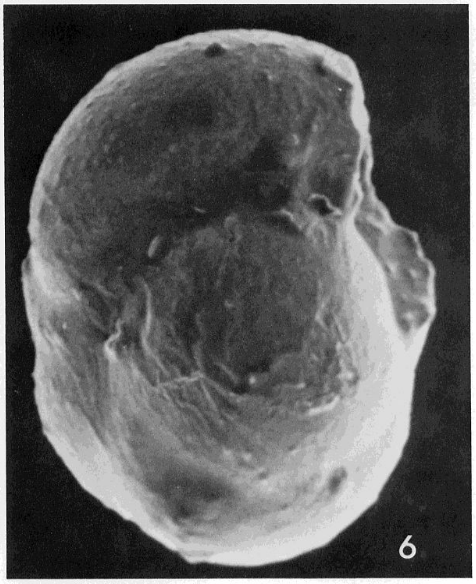


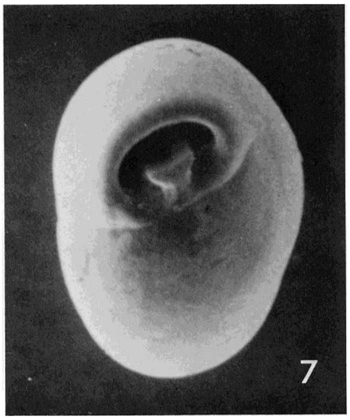


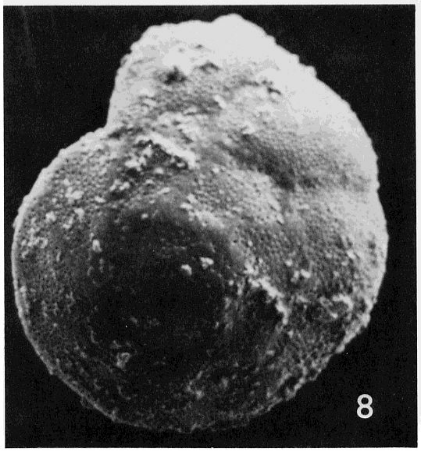












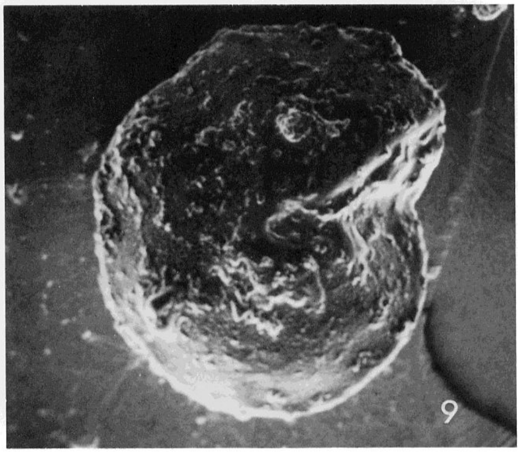


PLATE 5

1-3 *Palliolatella crebra* (Matthes), hypotype (USNM 383351). **1** Edge view, x 420; **2** side view, x 350; **3** apertural view, showing oval aperture within carina, x 420. **4,7** *Triloculina inflata* d'Orbigny. **4** Side view of hypotype (USNM 383352), x 200; **7** apertural view of same hypo type showing triloculine arrangement and bifurcate tooth, x240. **5, 6** Foraminiferal sp. 3. **5** Side view of coiled specimen (USNM 383353) x455; **6** edge view of same specimen showing broken final chamber, x420. **8, 9** *Gyroidina gemma* Bandy, hypotype (USNM 383354), both x 120. **8** Spiral view showing finely perforate test and trochospiral coiling; **9** umbilical view.

METHODS

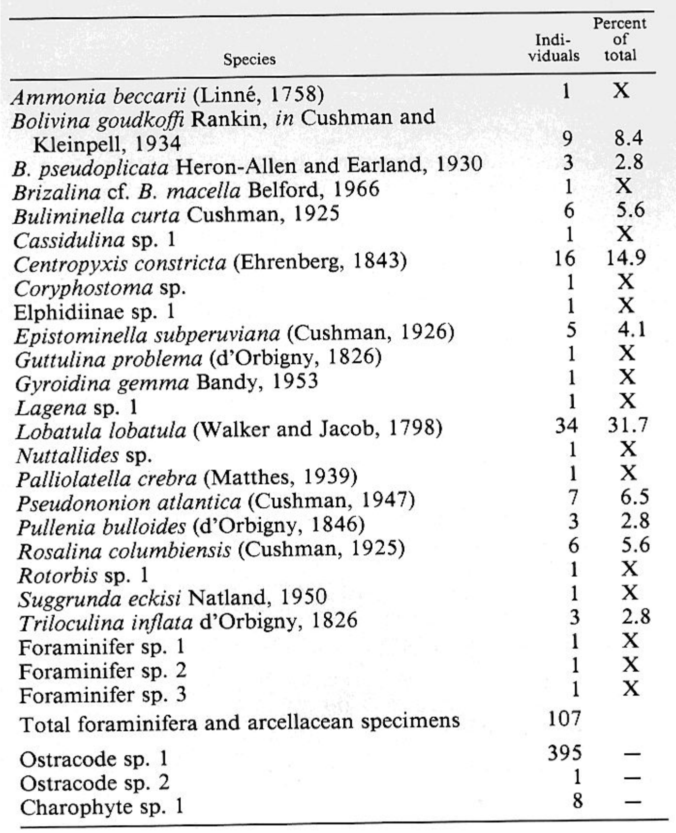
The 10-kg sample was soaked for three hours in kerosene, and after draining, was immersed in water to break down the partially consolidated sediment. The sample was then wet screened using a 200-mesh Tyler (75 µm) sieve to retain arcellaceans and foraminifera. Care was taken during decanting, as arcellaceans have a lower specific gravity than foraminifera. Microfossils were separated from the sandy residue by floating the washed sample in CCl_4. Illustrations (Pis. 1-5) are micrographs taken with an ISI Super-111A Scanning Electron Microscope, using Polaroid NP 55 film.

RESULTS

Twenty-two species of foraminifera, two species of ostracodes, and a single species each of arcellaceans and charophytes are recognized. Of these , seven species of foraminifera are not identifiable due to poor preservation. The ostracodes and charophytes are not identified.

The most abundant microfossil is a smooth-shelled, fresh water ostracode (Table I). Most abundant in the foraminiferal/arcellacean assemblage are *Lobatula lobatula* Walker and Jacob, 1798, comprising 31.7% (Table I), followed by the arcellacean *Centropyxis constricta* Ehrenberg, 1843 (14.9%) and *Bolivina goudkoffi* Rankin (in Cushman and Kleinpell, 1934) (8.4%). Each ofthe other foraminiferal species is represented by very few specimens.

TABLE 1. Foraminiferal, arcellacean, ostracode, and charophyte occurrences from the Pleistocene Lake Tecopa samples. X = < 1%.



Species	Indi-viduals	Percent of total
Ammonia beccarii (Linné, 1758)	1	X
Bolivina goudkoffi Rankin, *in* Cushman and Kleinpell, 1934	9	8.4
B. pseudoplicata Heron-Allen and Earland, 1930	3	2.8
Brizalina cf. *B. macella* Belford, 1966	1	X
Buliminella curta Cushman, 1925	6	5.6
Cassidulina sp. 1	1	X
Centropyxis constricta (Ehrenberg, 1843)	16	14.9
Coryphostoma sp.	1	X
Elphidiinae sp. 1	1	X
Epistominella subperuviana (Cushman, 1926)	5	4.1
Guttulina problema (d'Orbigny, 1826)	1	X
Gyroidina gemma Bandy, 1953	1	X
Lagena sp. 1	1	X
Lobatula lobatula (Walker and Jacob, 1798)	34	31.7
Nuttallides sp.	1	X
Palliolatella crebra (Matthes, 1939)	1	X
Pseudononion atlantica (Cushman, 1947)	7	6.5
Pullenia bulloides (d'Orbigny, 1846)	3	2.8
Rosalina columbiensis (Cushman, 1925)	6	5.6
Rotorbis sp. 1	1	X
Suggrunda eckisi Natland, 1950	1	X
Triloculina inflata d'Orbigny, 1826	3	2.8
Foraminifer sp. 1	1	X
Foraminifer sp. 2	1	X
Foraminifer sp. 3	1	X
Total foraminifera and arcellacean specimens	107	
Ostracode sp. 1	395	—
Ostracode sp. 2	1	—
Charophyte sp. 1	8	—

DISCUSSION

Pleistocene Lake Tecopa represents various environments, from fresh water near the inlets and along the margins, to highly toxic hypersaline conditions in the central basin (Sheppard and Gude, 1968; Fig. 2). Salinity of intermediate parts of the lake was very close to that of seawater, providing an ideal environment for foraminifera. Because none of the Pleistocene lakes in the area were interconnected with the ocean, normal foraminiferal colonization modes were precluded (Fig. 1). Several authors have suggested avian transport as a means of initial foraminiferal colonization (Howchin, 1901; Resig, 1974; Cann and De Deckker, 1981). This mechanism was illustrated for ostracodes by De Deckker (1977). Lake Tecopa is 300 km from the Pacific and was never in direct connection with it. It is probable that foraminifera were transported to the lake by ducks or other seabirds commuting from the ocean. This hypothesis is supported by the foraminiferal faunal list that consists primarily of marsh and other species common along the California coast.

The only typical marsh species present is *Ammonia beccarii*, represented by a single specimen in the Lake Tecopa material (Table I). This genus is among those most common in nonmarine foraminiferal assemblages (Arnal, 1955a, b, 1957, 1958; Resig, 1974; Cann and De Decker, 1981; Fontes and others, 1985).

The presence of arcellaceans in late Pleistocene sediments is also notable. Although there have been scattered reports of Arcellacea from throughout the Tertiary (Bradley, 1931; Deflandre, 1953), they usually occur only in Holocene deposits due to the delicate nature of their tests (Scott and Medioli, 1983; Patterson and others, 1985).

The association of fresh water arcellaceans, charophytes, and ostracodes with marine foraminifera suggests that the assemblage was partially transported. The arcellacean *Centropyxis constricta* is widespread and common in North American lakes (Scott and Medioli, 1983; Patterson and others, 1985), but is usually found only under fresh water conditions. The fresh water biota was probably carried into the marine part of the lake by the discharging Amargosa River, as the inlet is located near the sample locality (Fig. 2).

Smith (1984) claimed that Lake Tecopa was only partially filled and subject to periodic desiccation during the last half million years. Cann and De Deckker (1981) reported that only a few species offoraminifera can withstand prolonged periods of desiccation. Their field and laboratory experiments have shown that certain species of *Elphidium* and *Trochammina* can withstand ephemeral lake conditions. They found that some *Ammonia* and miliolids, although highly tolerant of variable salinities, cannot exist under such extremes. The low species diversity of Australian nonmarine foraminiferal habitats is probably attributable to the unstable environment (variable salinity, periodic desiccation), in which few species can survive and reproduce; random colonization also may be a significant factor.

The presence of *Ammonia beccarii, Triloculina inflata,* and a large number of other species seems to preclude yearly drying of Lake Tecopa, as occurs in some south Australian lakes (Cann and De Deckker, 1981). The large size and diversity of the fauna also precludes yearly colonization of the lake. Resig (1974) postulated that the foraminiferal assemblage in Salt Lake; Oahu, Hawaii, developed sometime between 1910 and 1967, following the termination of commercial salt production in the lake. Total desiccation events in the late Pleistocene history of Lake Tecopa may therefore have occurred on the order ofa few times a century. Further detailed sampling could provide a more definitive history offoraminiferal and arcellacean habitation in Lake Tecopa. This should result in a more accurate determination of paleolimnological conditions in the lake than is currently available from petrographical evidence. In addition, this study reminds us that the nonmarine occurrence of foraminifera is probably fairly common. This possibility must be taken into consideration when interpreting foraminiferal-bearing facies.

ACKNOWLEDGMENTS

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The figured hypotypes are deposited in the U.S, National Museum of Natural History, Washington, D.C.

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