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REEXAMINATION OF THE BENTHIC FORAMINIFERAL FAUNA FROM A LATE PLEISTOCENE MARINE TERRACE DEPOSIT NEAR GOLETA, CALIFORNIA

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ABSTRACT—A benthic foraminiferal fauna of 39 species was quantitatively examined from a late Pleistocene marine terrace deposit near Goleta, California. This foraminiferal fauna, dominated by *Cribroelphidium microgranulosum, Buccella tenerrima, Buliminella elegantissima,* and *Cribroelphidium tumidum,* is presently most common in cool, shallow (<12 m, but usually 0–5 m) subtidal environments north of Point Conception, California. This indicates slightly cooler water temperatures during the time of deposition than found near Goleta today, and agrees closely with the results of a previous paleoenvironmental interpretation of the section based on molluscan fossils.

INTRODUCTION

THE FORAMINIFERAL fauna from a Pleistocene terrace deposit near Goleta, California (Figure 1), was cursorily described by Arnal (*in* Wright, 1972). He recognized 18 different benthic and planktonic foraminiferal taxa, five of which were identified only to the genus level. Examination of other samples from this Pleistocene deposit, however, indicates the presence of a much larger benthic foraminiferal fauna than was previously reported.

The molluscan fauna was described in some detail by Grant and Gale (1934), Oldroyd and Grant (1931), and Wright (1972). Based on the in situ molluscan fauna and lithology, Wright (1972) interpreted the deposit as representing an open coast, rocky-shore to level-bottom, inner sublittoral environment. Based on previously published ages of raised marine terraces from around southern California, Wright (see Wright, 1972, for summary) suggested that the terrace near Goleta may be Sangamonian in age. However, the closed-system uranium-series age estimate of 69,000 ± 10,000 years B.P. for the lowest emergent terrace deposits at Newport Beach–Laguna Beach and Palos Verdes Hills, California (Szabo and Vedder, 1971), suggests that the deposit may have actually been deposited during the earliest part of the Wisconsinian Stage (Harland et al., 1982).

The purpose of this study is to describe and quantify the entire benthic foraminiferal fauna, make a paleoenvironmental interpretation based on this data, and determine how closely the interpretation based on foraminifera matches that provided by the molluscan fauna (Wright, 1972).

MATERIALS AND METHODS

Six 3–4 kilogram samples were collected from the Miocene–Pliocene Sisquoc Formation and an overlying unconsolidated Pleistocene marine terrace deposit. These deposits are exposed continuously along the coast 4.0 km southwest of Goleta, California. The fossiliferous sandy–silty Pleistocene deposit ranges in thickness from 0.3 to 1.0 m, occurs 2–6 m above the present beach, and unconformably overlies the north–northeastward dipping diatomaceous shale of the Miocene–Pliocene Sisquoc Formation. Sample localities were measured from the foot of the stairs to the beach at the seaward end of Camino Majorca Road (Figure 1).

Foraminifera were examined from the following localities:

1. Miocene–Pliocene: Sisquoc Formation, 100 m east of the stairs to beach.
2. Miocene–Pliocene: Sisquoc Formation, 51.3 m east of the stairs to beach.
3. Miocene–Pliocene: Sisquoc Formation, at base of the stairs to beach.
4. Pleistocene: terrace deposit, from drainage ditch cutting the 0.3-m-thick unit, 31 m west of stairs to beach.
5. Pleistocene: terrace deposit, from 0.3-m-thick portion of unit, 90.6 m west of stairs to beach.
6. Pleistocene: terrace deposit, from 0.3-m-thick portion of unit, 256.5 m west of stairs to beach.

The consolidated Pliocene samples were oven dried and then soaked in kerosene for a few hours. The kerosene was then decanted and the samples covered by water to speed disaggregation. This process was not required for the Pleistocene samples as they were unconsolidated. All samples were then boiled in water to which soda ash was added, then washed over a 250 mesh (63 μm) Tyler equivalent sieve, and then dried. The Pleistocene samples had large benthic foraminiferal populations and were split using a modified Otto microsplitter to obtain a random subsample of at least 1,000 benthic foraminiferal specimens per sample (Table 1). The foraminiferal assemblage of the Sisquoc samples was much less diverse; hence, the entire sample residue was examined. The benthic foraminifers were then quantitatively examined under a binocular stereoscopic microscope, usually at ×20. Figured hypotypes are deposited in the U.S. National Museum of Natural History, Washington, D.C.

RESULTS

A total of 41 different benthic foraminiferal species were observed, with 39 species present in samples 4–6 from the Pleistocene marine terrace deposit. Most species were rare, with only four species being abundant in all samples: *Buccella tenerrima* (Bandy, 1950), *Buliminella elegantissima* (d'Orbigny, 1839), *Cribroelphidium microgranulosum* (Galloway and Wissler, 1927), and *Cribroelphidium tumidum* (Natland, 1938). *Buliminella curta* (Cushman, 1925) was common, ranging from 1.9 percent in sample 6 to 5.7 percent in sample 5. *Elphidiella hannai* (Cushman and Grant, 1927), although common in sample 4 (3.5%) and sample 6 (3.0%), was not found in sample 5. Similarly, *Quinqueloculina triangularis* d'Orbigny, 1846, made up 7.4 percent of the fauna of sample 5, but was absent from samples 4 and 6.

Cribroelphidium microgranulosum was the most abundant species in these samples, ranging from 23.7 percent of the benthic foraminiferal population in sample 5 to 52.3 percent in sample 6. The next most abundant species, *Buccella tenerrima,* varied from 11.5 percent in sample 5 to 20.0 percent in sample

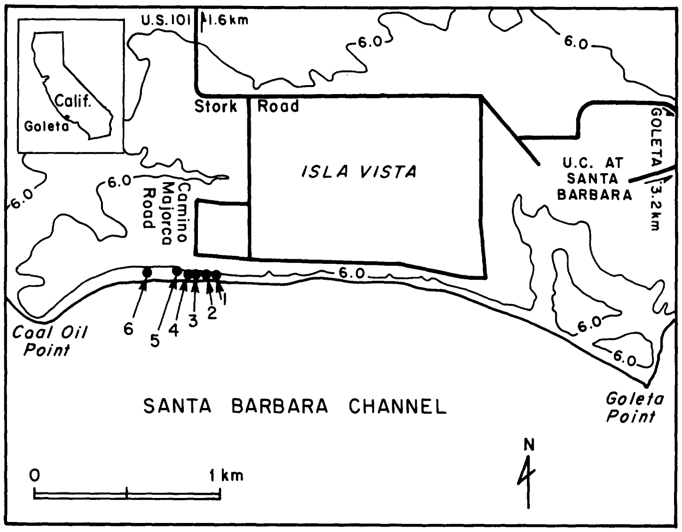

FIGURE *1*—Index map showing sample localities.

4. Third most abundant was *Buliminella elegantissima*, which ranged from 3.9 percent of the benthic foraminifera in sample 4 to 18.7 percent in sample 5. Fourth most numerous was *Cribroelphidium tumidum*, which ranged from 6.2 percent in sample 6 to 18.2 percent in sample 5.

Samples 1–3 from the silty shales of the Miocene–Pliocene Sisquoc Formation, although rich in diatoms, yielded a very meager foraminiferal fauna of only three species. Abundances ranged from only six specimens recovered from sample 1 to eight specimens found in sample 2. Sample 1 had the most diverse fauna, consisting of *Bolivina wissleri* Kleinpell and Tipton, 1980, *Buliminella brevior* Cushman, 1925, and *Nonionella stella* Cushman and Moyer, 1930, with the latter two species being found in all samples. *Nonionella stella* dominated the fauna of the Pliocene samples, ranging from 50.0 percent of the fauna in sample 1 to 75.0 percent in sample 2. *Buliminella brevior* ranged from 25 percent of the fauna in sample 2 to 42.9 percent in sample 3. It should be noted, however, that due to the low recovery of specimens from the Pliocene samples these percentages have little significance.

DISCUSSION

The Pleistocene terrace deposit yielded a fauna of 39 benthic foraminiferal species. However, as many small clasts of the underlying Miocene–Pliocene Sisquoc Formation occurred within the Pleistocene deposit, reworking of older foraminiferal species was a major concern. Of the three species recovered from the meager Sisquoc Formation benthic foraminiferal fauna, only *Nonionella stella* was found in both units and thus could possibly have been reworked from the Pliocene deposits. This is not necessarily the case though, as this species ranges into the Recent and is found ubiquitously along the present California coast. In addition, the species is much more abundant in the Pleistocene material than in the Sisquoc Formation samples. Thus, there is little evidence that local exposures of the Sisquoc Formation were a major source of contaminating foraminifers.

However, two species found in the Pleistocene terrace deposits, *Pullenia miocenica* Kleinpell, 1938, and *Brizalina californica* (Cushman, 1925), definitely were reworked from Miocene outcrops elsewhere (Vedder et al., 1969), as their last reported stratigraphic occurrences have been from the Luisian Stage of the Middle Miocene and from lower Mohnian Stage deposits of the Late Miocene, respectively (Kleinpell, 1980). In addition, the less well known *Bolivina adelaidana* Cushman and Kleinpell, 1934, also described from the Miocene, was probably reworked.

The fauna of this California Pleistocene terrace deposit is dominated by four species (Table 1), *Cribroelphidium microgranulosum, Buccella tenerrima, Cribroelphidium tumidum,* and *Buliminella elegantissima.* The assemblage is superficially similar to that described by Bandy (1950) from the raised Pleistocene terrace of the Elk River Formation at Cape Blanco, Oregon, which contained 13 percent *Cribroelphidium microgranulosum* and 18 percent *Buccella tenerrima,* cited as *Elphidium granulosum* (Galloway and Wissler, 1927) and *Rotalia tenerrima* Bandy, 1950, respectively, by Bandy (1950). Bandy (1950) interpreted the fauna as being indicative of very shallow, cool water.

Cribroelphidium microgranulosum, the most abundant species in the Pleistocene samples, currently ranges from southern California to northern Washington, but it is most abundant (up to 84% of the fauna) north of Point Conception and along the Oregon coast (Cooper, 1961; Lankford and Phleger, 1973). Living specimens are restricted to shallow water from 0 to 12 m and are most common in very shallow water (≤ 1 m) in tidepools and beach sediments.

Buccella tenerrima, the next most abundant species, is presently most common in sandy beach and tidepool sediments, and offshore at water depths of less than 12 m. Its wide geographic distribution ranges from Baja California, Mexico, northward to Washington. However, the species is rare south of Point Conception, and most abundant between Morro Bay and San Francisco Bay, where it comprises 8–30 percent of the intertidal foraminiferal fauna (Cooper, 1961; Lankford and Phleger, 1973).

Cribroelphidium tumidum and *Buliminella elegantissima* are the other most important species of the Pleistocene terrace deposit. Both are ubiquitous along the west coast of North America from Baja California to Alaska (Lankford and Phleger, 1973). *Cribroelphidium tumidum,* although found at many depths, is most common at around 30 m on rocky to sandy substrates, whereas *Buliminella elegantissima* is most common at depths of less than 12 m, almost exclusively on fine sand (Lankford and Phleger, 1973).

Based on present-day distribution of the major foraminiferal faunal elements in the raised Pleistocene marine terrace near Goleta, an analysis of the quantitative results suggests a cool, shallow (0–12 m and probably less than 5 m), subtidal environment of deposition. The foraminiferal fauna is most similar to that presently found north of Point Conception to Oregon and indicates cooler local conditions than presently found in the Goleta area. This interpretation closely matches that proposed by Wright (1972), based on a semi-quantitative analysis of the molluscan fauna.

FAUNAL LIST

Species are listed alphabetically. Generic designations follow Loeblich and Tappan (1987).

ANGULOGERINA FLUENS Todd

Angulogerina fluens TODD, *in* Cushman and Todd, 1947, p. 67, Pl. 16, figs. 6, 7 (nomen nudum).
Angulogerina fluens TODD, *in* Cushman and McCulloch, 1948, p. 288.

BOLIVINA ACUMINATA (Natland)

Bolivina subadvena Cushman var. *acuminata* NATLAND, *in* Cushman and Gray, 1946b, p. 34, Pl. 5, fig. 46.

TABLE 1—Percent occurrences of benthic foraminifera from measured section at Goleta locality. Samples 1–3 are from the Miocene–Pliocene Sisquoc Formation, and samples 4–6 are from the late Pleistocene marine terrace deposit.

Sample	1	2	3	4	5	6
No. of species	3	2	2	27	26	25
Total individuals	6	8	7	1,155	1,103	1,143
Angulogerina fluens	—	—	—	—	—	0.1
Bolivina acuminata	—	—	—	1.6	—	1.1
Bolivina decussata	—	—	—	0.8	0.5	0.8
Bolivina wissleri	16.7	—	—	—	—	—
Brizalina adelaidana	—	—	—	0.3	1.6	0.1
Brizalina californica	—	—	—	0.7	1.7	0.4
Brizalina humilis	—	—	—	0.3	1.6	—
Brizalina quadrata	—	—	—	2.0	2.1	0.8
Buccella tenerrima	—	—	—	20.0	11.5	14.0
Buliminella brevior	33.3	25.0	42.9	—	—	—
Buliminella curta	—	—	—	5.3	5.7	1.9
Buliminella elegantissima	—	—	—	3.9	18.7	8.7
Cribroelphidium microgranulosum	—	—	—	42.6	23.7	52.3
Cribroelphidium tumidum	—	—	—	11.9	18.2	6.2
Dyocibicides biserialis	—	—	—	0.6	—	6.7
Elphidiella hannai	—	—	—	3.5	—	3.0
Euuvigerina juncea	—	—	—	—	—	0.1
Favulina squamosa	—	—	—	0.6	0.2	0.1
Fissurina sp. 1	—	—	—	0.2	—	—
Fissurina copiosa	—	—	—	—	—	0.2
Fissurina romettensis	—	—	—	—	—	0.2
Fissurina vitreola	—	—	—	—	0.4	0.2
Homalohedra apiopleura	—	—	—	0.1	0.4	—
Lagena flexa	—	—	—	0.2	—	—
Lagena pliocenica	—	—	—	—	0.2	—
Lagena spicata	—	—	—	0.2	—	—
Lagena striata	—	—	—	0.1	0.4	—
Lobatula fletcheri	—	—	—	1.9	1.0	0.4
Nonionella stella	50.0	75.0	57.1	0.3	0.2	0.2
Oolina caudigera	—	—	—	—	0.1	—
Palliolatella ronani	—	—	—	0.7	0.6	0.9
Patellina corrugata	—	—	—	—	0.1	—
Procerolagena meridionalis	—	—	—	0.1	0.4	—
Pseudononion basispinata	—	—	—	0.1	—	0.2
Pseudotriloculina oblonga	—	—	—	—	0.5	0.7
Pullenia cf. *P. miocenica*	—	—	—	—	0.2	—
Quinqueloculina gigas	—	—	—	—	—	0.5
Quinqueloculina triangularis	—	—	—	—	7.4	—
Rosalina columbiensis	—	—	—	1.1	1.4	—
Sigmomorphina frondicularis	—	—	—	0.1	—	—
Tretomphalus pacificus	—	—	—	0.7	—	0.3

BOLIVINA ADELAIDANA Cushman and Kleinpell
Figure 2.1, 2.2

Bolivina marginata Cushman var. *adelaidana* CUSHMAN AND KLEINPELL, 1934, p. 10, Pl. 2, figs. 1, 2.

BOLIVINA DECUSSATA Brady

Bolivina decussata BRADY, 1881, p. 58.
Bolivina decussata BRADY, 1884, p. 423, Pl. 53, figs. 12, 13.

BOLIVINA WISSLERI Kleinpell and Tipton
Figure 2.6, 2.7

Bolivina wissleri KLEINPELL AND WISSLER, *in* Kleinpell, 1980, p. 74, 75, Pl. 8, figs. 14–16.

BRIZALINA CALIFORNICA (Cushman)
Figure 2.3–2.5

Bolivina californica CUSHMAN, 1925a, p. 32, Pl. 5, fig. 10.

BRIZALINA cf. B. HUMILIS (Cushman and McCulloch)

Bolivina seminuda Cushman var. *humilis* CUSHMAN AND MCCULLOCH, 1942, p. 211, Pl. 26, figs. 1–6.

BRIZALINA QUADRATA (Cushman and McCulloch)

Bolivina quadrata CUSHMAN AND MCCULLOCH, 1942, p. 205, Pl. 25, fig. 13.

BUCCELLA TENERRIMA (Bandy)
Figure 2.8, 2.9

Rotalia tenerrima BANDY, 1950, p. 278, Pl. 42, fig. 3.

BULIMINELLA BREVIOR Cushman
Figure 2.11

Buliminella brevior CUSHMAN, 1925a, p. 33, Pl. 5, fig. 14.

BULIMINELLA CURTA Cushman
Figure 2.10

Buliminella curta CUSHMAN, 1925a, p. 33, Pl. 5, fig. 13.

BULIMINELLA ELEGANTISSIMA (d'Orbigny)
Figure 3.1

Bulimina elegantissima D'ORBIGNY, 1839, p. 51, Pl. 7, figs. 13, 14.

CRIBROELPHIDIUM MICROGRANULOSUM (Galloway and Wissler)
Figure 3.3

Themeon decipiens GALLOWAY AND WISSLER, 1927a, p. 83, Pl. 12, figs. 15, 16 (not *Polystomella decipiens* Costa, 1856).
Themeon granulosus GALLOWAY AND WISSLER, 1927b, p. 193 (not *Polystomella macella* (Fichtel and Moll) var. *granulosa* Sidebottom, 1909).
Elphidium microgranulosum GALLOWAY AND WISSLER, *in* Thalmann, 1951, p. 222.

CRIBROELPHIDIUM TUMIDUM (Natland)
Figure 3.4–3.6

Elphidium tumidum NATLAND, 1938, p. 144, Pl. 5, figs 5, 6.

DYOCIBICIDES BISERIALIS Cushman and Valentine

Dyocibicides biserialis CUSHMAN AND VALENTINE, 1930, p. 31, Pl. 10, figs. 1, 2.

ELPHIDIELLA HANNAI (Cushman and Grant)

Elphidium hannai CUSHMAN AND GRANT, 1927, p. 77, Pl. 8, fig. 1.

EUUVIGERINA JUNCEA (Cushman and Todd)

Uvigerina juncea CUSHMAN AND TODD, 1941, p. 78, Pl. 20, figs. 4–11.

FAVULINA SQUAMOSA (Montagu)

Vermiculum squamosa MONTAGU, 1803, p. 526, Pl. 14, fig. 2.

FISSURINA COPIOSA McCulloch

Fissurina copiosa MCCULLOCH, 1977, p. 97, Pl. 63, fig. 1.

FISSURINA ROMETTENSIS Seguenza

Fissurina (Fissurine) romettensis SEGUENZA, 1862, p. 66, Pl. 2, fig. 24.

FISSURINA sp. 1

This new species will be described in a forthcoming taxonomic treatment (Patterson, in prep.) of Pleistocene foraminifera from Santa Barbara, California.

FISSURINA VITREOLA (Buchner)

Lagena vitreola BUCHNER, 1940, p. 477, Pl. 13, figs. 256–258.

HOMALOHEDRA APIOPLEURA (Loeblich and Tappan)

Lagena apiopleura LOEBLICH AND TAPPAN, 1953, p. 59, Pl. 10, figs. 14, 15.

LAGENA FLEXA Cushman and Gray

Lagena flexa CUSHMAN AND GRAY, 1946a, p. 68, Pl. 12, figs. 18–21.

LAGENA PLIOCENICA Cushman and Gray

Lagena pliocenica CUSHMAN AND GRAY, 1946a, p. 68, Pl. 12, figs. 22–25.

LAGENA SPICATA Cushman and McCulloch

Lagena sulcata (Walker and Jacob) var. *spicata* CUSHMAN AND MCCULLOCH, 1950, p. 360, Pl. 48, figs. 4, 5, 7, (not 3, 6).

LAGENA STRIATA (d'Orbigny)

Oolina striata D'ORBIGNY, 1839, p. 21, Pl. 5, fig. 12.

LOBATULA FLETCHERI (Galloway and Wissler)

Cibicides fletcheri GALLOWAY AND WISSLER, 1927, p. 64, Pl. 10, figs. 8, 9.

NONIONELLA STELLA Cushman and Moyer
Figure 3.2

Nonionella miocenica Cushman var. *stella* CUSHMAN AND MOYER, 1930, p. 56, Pl. 7, fig. 17.

OOLINA CAUDIGERA (Wiesner)

Lagena (Entosolenia) globosa (Montagu) var. *caudigera* WIESNER, 1931, p. 119, Pl. 18, fig. 214.

PALLIOLATELLA RONANI (Young)

Fissurina ronani YOUNG, 1981, p. 905, Pl. 1, figs. 12, 13.

PATELLINA CORRUGATA Williamson

Patellina corrugata WILLIAMSON, 1858, p. 46, Pl. 3, figs. 86–89, 89a.

PROCEROLAGENA MERIDIONALIS (Wiesner)

Lagena gracilis Williamson var. *meridionalis* WIESNER, 1931, p. 117, Pl. 218, fig. 211.

PSEUDONONION BASISPINATA (Cushman and Moyer)

Nonion pizarrensis Berry var. *basispinata* CUSHMAN AND MOYER, 1930, p. 54, Pl. 7, fig. 18.

PSEUDOTRILOCULINA OBLONGA (Montagu)

Vermiculum oblonga MONTAGU, 1803, p. 522, Pl. 14, fig. 9.

PULLENIA MIOCENICA Kleinpell

Pullenia miocenica KLEINPELL, 1938, p. 338, Pl. 14, fig. 6.

QUINQUELOCULINA GIGAS Natland

Quinqueloculina gigas NATLAND, 1938, p. 141, Pl. 4, fig. 4.

QUINQUELOCULINA TRIANGULARIS d'Orbigny

Quinqueloculina triangularis D'ORBIGNY, 1846, p. 288, Pl. 18, figs. 7–9.

ROSALINA COLUMBIENSIS (Cushman)

Discorbis columbiensis CUSHMAN, 1925b, p. 43, Pl. 6, fig. 13a–c.

SIGMOMORPHINA FRONDICULARIS (Galloway and Wissler)

Polymorphina frondicularis GALLOWAY AND WISSLER, 1927, p. 55, Pl. 9, fig. 6.

TRETOMPHALUS PACIFICUS Cushman

Tretomphalus pacificus CUSHMAN, 1934, p. 93, Pl. 11, fig. 7; Pl. 12, figs 8–12.

VASICOSTELLA SEMIALATA (Balkwill and Millett)

Lagena quadrata (Williamson) var. *semialata* BALKWILL AND MILLETT, 1884, p. 81, Pl. 2, fig. 9.

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FIGURE *2—1, 2, Bolivina adelaidana* Cushman and Kleinpell. *1,* side view of reworked hypotype (USNM 409100) showing distinctive, leaf-like twisted test, ×260 (sample 4, Pleistocene terrace deposit); *2,* apertural view of same specimen showing very compressed section, ×380. *3–5, Brizalina californica* (Cushman). *3,* edge view of a reworked hypotype (USNM 409101) with an unusually high number of longitudinal costae, ×340, (sample 6, Pleistocene terrace deposit); *4,* apertural view of same specimen showing slightly compressed test, ×440; *5,* side view of a second reworked hypotype (USNM 409101) showing typical inflated and twisted chamber arrangement with diagnostic discontinuous longitudinal costae, ×280 (sample 6, Pleistocene terrace deposit). *6, 7, Bolivina wissleri* Kleinpell and Tipton. *6,* side view of minute hypotype (USNM 409102) showing coarse perforations and characteristic lobate reentrants on final chambers, ×430 (sample 1, Miocene–Pliocene Sisquoc Formation); *7,* apertural view of same hypotype showing lip around aperture, ×710. *8, 9, Buccella tenerrima* (Bandy). *8,* spiral view of smoothly surfaced hypotype (USNM 409103), ×130 (sample 6, Pleistocene terrace deposit); *9,* umbilical view of same specimen showing characteristic eight chambers of the final whorl, ×130. *10, Buliminella curta* Cushman, side view of typical hypotype (USNM 409106), ×250, (sample 4, Pleistocene terrace deposit). *11, Buliminella brevior* Cushman, side view of hypotype (USNM 409104) showing coarsely perforate test resulting from weathering of outermost lamellae, ×250 (sample 1, Miocene–Pliocene, Sisquoc Formation).

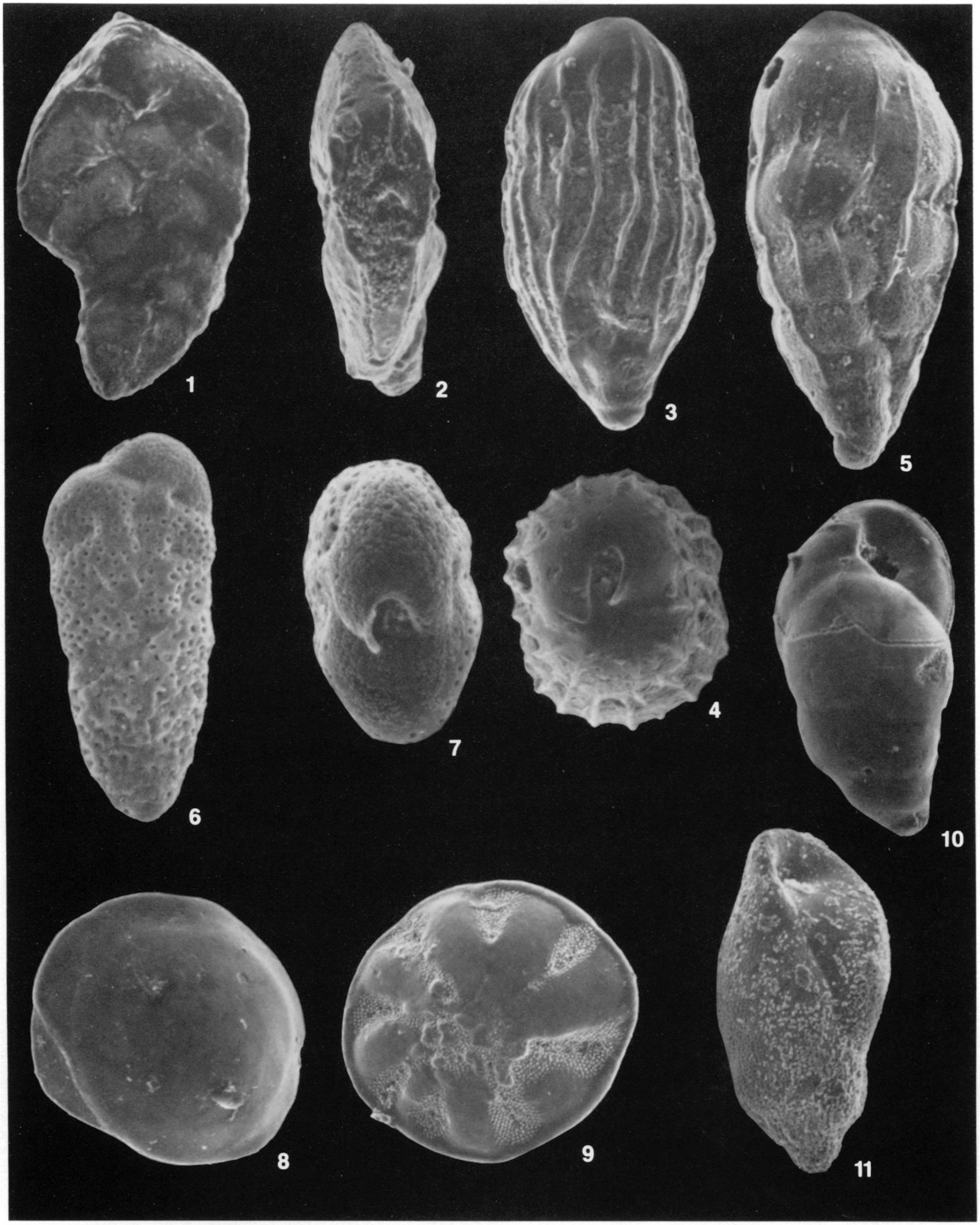
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FIGURE 3—*1, Buliminella elegantissima* (d'Orbigny), side view of typical hypotype (USNM 409105), ×250, (sample 4, Pleistocene terrace deposit). *2, Nonionella stella* Cushman and Moyer, umbilical view of typical hypotype (specimen shattered subsequent to being photographed so has not been assigned a USNM number), the only species found in both the Sisquoc Formation and the Pleistocene terrace deposit, ×260, (sample 3, Miocene–Pliocene Sisquoc Formation). *3, Cribroelphidium micrograndulosum* (Galloway and Wissler), side view of hypotype (USNM 409107) showing distinctive pustules over entire surface, ×120, (sample 6, Pleistocene terrace deposit). *4–6, Cribroelphidium tumidum* (Natland). *4,* side view of hypotype (USNM 409108) clearly showing finely perforate chambers, ×280, (sample 6, Pleistocene terrace deposit); *5,* side view of different hypotype (USNM 409108) showing pustules along strongly incised sutures, ×280, (sample 6, Pleistocene terrace deposit); *6,* view of apertural face of same specimen showing pustules partially constricting aperture, ×370.

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