

A PALEOENVIRONMENTAL STUDY OF EARLY TO MIDDLE PLEISTOCENE FORAMINIFERA OF THE SANTA BARBARA FORMATION AT SANTA BARBARA, CALIFORNIA

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ABSTRACT—An interval of the Early to Middle Pleistocene history of the California Borderland was assessed using multivariate analysis of foraminifera from the Santa Barbara Formation at Bathhouse Beach, Santa Barbara, California. A census of 93 species of benthic foraminifera and nine species of planktonic foraminifera was compiled from 11 samples from the shelly marls, silts, and sands of the lower member. Most species of benthic foraminifera are rare and only 38 species comprise one percent or more of the population in one or more samples.

Paleoenvironment of the sea floor was determined based on benthic foraminifera. R-mode cluster analysis defined five associations which are similar to those of the present-day banks and terraces of the California Borderland. Q-mode cluster analysis grouped samples into four biofacies which characterize shallow banks near 50 meters water depth and off-shore ridges and deep banks averaging 150 meters water depth. The stratigraphic succession of biofacies indicates two transgressive cycles separated by an apparent disconformity between 7.5 and 8.9 meters above the base of the section (between samples 3 and 4).

Paleoceanography of surficial waters was interpreted from planktonic foraminifera. Paleotemperature was assessed from the proportion of sinistral to dextral morphs and from the proportion of encrusted, compact morphs to reticulate, globular morphs of *Neogloboquadrina pachyderma*. The coiling morphs show a warm interval from the base of the section to about 12 meters (between samples 5 and 6), and a cooler interval from about 12 meters to about 24 meters (between samples 10 and 11), and an interval of intermediate paleotemperature in the topmost sample of the section. Changes in the planktonic assemblage do not coincide with the transgressive cycles inferred from the benthic biofacies.

The Bathhouse Beach section can be placed chronostratigraphically based on planktonic foraminiferal coiling shifts and strontium isotopic data. The isotopic age range of 400 to 900 Kyr brackets the 600 Kyr age assigned by Lagoe and Thompson (1988) to the *Neogloboquadrina pachyderma* coiling dominance interval CD9/CD8 boundary which occurs midway in the section, between samples 5 and 6.

INTRODUCTION

NUMEROUS STUDIES of Late Pleistocene foraminifera from sediments of the North American Pacific continental margin have used quantitative methods to define assemblages and compare them with core top and living assemblages (Bandy, 1953; Crouch, 1952; McGlasson, 1959; Lankford and Phleger, 1973; Douglas et al., 1976; Keller, 1978; Bergen and O'Neil, 1979; Echols and Armentrout, 1980; Brunner and Ledbetter, 1987; Quinterno and Gardner, 1987; Patterson and Cameron, in press; and others). This quantitative characterization has enhanced the resolution, reproducibility, and confidence of paleoenvironmental interpretation within and between late Quaternary sections.

The paleoenvironmental history of the Early to Middle Pleistocene of the California Borderland, however, is less well studied than that of the Late Pleistocene using quantitative methods. Natland (1952) divided bathyal Pliocene–Pleistocene strata into locally useful stages on the basis of benthic foraminifera. Natland (1957) and Ingle (1980) used quantitative data to assess paleoenvironment based on Early to Late Pleistocene assemblages of benthic foraminifera from Ventura Basin, and several workers (Bandy, 1960; Ingle, 1972; Knott, 1986; Lagoe and Thompson, 1988) used quantitative methods to infer paleoenvironment from planktonic foraminifera of Early Pleistocene sediments of the California Borderland. The paleoenvironment of other Early to Middle Pleistocene sections from the California Borderland need reinterpretation using quantitative methods.

The foraminiferal species from the Bathhouse Beach locality (also known as Breakwater Beach) of the Santa Barbara Formation (Figure 1) have been described qualitatively by several

workers (Bagg, 1912; Loeblich and Tappan, 1963; Young, 1979, 1981) and the locality has been compared qualitatively to other southern California Pleistocene sections such as Lomita Quarry in Palos Verdes (Galloway and Wissler, 1927a) and the exposure of Timm's Point Formation in San Pedro (Cushman and Gray, 1946a, 1946b). The fossil molluscan fauna has also been qualitatively described by Grant and Gale (1934), Keen and Bentson (1944), Valentine (1958), and others. The Bathhouse Beach fauna shares many foraminiferal species with faunas of the modern banks, ridges, and terraces of the California Borderland (Emery, 1960; Blake, 1976; Douglas et al., 1979; Douglas, 1981), but to date the Bathhouse Beach fauna neither has been described quantitatively nor has its paleoenvironment been interpreted in terms of environments known from the present-day California Borderland.

This study quantifies the benthic and planktonic foraminiferal assemblages of the Bathhouse Beach locality and interprets paleoenvironment by comparison of fossil faunas with present-day foraminiferal distributions associated with specific environments of the California Borderland (Blake, 1976; Douglas et al., 1979; Coulbourn et al., 1980; Douglas, 1981). The section is placed in a chronostratigraphic framework for other parts of the California Borderland and the North Pacific Ocean using strontium isotope data and planktonic foraminiferal coiling dominance interval boundaries.

LITHOLOGY AND STRATIGRAPHY

Tectonic activity was extensive along the California coastal margin during the late Pliocene and Pleistocene. The Oligocene Sespe and Miocene Monterey Formations were uplifted and

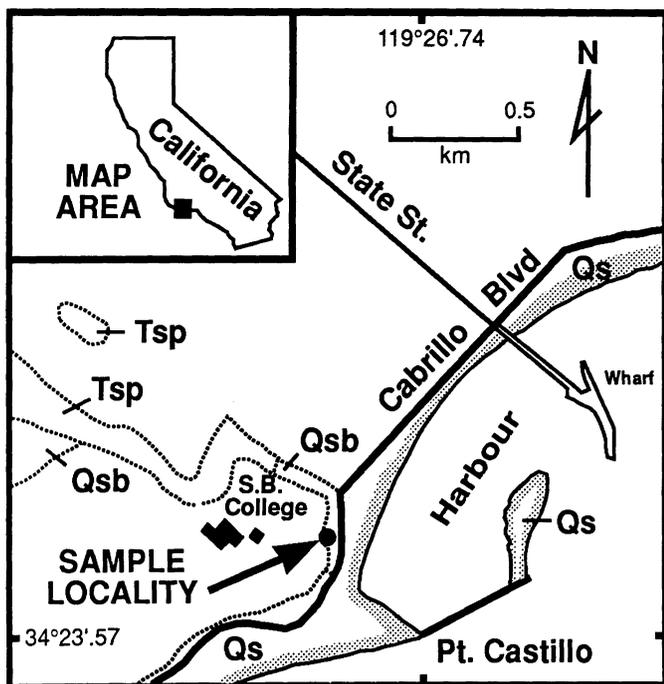


FIGURE 1—Geologic map showing Pleistocene Bathhouse Beach locality of the Santa Barbara Formation, Santa Barbara, California. Tsp, Sespe Formation (Oligocene); Tr, Rincon Shale (Miocene); Qsb, Santa Barbara Formation (Pleistocene); Qs, surficial sediments (after Dibblee, 1966).

eroded during the Pliocene (Dibblee, 1966) and the Santa Barbara Formation was subsequently deposited on the older formations during Pleistocene marine transgressions as topographic highs of dominantly biogenic material isolated from terrigenous sands. The transgressive deposits extend inland to the foothills of Goleta Valley and to the northern edge of Carpinteria Valley.

The Santa Barbara Formation crops out in the hills southwest and west of the city of Santa Barbara, east of Carpinteria Valley, and at Bathhouse Beach, the locality of this study. The formation is divided into two members: a highly fossiliferous lower member, and an upper member that is thicker and sandier than the lower member and nearly barren of fossils. Although subsurface sections of the formation are thicker than 675 meters in Goleta Valley, only 30 meters are exposed at Bathhouse Beach in the City of Santa Barbara (Figure 2). The lower member is well exposed at only one other locality, Packard's Hill (now better known as TV Hill), in the southwestern part of the city, where 28 meters of section crop out (Dibblee, 1966). Unfortunately, current landscaping activities will probably bury the Packard's Hill exposure.

The Bathhouse Beach section of the Santa Barbara Formation exposes 25 meters of the lower unit and five meters of the upper unit (dip corrected) in a road cut along Cabrillo Boulevard south of the paved bicycle path which lies between Santa Barbara College and City Park. The road cut is perpendicular to the strike of the beds, which dip south 20 degrees in the lower member and less steeply in the upper member. The contact between members may be unconformable.

The lower member, the object of this study, consists of bedded silty sands, gray bryozoan marls, and tan sandy silts. The units are soft to moderately indurated and all are highly fossiliferous. The marl beds vary in thickness from 2.5–25.0 cm and include some indurated calcareously-cemented beds. The megafauna is

characterized by numerous well-preserved mollusc shells and by abundant bryozoan fragments. The microfauna includes a diverse foraminiferal fauna, abundant worm tubes, rare radiolarians, and a few sponge and holothurian spicules.

The paleoenvironment of the Bathhouse Beach section is considered analogous to the present-day banks and ridges on the California Borderland (Emery, 1960, p. 244; Douglas et al., 1979) because the lithologies are similar. Modern bank and ridge environments are isolated from shore so only silt and clay-sized terrigenous material reaches them. Larger fragments are entirely biogenic and consist of marine mollusc shells, bryozoans, and foraminifera. Bank top sediments are winnowed by currents driven by rotary tides, upwelling, and waves so units are frequently silty and sandy in texture. In places, biogenic material is concentrated into marly hash. These same facies are also characteristic of the lower member of the Santa Barbara Formation at Bathhouse Beach.

AGE

The Ventura–Santa Barbara and Los Angeles active margin basins reflect complex depositional, tectonic, and paleoceanographic processes affecting the Cenozoic southern California borderland basins (Gorsline, 1978, 1980; Teng and Gorsline, 1989). Both basins contain thick accumulations of Pliocene–Pleistocene marine sediments and large petroleum reserves; therefore, precise chronostratigraphic correlation of these deposits is important for understanding the depositional and tectonic history of the basins as well as for economic reasons (Nagle and Parker, 1971; Lagoe and Thompson, 1988). The biostratigraphic divisions of California borderland Upper Pliocene and Quaternary rocks (i.e., Venturian, Wheelerian, and Hallian stages) have traditionally been based on benthic foraminifera (Natland, 1952). However, these stages and zones, although locally useful, reflect local tectonic and environmental conditions and can be time-transgressive away from their type areas principally in an eastward direction (Holman, 1958; Ingle, 1980; Lagoe and Thompson, 1988). This time transgression is also seen in planktonic foraminifera and nannofossils in sediments assigned to the Pico, Santa Barbara, and San Pedro Formations (Ingle, 1967).

Pleistocene marls are exposed in three localities in southern California: the Palos Verdes Hills, the onshore Ventura basin, and the Bathhouse Beach/Packard's Hill localities in Santa Barbara. Lagoe and Thompson (1988) determined coiling interval boundaries, controlled by glacially-induced late Cenozoic climatic fluctuations, in the planktonic foraminifera *Neoglobobulimina pachyderma* Ehrenberg, 1861, within the Ventura basin. These coiling dominance intervals were then correlated to sections calibrated by paleomagnetic stratigraphy and assigned ages. The Sr isotope dating method has previously been used to correlate the Pleistocene Lomita Marl of the Palos Verdes peninsula (Capo and DePaolo, 1986). Both methods can be used to correlate the Pleistocene marls of the Palos Verdes and Santa Barbara areas and to fit these localities into a North Pacific chronostratigraphic framework.

The Lomita Marl, Timm's Point Silt, and San Pedro Sand Members of the San Pedro Formation of Palos Verdes Peninsula are considered the classical type section for marine sediments in southern California. The Lomita Marl overlies Late Miocene and Pliocene deposits of the Fernando Formation; the base of the Lomita Marl has been regarded as basal Pleistocene (Woodring et al., 1946; Yule and Zenger, 1987). However, attempts to date this important unit have yielded widely discordant ages: Fanale and Schaeffer (1965) obtained a He/U age of 155 ± 30 Kyr; unpublished amino acid racemization data by Wehmiller cited in Yule and Zenger (1987) suggested a <700 Kyr Middle

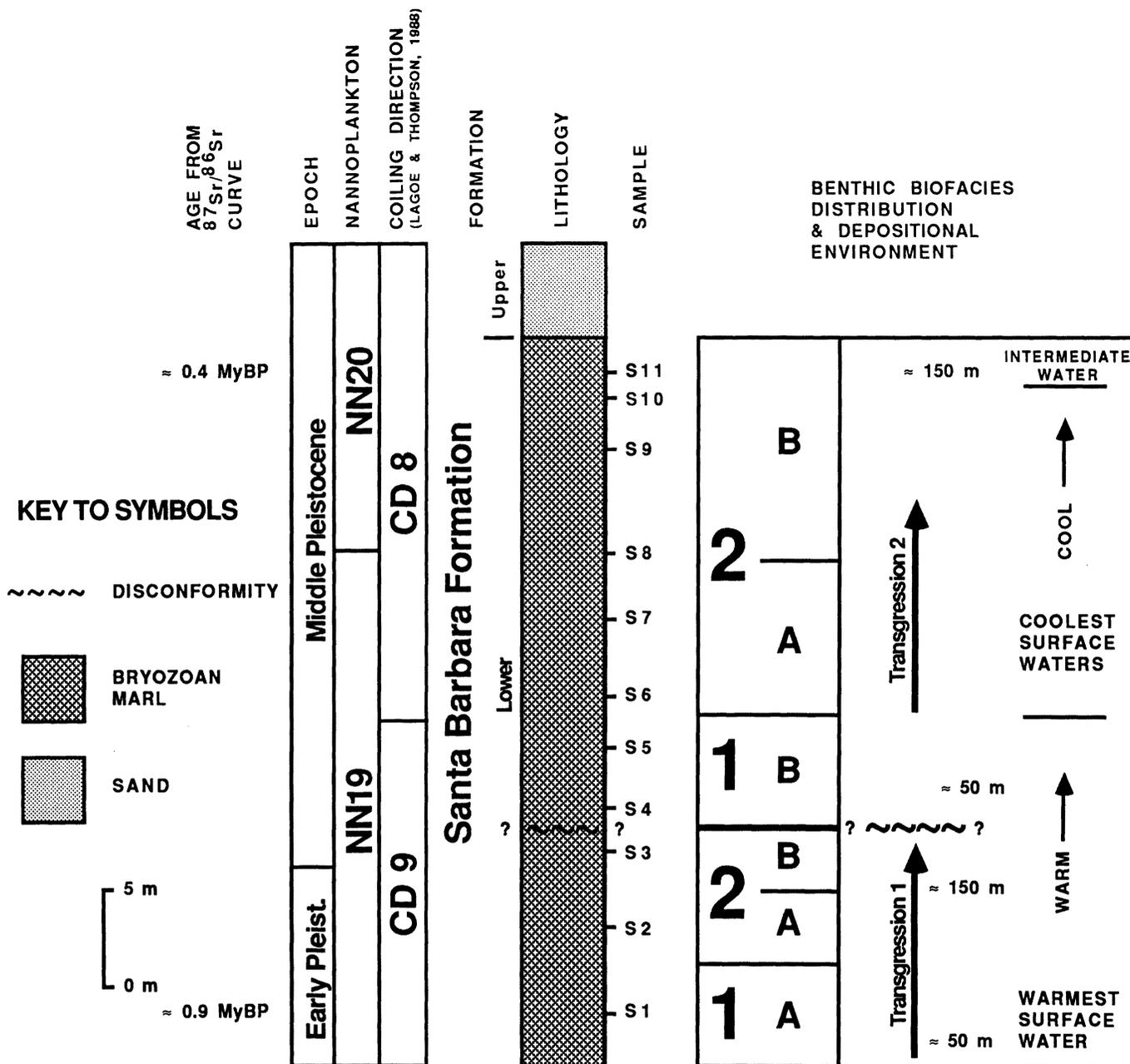


FIGURE 2—Bathhouse Beach stratigraphic section showing age of unit, sampled intervals, assigned assemblage zones, and depositional environment.

Pleistocene age; Bandy and others (1971) reported an age of 700–800 Kyr; Obradovich (1968) and Naeser et al. (1981) determined an age of 3.04 ± 0.09 Myr using K/Ar and Rb/Sr isotopic data on glauconite samples within the marl. Ambiguous stratigraphic relationships have not permitted resolution of the age discrepancy.

The Santa Barbara Formation outcrops in the marl deposits of the Bathhouse Beach locality and the Packard's Hill area have been compared to other southern California Pleistocene sections such as the Lomita Quarry and Timm's Point Formation in San Pedro. Correlation with ash beds in the Pico and Santa Barbara Formation outcrops in the Ventura basin indicate an age of 0.2 to approximately 1.2 Myr for the Santa Barbara Formation (Sarna-Wojcicki et al., 1984).

MATERIALS AND METHODS

Eleven samples of approximately five kg each were collected from the lower member (Figures 1, 2).

Samples were collected at the following intervals:

- S1. 6.0 m from north end of road cut.
- S2. 13.8 m from north end of road cut.
- S3. 22.0 m from north end of road cut.
- S4. 26.0 m from north end of road cut.
- S5. 32.0 m from north end of road cut.
- S6. 37.0 m from north end of road cut.
- S7. 45.0 m from north end of road cut.
- S8. 52.0 m from north end of road cut.
- S9. 62.8 m from north end of road cut.

TABLE 1—Percent occurrences of benthic foraminifera from measured section at Bathhouse Beach locality. * designates a new species to be described in a later systematic treatment and @ designates those species comprising ≥ 1 percent of any sample, which were then used in the multivariate analysis.

Sample	1	2	3	4	5	6	7	8	9	10	11
Height (m) from base of section	2.05	4.72	7.5	8.9	10.9	12.7	15.4	17.8	21.5	23.1	24.4
No. of species	55	40	47	39	52	32	46	50	38	43	47
Total individuals counted	385	1,067	571	333	414	475	508	874	549	442	489
1. <i>Gaudryina arenaria</i>	—	0.1	—	—	—	—	0.4	—	—	—	—
2. <i>Gaudryina subglabrata</i>	—	—	—	—	—	0.8	0.2	—	—	—	—
3. <i>Karreriella bradyi</i>	0.3	—	—	—	—	—	0.2	—	—	—	—
4. <i>Massilina pulchra</i>	—	0.3	0.5	—	—	—	—	—	—	0.2	0.4
5. @ <i>Pateoris hauerinoides</i>	1.0	—	1.1	—	—	—	—	—	—	—	0.2
6. @ <i>Pyrgo depressa</i>	2.9	2.7	0.5	0.3	0.7	—	0.6	0.2	0.2	0.2	1.4
7. @ <i>Pyrgoella sphaera</i>	0.8	0.8	1.1	—	0.5	—	0.2	0.9	—	—	0.2
8. @ <i>Q. triangularis</i>	8.1	7.5	7.7	2.6	4.3	1.3	2.0	6.1	6.0	7.9	5.1
9. <i>Quinqueloculina gigas</i>	—	—	0.7	—	—	—	—	0.2	—	—	—
10. <i>Pseudotriloculina oblonga</i>	—	0.8	—	—	—	—	—	0.1	—	—	—
11. @ <i>Spirosigmoilina tenuis</i>	—	—	0.4	0.3	0.2	0.4	0.4	0.2	0.4	—	1.0
12. @ <i>Miliolinella californica</i>	2.3	0.5	0.4	—	0.5	—	—	0.3	—	—	1.0
13. @ <i>Miliolinella sublineata</i>	1.6	0.6	0.5	—	—	—	—	1.3	0.4	0.5	1.0
14. @ <i>Scutullorhis tegminis</i>	1.3	—	1.2	—	0.7	—	—	0.2	0.2	—	0.6
15. <i>Spiroloculina californica</i>	0.3	—	—	—	—	—	—	—	—	—	—
16. @ <i>Patellina corrugata</i>	1.3	0.2	0.7	0.3	1.4	—	—	0.6	—	0.2	1.4
17. * <i>Lagena</i> sp. 1	0.3	—	—	—	—	—	—	—	—	—	—
18. * <i>Lagena</i> sp. 2	—	—	—	—	—	—	—	0.1	0.2	0.2	0.2
19. <i>Lagena laevicosta</i>	—	—	0.2	0.3	—	—	—	—	—	—	—
20. <i>Lagena spicata</i>	0.3	—	0.2	—	0.5	—	—	—	—	—	—
21. <i>Procerolagena distoma</i>	—	—	—	—	—	—	—	0.1	—	—	—
22. <i>P. meridionalis</i>	0.3	—	—	0.3	—	—	—	—	—	—	—
23. * <i>Cerebrina</i> sp. 1	—	—	—	—	—	—	—	—	—	—	0.2
24. <i>C. obscurocostata</i>	—	—	—	0.9	0.7	—	0.4	0.2	0.2	—	0.2
25. @ <i>Favulina squamosa</i>	1.6	0.9	0.4	—	0.7	0.4	0.4	—	0.4	—	0.2
26. <i>Fissurina copiosa</i>	0.3	—	0.4	—	0.7	0.2	0.2	—	—	0.2	—
27. <i>Fissurina evolutigera</i>	—	—	—	—	—	—	0.6	0.1	—	—	—
28. @ <i>Fissurina faba</i>	1.3	—	0.5	0.6	1.4	0.2	1.2	1.3	0.2	0.2	2.2
29. <i>Fissurina habenifera</i>	0.3	—	0.5	—	—	—	0.2	—	—	—	0.4
30. * <i>Fissurina</i> sp. 1	—	—	—	0.3	—	—	0.2	—	0.5	—	—
31. @ <i>F. quadricostulata</i>	1.3	—	0.7	—	1.0	—	0.6	0.7	—	0.5	0.2
32. <i>Fissurina romettensis</i>	0.3	—	—	0.3	0.2	—	0.4	0.5	—	0.5	0.2
33. <i>F. semimarginata</i>	0.3	—	0.4	—	0.5	—	0.6	0.1	0.2	—	—
34. @ <i>Fissurina vitreola</i>	0.5	—	0.5	0.6	0.7	0.4	1.2	0.8	0.7	1.6	1.2
35. <i>Homalohedra apiopleura</i>	0.5	0.4	0.4	—	—	0.2	—	—	—	0.2	—
36. <i>Homalohedra borealis</i>	—	—	—	—	—	—	—	—	—	0.2	—
37. * <i>Homalohedra</i> sp. 1	0.3	—	—	—	—	—	—	—	—	—	0.2
38. @ <i>Homalohedra lineata</i>	1.0	0.3	—	—	—	—	—	0.1	0.4	—	—
39. <i>Homalohedra neocosta</i>	0.3	—	—	—	0.2	—	—	—	—	—	0.2
40. * <i>Homalohedra</i> sp. 1	0.3	—	—	—	—	—	—	—	—	—	—
41. <i>Oolina caudigera</i>	—	—	—	—	—	—	—	—	—	—	0.2
42. <i>Palliatella frangens</i>	0.3	—	0.2	—	—	—	0.2	0.1	—	—	0.8
43. * <i>Palliatella</i> n. sp.	0.8	—	0.5	0.3	0.2	—	—	0.2	0.7	—	0.4
44. <i>Palliatella laguncula</i>	—	—	—	—	—	—	—	0.2	—	—	—
45. <i>Palliatella romani</i>	—	—	—	—	—	—	—	—	0.2	—	0.4
46. @ <i>P. cf. P. carinata</i>	0.8	—	—	0.3	0.2	0.4	—	0.1	—	0.2	1.0
47. <i>Parafissurina removens</i>	0.5	—	—	0.3	0.2	—	0.2	0.1	—	—	—
48. <i>Parafissurina lateralis</i>	—	—	—	0.3	—	—	0.4	0.2	—	0.2	—
49. @ <i>P. semicarinata</i>	1.0	—	0.9	0.6	0.7	—	0.4	0.1	0.2	0.7	0.4
50. <i>Solenina timmsensis</i>	0.5	0.2	—	—	—	—	—	—	—	0.5	—
51. <i>Vasicostella semialata</i>	—	—	—	—	—	0.2	—	—	—	—	—
52. <i>Pytine lemniscata</i>	—	0.1	—	—	—	—	0.2	—	—	—	—
53. <i>Planularia planulatus</i>	0.3	—	—	—	—	—	—	0.1	—	—	0.2
54. <i>M. charlottensis</i>	0.3	—	—	—	—	—	—	0.1	—	—	0.2
55. <i>S. frondicularis</i>	—	0.2	—	—	—	0.2	0.4	0.1	—	0.2	—
56. <i>R. charlottensis</i>	0.3	0.6	0.5	—	0.5	—	—	0.1	—	—	0.2
57. <i>Bulimina marginata</i>	—	—	—	0.3	—	—	—	—	—	—	—
58. <i>P. pupoides</i>	—	—	—	0.3	0.5	—	—	—	—	—	—
59. <i>Euvigerina juncea</i>	0.3	—	—	0.6	0.5	0.4	—	—	—	0.2	—
60. @ <i>Trifarina baggi</i>	0.3	0.4	—	0.6	0.5	4.9	0.4	—	0.4	0.2	—
61. <i>Gyroidina neosoldanii</i>	—	—	—	—	0.2	—	0.2	—	—	—	—
62. @ <i>Buccella frigida</i>	3.9	6.7	8.1	3.5	3.6	3.8	6.7	16.5	18.2	15.4	16.3
63. <i>Tretomphalus pacificus</i>	—	0.1	0.5	0.9	—	—	0.2	0.3	0.2	—	—
64. @ <i>G. campanulata</i>	8.1	5.2	8.2	15.7	20.3	2.5	10.1	8.1	9.7	10.6	11.2
65. <i>Sestronophora arnoldi</i>	—	—	—	—	—	0.2	0.2	—	—	—	—
66. @ <i>Bolivina acuminata</i>	0.3	—	—	—	1.0	0.2	—	—	—	—	—
67. @ <i>Bolivina decussata</i>	6.0	2.4	4.7	13.1	13.3	2.5	4.0	9.8	3.1	5.9	5.9
68. <i>Brizalinac cf. B. humilis</i>	—	—	—	—	—	0.2	—	—	—	—	—
69. <i>Brizalina pacifica</i>	—	—	—	—	0.2	0.2	0.8	0.1	—	0.2	0.2

TABLE 1—(continued).

Sample	1	2	3	4	5	6	7	8	9	10	11
70. @ <i>Brizalina quadrata</i>	0.5	0.3	0.4	2.0	1.0	0.6	2.8	1.4	0.9	3.4	2.0
71. * <i>Rectobolivina</i> sp. 1	—	—	—	—	—	—	0.2	—	—	—	—
72. <i>Angulodiscorbis duncani</i>	—	—	0.4	—	—	—	—	—	0.2	0.2	—
73. @ <i>Islandiella californica</i>	1.3	3.5	4.6	7.0	1.9	11.6	15.5	3.5	5.1	10.4	4.1
74. @ <i>Islandiella limbata</i>	11.9	41.3	21.0	15.5	11.1	49.6	27.2	25.2	32.6	17.9	14.1
75. <i>Astrononion fijiense</i>	—	—	0.4	0.3	—	—	—	0.2	—	0.2	—
76. @ <i>A. viragoense</i>	3.6	4.0	2.1	2.3	2.7	0.8	2.2	1.4	—	2.7	5.9
77. @ <i>P. basispinata</i>	0.3	0.9	—	2.6	1.7	—	—	2.1	1.3	0.9	1.4
78. @ <i>Nonionella stella</i>	0.3	0.4	0.4	2.6	1.7	—	1.6	1.0	1.8	1.1	2.9
79. <i>Pullenia salisburyi</i>	0.3	—	0.4	0.3	—	—	—	—	—	—	—
80. @ <i>G. ornatissima</i>	0.5	0.1	1.2	0.3	0.2	—	—	0.3	1.6	0.9	0.4
81. @ <i>D. biserialis</i>	3.6	0.3	2.1	1.2	3.1	1.3	1.0	0.9	0.9	1.8	0.4
82. @ <i>Lobatula mckannai</i>	0.5	1.1	1.1	0.3	1.2	1.5	0.2	0.1	0.7	0.2	0.2
83. @ <i>Lobatula fletcheri</i>	17.1	12.4	12.1	17.2	12.6	8.4	13.3	7.4	5.3	9.3	5.9
84. <i>H. hamadaensis</i>	—	—	0.2	—	—	—	—	—	—	—	—
85. @ <i>M. bramlettei</i>	—	0.8	0.2	0.9	1.4	1.1	0.6	—	—	1.6	—
86. <i>Planorbulina acervalis</i>	—	0.1	—	—	0.2	0.4	—	—	—	0.2	0.2
87. @ <i>Planulina ornata</i>	—	0.1	—	—	—	1.7	0.2	0.1	0.4	0.5	—
88. @ <i>Elphidium crispum</i>	—	0.2	1.4	0.6	0.5	—	—	—	0.4	0.2	0.8
89. @ <i>E. microgranulosum</i>	3.4	1.2	4.0	0.3	1.4	2.3	—	3.5	4.0	—	3.5
90. @ <i>Elphidiella hannai</i>	0.3	0.2	0.5	2.0	0.5	1.1	—	—	0.7	0.5	—
91. @ <i>Glabratella</i> sp. 1	4.4	2.0	5.4	1.2	0.2	—	—	1.7	1.3	0.5	2.7
92. <i>Buliminella punctata</i>	—	—	—	—	0.2	—	—	—	—	—	—
93. @ <i>Cassidulina bradshawi</i>	—	—	—	—	0.2	—	1.0	0.5	0.2	0.5	0.2

S10. 67.4 m from north end of road cut.

S11. 71.4 m from north end of road cut.

Sampling intervals varied to avoid sampling from slumps, thick vegetation, and indurated marls which are difficult to disaggregate for extraction of microfossils.

Bulk samples were dried, then a 500 gm aliquot was subsampled from each bulk sample, disaggregated in a solution of boiling soda ash, and washed in a sieve of 200 Tyler equivalent mesh size (75 μ m openings). The residue was dried and split by a modified Otto microsampler until a random subsample of at least 300 benthic foraminiferal specimens was separated (Table 1). A different and usually larger size split of the residue was used from which to extract approximately 300 tests of planktonic foraminifers (Table 2). A census was made of all benthic foraminifera larger than 75 μ m and planktonic species larger than 125 μ m. In addition, tallies were made of two phenotypes of *Neogloboquadrina pachyderma*.

Biofacies and faunas of benthic foraminifera were defined using cluster analysis. The BMDP program, P1M (Dixon, 1981), was used to generate R- and Q-mode cluster analyses utilizing relative frequencies of all benthic species comprising one percent or more of the population of any sample. R-mode analysis grouped together species which had similar patterns of frequency in the samples. Simple correlation coefficients measured similarity between pairs of species and the average linkage method arranged species pairs and groups into a hierarchic dendrogram (Figure 3). Distinct clusters of species with correlation coefficients greater than the selected level were considered faunal associations.

Q-mode cluster analysis grouped together samples with similar species composition. The matrix of relative frequency data used in the R-mode analysis was transposed and used in the P1M program to produce Q-mode clusters with the same simple correlation coefficient and average linkage method as the R-mode

analysis (Figure 4). Distinct clusters of samples with correlation coefficients greater than a selected level were considered biofacies.

Strontium isotopic measurements ($^{87}\text{Sr}/^{86}\text{Sr}$) were made at the University of California, Los Angeles, on samples from the stratigraphically lowest and highest parts of the section (S1 and S11). Both mollusc shells and tests of the benthic miliolid *Quinqueloculina triangularis* d'Orbigny, 1846, were prepared for analysis. Samples of 25–150 mg of either hand-picked foraminifera or mollusc shells were cleaned of sediment in an ultrasonic bath with distilled water, crushed, and dissolved. Only the fraction soluble in 1.0 N acetic acid was analyzed in order to avoid contamination with any noncarbonate phases (DePaolo et al., 1983). Following evaporation and redissolution in 1.5 N HCl, standard ion-exchange techniques were used to separate strontium for mass spectrometric analysis. Concentrations of K, Rb, Sr, Nd, and Sm were determined by isotope dilution analysis. Mass spectrometric procedures follow that described in DePaolo (1986). Rb/Sr ratios were too low to necessitate any correction to the measured $^{87}\text{Sr}/^{86}\text{Sr}$ for in situ decay of ^{87}Rb . Samples were assigned ages based on the high-precision strontium isotope seawater reference curve for the Pleistocene determined by Capo and DePaolo (1986), which used the time scale of Berggren et al. (1985). Isotopic data, inferred ages, and elemental concentrations are presented in Table 3.

Oxygen and carbon isotope ratios were measured in all 11 samples from the section. *Quinqueloculina triangularis* tests were used because they were large and abundant and the test is precipitated in near-equilibrium with sea water (Grossman, 1987). Approximately 100 specimens were picked from each sample to yield about 20 mg of calcium carbonate. The specimens were crushed, heated to 40°C, bleached in Clorox® overnight to remove organic matter, washed several times with distilled water, and freeze-dried. The residue was reacted with 100 percent phosphoric acid for 24 hours at 25°C to produce CO₂ gas, which

TABLE 2—Percent and total occurrences of planktonic foraminifers from the measured section at the Bathhouse Beach locality.

Sample		1	2	3	4	5	6	7	8	9	10	11
Height in section (m)		2.05	4.72	7.5	8.9	10.9	12.7	15.4	17.8	21.5	23.1	24.4
No. of species		6	7	5	6	5	7	7	5	5	5	5
Total individuals		489	719	313	417	341	539	414	269	286	283	394
Percent of foraminiferal fauna		16.7	34.3	7.9	17.2	23.0	14.1	29.5	25.8	22.1	16.0	20.1
<i>Globigerina bulloides</i>	%	X	2.1	1.9	2.2	1.8	3.9	X	2.2	X	1.8	2.3
	T	3	15	6	9	6	21	2	6	2	5	9
<i>Globigerina falconensis</i>	%	X	X	—	—	—	—	—	—	—	—	X
	T	2	1	—	—	—	—	—	—	—	—	1
<i>Globigerina quinqueloba</i>	%	27.1	30.7	41.0	41.0	38.4	20.4	31.4	29.7	29.4	32.2	43.1
	T	131	221	128	171	131	110	130	80	84	91	170
<i>Globigerinoides ruber</i>	%	—	—	—	—	—	X	X	—	—	—	—
	T	—	—	—	—	—	1	1	—	—	—	—
<i>Globigerinita uvula</i>	%	1.0	X	X	X	—	1.5	X	2.2	2.8	X	—
	T	5	7	1	3	—	8	2	6	8	2	—
<i>Globorotalia inflata</i>	%	—	X	—	X	X	X	—	—	—	—	—
	T	—	3	—	2	2	1	—	—	—	—	—
<i>Orbulina universa</i>	%	—	—	—	—	—	—	X	—	—	—	—
	T	—	—	—	—	—	—	1	—	—	—	—
<i>Tinophodella glutinata</i>	%	13.7	21.0	12.1	8.2	16.7	14.8	10.1	30.1	21.0	33.6	28.7
	T	66	150	38	34	57	80	42	81	60	95	113
<i>N. pachyderma</i>	%	57.8	42.0	44.7	47.5	42.5	59.0	57.0	35.7	46.2	31.8	25.6
	T	276	299	140	198	145	318	236	96	132	90	101
<i>N. pachyderma</i> sinistral coil	%	1.8	4.7	10.0	16.2	3.4	39.3	36.4	46.9	40.2	40.0	21.8
	T	267	278	125	125	115	145	89	38	56	58	64
<i>N. pachyderma</i> encrusted	%	3.3	7.0	10.7	20.7	20.7	54.4	62.3	60.4	57.6	35.6	36.6
	T	9	21	15	73	30	173	147	58	76	32	37

was analyzed on a Varian MAT 250 triple-collecting mass-spectrometer. Both carbon and oxygen are reported with respect to the P.D.B. standard (Figure 5).

CORRELATION TO A NORTH PACIFIC CHRONOSTRATIGRAPHIC FRAMEWORK

Results of coiling interval correlation.—The section at Bathhouse Beach was correlated to the chronostratigraphy of Lagoe and Thompson (1988), which integrated planktonic evolutionary datums with coiling shifts in *Neogloboquadrina pachyderma* in North Pacific sections. Lagoe and Thompson defined intervals of coiling dominance from CD16 to CD1 and dated interval boundaries by interpolation with datums correlated to a numerical time scale in sections calibrated with paleomagnetic stratigraphy. They then successfully placed three sections of the Pico Formation of the central Ventura basin into this chronostratigraphic framework.

The Bathhouse Beach section is correlated to the CD8/CD9 boundary for the reasons stated below. Although no species used by Lagoe and Thompson to mark North Pacific first and last appearance datums were found in samples from the section, some planktonic foraminifera may have been excluded by the shallow-water environment and/or the cool water conditions. For example, *Globorotalia tosaensis* Takayanagi and Saito, 1962, is extremely rare even in bathyal sections of the California Borderland due to cool conditions, and its absence from Bathhouse Beach cannot be viewed as evidence that the section lies above its last occurrence in the North Pacific sections. In contrast, *Neogloboquadrina asanoi* (Maiya, Saito, and Sato, 1976) and *Neogloboquadrina humerosa* (Takayanagi and Saito, 1962) do occur in bathyal Pliocene and Pleistocene sections of the California Borderland, and it is assumed, with caution in light of our caveat concerning exclusion from the shelf environment, that their absence from Bathhouse Beach places the section above their last appearance datums (1.85 and 1.1 myBP, respectively) and therefore above the Thompson and Lagoe (1988)

CD10/CD9 boundary. The presence, albeit rare, of *Globorotalia truncatulinoides* (d'Orbigny, 1839) two meters above the base of the section (Young, 1981; and references therein) further supports a Pleistocene age for the section (Dowsett, 1988). The stratigraphic context of the Santa Barbara Formation precludes its correlation to the latest Quaternary CD6/CD7 boundary, which is equivalent to the oxygen isotopic Stage 6/7 boundary, or younger coiling dominance intervals. Hence, the coiling shift from dextral to sinistral phenotypes of *Neogloboquadrina pachyderma* between samples 5 and 6 in the Bathhouse Beach section is thought to correlate to the CD9/CD8 boundary, assigned a 0.6 Myr age, or perhaps to a minor change in coiling within CD9 (Peter Thompson, personal commun.).

Strontium isotope results.—Strontium isotopic data for samples from Bathhouse Beach and Lomita Marl are presented in Table 3. Analysis of calcareous material handpicked from the unconsolidated glauconitic calcarenite as well as separated foraminifera (*Neogloboquadrina pachyderma*, *Elphidium crispum* and *Islandiella* sp.) and a gastropod shell (*Glossaulax reclusianis*) from the Hilltop Quarry locality of the Lomita Marl in Palos Verdes yielded an average Sr ratio of 0.709203 ± 8 . Comparison with the Plio-Pleistocene reference curve (Capo and DePaolo, 1986) shows that this value intersects the curve in three places, which correspond to ages of 750, 900, or 1,200 Kyr. It is believed that the 750 Kyr is the most likely age since it is in agreement with the 700–800 Kyr age for the Lomita Marl suggested by Bandy et al. (1971) based on planktonic foraminiferal datum planes and radiometric dates for Pliocene and Pleistocene ash beds in correlative marine units near Ventura. In any event, the Lomita Marl is clearly younger than the 3 Myr age determined by Obradovich (1968) and Naeser et al. (1981). Therefore, the glauconite pellets dated by these workers either inherited detrital radiogenic argon or represent reworked material from the glauconitic Fernando Formation which underlies the Lomita. K/Ar ages obtained from the Fernando glauconites yield ages of 3.1 Myr (Obradovich, 1968).

R MODE ANALYSIS

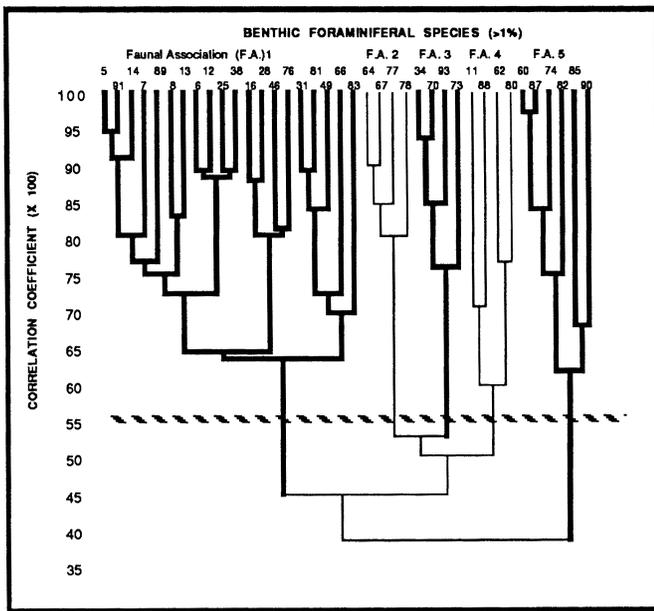


FIGURE 3—R-mode dendrogram showing the 38 species found in abundances of ≥ 1 percent in any sample from the Bathhouse Beach locality separated into five faunal associations.

Strontium isotope values for foraminifera and macrofossils do not yield consistent results in the Bathhouse Beach section, unlike the Lomita Marl. $^{87}\text{Sr}/^{86}\text{Sr}$ values for separated foraminifera (*Quinqueloculina triangularis*) from the upper part of the lower fossiliferous portion of the Santa Barbara Formation at Bathhouse Beach indicate an age of 480–800 Kyr for the section. Strontium isotope values for foraminifera are well-constrained for the top of the section (P-11) with an age of 550 Kyr and an uncertainty of ± 70 Kyr, but samples from the base of the Bathhouse Beach section (P-1) have a larger error associated with them (650 ± 250 Kyr). Two mollusc samples (pecten) from the upper and lower parts of the Bathhouse Beach section (S-1 and S-11) have similar Sr isotope values which suggest an age of about 400 Kyr. $\delta^{18}\text{O}$ and $\delta^{13}\text{C}$ values for the miliolids at Bath-

Q MODE ANALYSIS

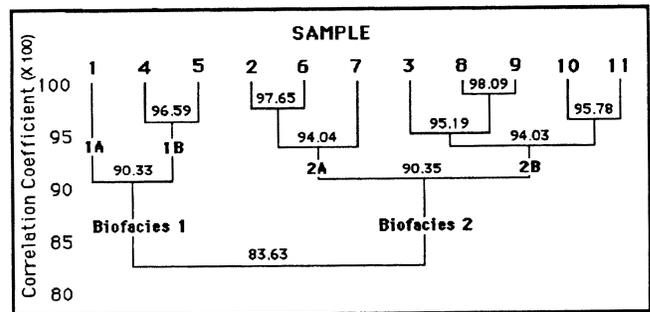


FIGURE 4—Q-mode dendrogram showing the 11 samples from the Bathhouse Beach locality separated into two distinct biofacies and four sub-biofacies.

house Beach suggest some post-depositional alteration has taken place; the low-magnesian calcite pectens are less susceptible to diagenetic alteration and recrystallization so their Sr isotopic ratios are less likely to be disturbed. Another possibility for disparate ages is that the fossils may have been reworked. Based on the available Sr isotope data, the lower portion of the Santa Barbara Formation at Bathhouse Beach has an Early Pleistocene to Middle Pleistocene age of approximately 400–900 Kyr (Halian stage). This range brackets the age of 0.6 Myr assigned by Lagoe and Thompson (1988) to the CD8/CD9 coiling interval boundary, which falls within the Bathhouse Beach section.

In a regional context, the data from strontium isotopes combined with *Neogloboquadrina pachyderma* coiling shifts indicate that the Santa Barbara Formation is in part syndepositional with western portions of the nearby Pliocene–Middle Pleistocene Pico Formation of the Ventura Basin (Ingle, 1978, 1980; Lagoe and Thompson, 1988) and with the lithologically similar Lomita Marl of the San Pedro Formation at Palos Verdes.

PALEOENVIRONMENTAL INTERPRETATION

Studies of the modern surface distribution of foraminifera in the California Borderland by Blake (1976), Douglas et al. (1979), and Douglas (1981), which defined various assemblage zones and their associated oceanographic parameters, have been very useful in interpreting the quantitative foraminiferal data from

TABLE 3— $^{87}\text{Sr}/^{86}\text{Sr}$ values and derived ages (from Capo and DePaulo, 1986, reference curve) of foraminifera and pecten shells from various Pleistocene localities in southern California. Potassium (K), Rubidium (Rb), Strontium (Sr), Neodymium (Nd), and Samarium (Sm) concentrations are given in parts per million.

Sample	Average $^{87}\text{Sr}/^{86}\text{Sr}$	\pm	Age (Myr)	K	Rb	Sr	Nd	Sm
Bathhouse Beach								
P-1 (<i>Q. triangularis</i>)	0.709211	26	0.80 (0.38–1.21)	55	0.2	1,324	8.3	1.7
P-1 (Pecten)	0.709241	23		15	0.1	2,809	0.3	—
P-11 (<i>Q. triangularis</i>)	0.709223	5	0.56 (0.48–0.63)	36	0.1	1,579	12.7	2.5
P-11 (Pecten)	0.709237	18						
Packard's Hill								
PH (<i>Q. triangularis</i>)	0.709256	13	0.23 (0.00–0.45)	63	0.2	831	21.4	3.6
Lomita Marl								
L279g (<i>G. reclusianses</i>)	0.709201	18	0.92 (0.68–1.15)	48	0.1	1,567	0.2	0.0
L-6 (Shell fragments)	0.709198	5		66	0.1	1,771	2.2	0.2
L-8 (Foram separate)	0.709207	5		28	0.1	434	1.0	0.2
Timm's Point Silt								
TP-f (Foram separate)	0.709198	21	0.92 (0.68–1.15)	296	0.5	1,692	12.2	2.4
TP-p (Pecten)	0.709091	6		12	0.1	2,188	11.6	1.0

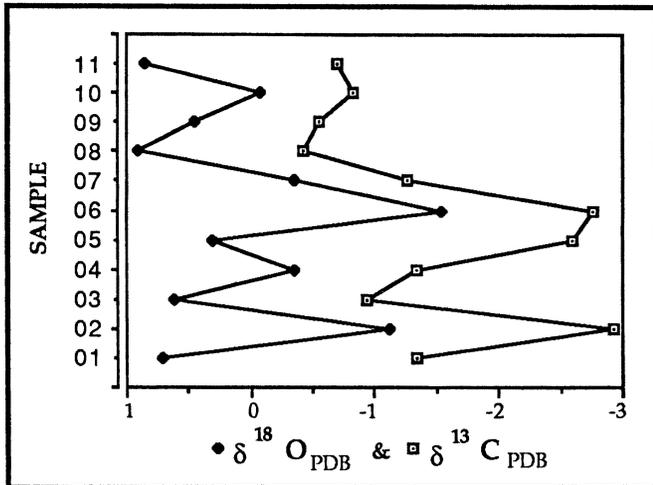


FIGURE 5—Composite of the $\delta^{18}\text{O}/^{16}\text{O}$ and $\delta^{13}\text{C}/^{12}\text{C}$ ratios recorded from the samples collected in the Santa Barbara Formation at Bathhouse Beach. Abnormally negative values indicate post-depositional diagenesis, probably from fresh-water contamination.

Bathhouse Beach, as most fossilized species are still living in California coastal waters.

Oxygen and carbon isotopic results.—Both carbon and oxygen isotopic anomalies suggest post-depositional alteration. The carbon isotopic anomalies of several samples (S1, S5, S6; Figure 5) are lighter than the range of normal marine carbonate, and fall within the range of freshwater carbonates (Keith et al., 1964; Keith and Weber, 1964). Two of the suspect samples, S2 and S6, also have the most negative oxygen isotopic anomalies of all samples from the section. This combined with the presence of carbonate cement in some units suggests that ground-water infiltration has diagenetically altered the section to various degrees. Therefore, the oxygen isotopic values are not believed to indicate temperature at the time of deposition.

Results of benthic foraminiferal analysis.—Ninety-three species of benthic foraminifera were observed in 11 Pleistocene samples from Bathhouse Beach (Table 1). Most species are rare and only 38 comprise one percent or more of the specimens in one or more samples. R-Mode cluster analysis united the 38 species into five groups with correlation coefficients greater than 0.60 (Figure 6).

Faunal Association 1 (Figure 6) is characterized by large robust miliolids such as *Quinqueloculina triangularis* d'Orbigny, 1846, and attached low profile species like *Lobatula fletcheri* (Galloway and Wissler, 1927), *Dyocibicides biserialis* Cushman and Valentine, 1930, and *Patellina corrugata* Williamson, 1848. Faunal Association 2 (Figure 6) is characterized by *Gavelinopsis campanulata* (Galloway and Wissler, 1927), and *Bolivina decussata* Brady, 1881. In combination, Faunal Associations 1 and 2 are similar to the *Cassidulina-Hanzawaia* Assemblage (Douglas, 1981) which is characteristic of shallow banks (50 m) of the California Borderland.

Faunal Association 3 (Figure 6) is characterized by *Islandiella californica* (Cushman and Hughes, 1925). Faunal Association 4 (Figure 6) is characterized by *Buccella frigida* (Cushman, 1922), *Elphidium crispum* (Linné, 1758), and *Glabratella ornatissima* (Cushman, 1925). Faunal Association 5 (Figure 6) clustered very distinctly from the other faunal associations. It consists primarily of *Islandiella limbata* (Cushman and Hughes, 1925), the most abundant species in most samples, and small numbers of such species as *Montfortella bramlettei* Loeblich and Tappan,

Faunal Assoc. 1	F.A. 2	F.A. 3
76. <i>A. viragoense</i> 89. <i>C. microgranulosum</i> 81. <i>D. biserialis</i> 91. <i>Glabratella</i> sp. 83. <i>L. fletcheri</i> 12. <i>M. californica</i> 13. <i>M. sublineata</i> 05. <i>P. hauerinoides</i> 16. <i>P. corrugata</i> 06. <i>P. depressa</i> 07. <i>P. sphaera</i> 08. <i>Q. triangularis</i> 14. <i>S. tegminis</i>	67. <i>B. decussata</i> 64. <i>G. campanulata</i> 78. <i>N. stella</i> 77. <i>P. basispinata</i>	70. <i>B. quadrata</i> 93. <i>C. bradshawi</i> 34. <i>F. vitreola</i> 73. <i>I. californica</i>
	F.A. 4	F.A. 5
	62. <i>B. frigida</i> 88. <i>E. crispum</i> 11. <i>S. tenuis</i>	60. <i>A. baggi</i> 90. <i>E. hannai</i> 74. <i>I. limbata</i> 82. <i>L. mckannai</i> 85. <i>M. bramlettei</i> 87. <i>P. ornata</i>

FIGURE 6—Benthic foraminiferal species characterizing faunal associations defined by R-mode analysis.

1963, *Lobatula mckannai* (Galloway and Wissler, 1927), and *Angulogerina baggi* (Galloway and Wissler, 1927). In combination, Faunal Associations 3, 4, and 5 resemble the *Buccella-Angulogerina* Assemblage of Douglas (1981) which is characteristic of deep banks (150 m) of the California Borderland.

The major faunal differences between these previous studies (Blake, 1976; Douglas et al., 1979; and Douglas, 1981) and the present one are largely systematic in nature. For example, in the Bathhouse Beach material *Islandiella tortuosa* (Cushman and Hughes, 1925), and *Islandiella limbata* tend to intergrade and may therefore be ecophenotypic variants of a single species. For this study both species were therefore lumped under the latter name. However, Douglas et al. (1979) separated these species, regarding his *Islandiella limbata* form as a very important species under certain shallow-water conditions. Other major differences include the almost complete absence of the genus *Hanzawaia* Asano, 1944, from the Santa Barbara material. Species of this genus were found to be a major component in both Blake's (1976) and Douglas et al.'s (1979) studies. Several other species, such as *Montfortella bramlettei*, are quite common at Bathhouse Beach, but were not recorded by these workers.

Q-mode cluster analysis amalgamated samples with similar relative frequencies of benthic foraminiferal species. Samples clustered into two main groups, or biofacies, with average correlations greater than 90. Biofacies 1 was in turn subdivided into Biofacies 1A and Biofacies 1B. Similarly Biofacies 2 was subdivided into Biofacies 2A and Biofacies 2B at average correlations above 94. Stratigraphically, the succession of groups proceeds in two cycles. The first cycle includes samples 1, 2, and 3 which, respectively, belong to Biofacies 1A, 2A, and 2B. The second cycle includes samples 4 to 11; samples 4 and 5 belong to Biofacies 1B, samples 6 and 7 belong to Biofacies 2A, and samples 8 through 11 belong to Biofacies 2B. The bases of the two cycles differ more from one another than do their middle and top units.

Faunal Associations 1 and 2 (Figure 6), characterized by various robust miliolid species, *Patellina corrugata*, and attached low profile species like *Lobatula fletcheri*, *Dyocibicides biserialis*, and *Gavelinopsis campanulata*, correspond most closely to the foraminiferal faunas of the samples comprising Biofacies 1. Analysis of the corresponding foraminiferal faunas show that Biofacies 1 samples (Figure 7) are characterized by an *Islandiella limbata* population of less than 16 percent, a *Lobatula fletcheri* population of 12–17 percent, and a *Buccella frigida* population of ≤ 4.0 percent. The subdivision of Biofacies 1, perhaps easier remembered as the *Lobatula/Gavelinopsis* Biofacies, into Biofacies 1A and 1B is based on differences in the proportion of *Gavelinopsis campanulata* ($< 15\%$ in 1A, and 15–20% in 1B)

Biofacies	Lobatula/ Gavelinopsis 1		Buccella/ Islandiella 2	
	1A	1B	2A	2B
<i>B. decussata</i>	<10%	>10%	<10%	
<i>B. frigida</i>	≤4%		4-7%	8-18%
<i>I. limbata</i>	<16%		>14%	
<i>L. fletcheri</i>	12-17%		5-13%	
<i>G. campanulata</i>	<15%	15-20%	<15%	

FIGURE 7—Benthic foraminiferal species characterizing biofacies and sub-biofacies from Bathhouse Beach derived from analysis of faunal associations.

and *Bolivina decussata* (<10% in 1A, and >10% in 1B) and is probably not water depth controlled. These foraminiferal faunas correspond most closely to Douglas's (1981) *Cassidulina-Hanzawaia* Assemblage, characteristic of offshore banks and terraces, a high-energy environment averaging 50 meters in the modern offshore region (Figure 8).

Faunal Association 3, (Figure 6) characterized by *Islandiella californica*, did not clearly correspond with any particular biofacies.

Faunal Associations 4 and 5, (Figure 6) characterized by less

PLEISTOCENE SANTA BARBARA FORMATION <i>Lobatula/Gavelinopsis</i> Biofacies (1) Faunal Associations 1&2	
CHARACTERISTIC FAUNA Robust miliolids and attached low profile species such as:	<i>L. fletcheri</i> <i>D. biserialis</i> <i>G. campanulata</i>
RECENT CALIFORNIA BORDERLAND ANALOGUE <i>Cassidulina/Hanzawaia</i> Biofacies	
CHARACTERISTIC FAUNA <i>A. viragoense</i> <i>G. campanulata</i> <i>I. limbata</i> <i>L. fletcheri</i>	ENVIRONMENT Offshore Ridge and Deep Bank Ave. Depth = 50 m (20-400 m) Water Mass = California Current Temperature = 7-16° C Salinity = 33.4-34.2 ‰ Carbonate = 25-36 %

FIGURE 8—Comparison of the Pleistocene *Lobatula-Gavelinopsis* Biofacies found at Bathhouse Beach with the typical fauna and environmental constraints of the probable modern analogue, Douglas's (1981) *Cassidulina-Hanzawaia* Biofacies.

PLEISTOCENE SANTA BARBARA FORMATION <i>Buccella/Islandiella</i> Biofacies (2) Faunal Associations 4&5	
CHARACTERISTIC FAUNA Light, free-living, non-miliolids such as:	<i>A. baggi</i> <i>B. frigida</i> <i>E. crispum</i> <i>I. limbata</i> <i>L. mckannai</i> <i>M. bramlettei</i>
RECENT CALIFORNIA BORDERLAND ANALOGUE <i>Buccella/Angulogerina</i> Biofacies	
CHARACTERISTIC FAUNA <i>B. frigida</i> <i>I. californica</i> <i>L. mckannai</i> <i>P. ornata</i> <i>A. baggi</i>	ENVIRONMENT Offshore Ridge and Deep Bank Ave. Depth = 150 m (100-400 m) Water Mass = California Current Temperature = 7-12 C Salinity = 33.6-34.4 ‰ Carbonate = 20-38 %

FIGURE 9—Comparison of the Pleistocene *Buccella-Islandiella* Biofacies found at Bathhouse Beach with the typical fauna and environmental constraints of the probable modern analogue, Douglas's (1981) *Buccella-Angulogerina* Biofacies.

robust, free living non-miliolid species such as *Angulogerina baggi*, *Buccella frigida*, *Elphidium crispum*, *Islandiella limbata*, *Lobatula mckannai*, and *Montfortella bramlettei*, correspond most closely with the foraminiferal faunas of the samples comprising Biofacies 2. Analysis of the faunas shows that Biofacies 2, easier remembered as the *Buccella/Islandiella* Biofacies, samples are characterized (Figure 7) by an *Islandiella limbata* population of >14 percent, a *Lobatula fletcheri* population from 5-13 percent, and, probably most importantly, a *Buccella frigida* population in excess of 4 percent of the population. Biofacies 2A differs from Biofacies 2B in the proportion of *Buccella frigida* present (4-7% in 2A, and 8-18% in 2B) in a relationship that may also be a function of increasing water depth with increasing proportion. These foraminiferal faunas are most closely related to Douglas's (1981) *Buccella-Angulogerina* Assemblage and are characteristic of offshore ridges and deep banks, averaging around 150 meters in depth, where wave and current activity is not intense (Figure 9).

Further evidence of the shallow depositional conditions at the Bathhouse Beach locality is provided by the planktonic/benthic foraminiferal ratio, which varied from about 8 to 35 percent, indicating typical shelf depths (Bandy et al., 1964).

With the exception of some rare taxa, no species were exclusively restricted to a particular biofacies. Biofacies and defined paleoenvironments are only recognizable by the proportions of dominant species present in a particular sample. For example, although miliolids and low profile attached species are characteristic of *Lobatula/Gavelinopsis* Biofacies (Biofacies 1) samples, individuals of all these species also are found in *Buccella/Islandiella* Biofacies (Biofacies 2) samples. Douglas (1981) reported that faunal overlap is common on the California Borderland near biofacies boundaries and particularly in shallow waters such as found on banks and ridges, due to the leveling effect of California Current waters (Figures 9, 10).

The two biofacies recognized by Douglas (1981) on the off-

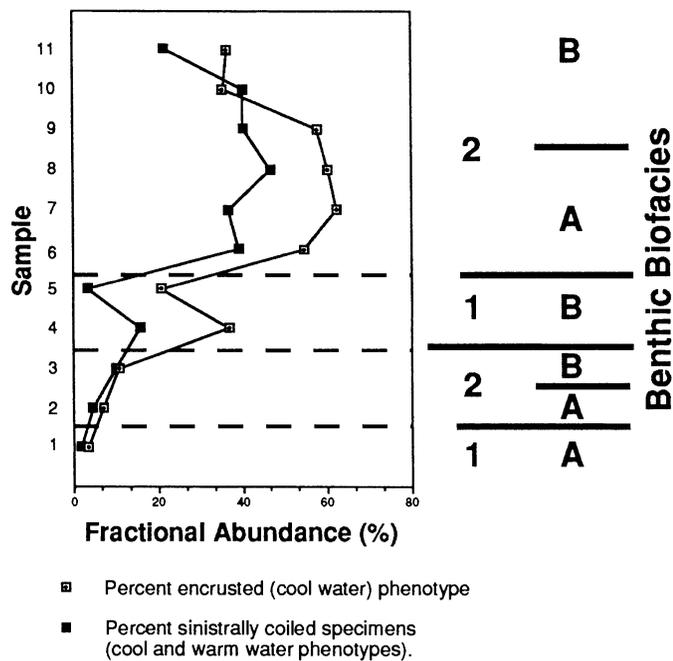


FIGURE 10—Percent cool water phenotype and percent sinistrally coiling cool and warm water phenotypes in total *Neogloboquadrina pachyderma* population. Assemblages defined by benthic foraminifera are also included.

shore banks and ridges are quite distinct from those of detrital-rich shelf environments at similar depths. Although Douglas (1981) reported that temperature and salinity accounts for much of the faunal variation between foraminiferal biofacies, the controlling limiting factor in these cases is most likely the high concentration of dissolved carbonate (20–38 percent) found on modern offshore banks and in the shell-rich deposits at Bathhouse Beach. Dissolved carbonate levels on the present day shelf are much lower, ranging between 3 and 12 percent.

Two transgressive cycles separated by an apparent disconformity are recognizable in the section at Bathhouse Beach (Figure 2). The first cycle is a short sequence, including samples 1, 2, and 3 that correspond respectively to *Lobatula/Gavelinopsis* Biofacies 1A, 1B, and *Buccella/Islandiella* Biofacies 2B. The second cycle is recorded in a thicker sequence from samples 4 to 11. Samples 4 and 5 correspond to *Lobatula/Gavelinopsis* Biofacies 1B, samples 6 and 7 belong to *Buccella/Islandiella* Biofacies 2B. Except for stratigraphic thickness, and the presence of *Lobatula/Gavelinopsis* Biofacies 1A in only the lower unit, the cycles are very similar. During the Pleistocene, however, many provincial and local diastrophic events occurred along the California coast, probably surpassing in intensity all earlier episodes of regional tectonism (Vedder and Howell, 1980). These events were superimposed on eustatic sea level changes brought on by glacial cycles. Hence, the benthic foraminiferal record at Bathhouse Beach can only define these transgressions as relative sea level events.

Unfortunately, the results of this report are not readily comparable, except by age, with previous studies of land exposed Early–Middle Pleistocene benthic foraminiferal faunas from localities elsewhere along the California Borderland. For example, benthic foraminiferal biofacies qualitatively described by Natland (1957) from the adjacent Ventura Basin are bathyal in nature and thus are characterized by an almost completely different benthic foraminiferal fauna. In addition, studies of other

similarly aged Pleistocene sections such as the lithologically and faunally closely related Lomita Marl at Palos Verdes, California (Galloway and Wissler, 1927a), have been qualitative in nature. Although it is likely that both the Bathhouse Beach locality and the Lomita Marl were deposited under similar conditions, quantitative analysis of samples from the latter is required as confirmation.

Planktonic foraminiferal analysis.—Nine species of planktonic foraminifera occur in the section, and only four species are present in all samples (Table 2). *Neogloboquadrina pachyderma* is the most common ranging from 25.6 to 59.0 percent, followed by *Globigerina quinqueloba* Natland, 1938, at 20.4 to 43.1 percent, *Tinophodella glutinata* (Egger, 1893) at 8.2 to 33.6 percent, and *Globigerina bulloides* d'Orbigny, 1826. The samples are all dominated by dextrally coiled *Neogloboquadrina pachyderma* relative to the sinistral morph. When considered with associated taxa, the fauna of the whole section is referable to the transitional assemblage of Coulbourn et al. (1980). Samples S1 to S5 and S11, which have fewer than 25 percent sinistral *Neogloboquadrina pachyderma*, have an assemblage similar to that found today offshore from southern and Baja California, whereas samples S6 to S10, which have more than 25 percent sinistral *Neogloboquadrina pachyderma*, have an assemblage similar to that found offshore from central California.

Phenotypes of *Neogloboquadrina pachyderma* have been used as an indicator of paleotemperature (Bandy, 1960; Kennett and Srinivasan, 1980; Keller, 1978; and others). The ratio of sinistral to dextral morphs [$100 \times \text{Sin}/(\text{Sin} + \text{Dex})$] was plotted upsection (Figure 10). Samples S1 to S5 bear fewer than 15 percent sinistral forms whereas samples S6 to S10 contain approximately 40 percent sinistral forms. Sample S11 is intermediate in value with about 25 percent sinistral forms. The coiling shift to more sinistral forms between samples S5 and S6 indicates an abrupt cooling, and a coiling shift to more dextral forms between samples S10 and S11 marks a modest abrupt warming.

The distribution of another phenotype of *Neogloboquadrina pachyderma* was also examined: the ratio [$100 \times \text{Enc}/(\text{Enc} + \text{Ret})$] of encrusted, compact morphs (Group A of Reynolds and Thunell (1986) and Form 1 of Keller (1978)) to reticulate, globular morphs (Groups B of Reynolds and Thunell and forms 2 plus 3 of Keller (1978)). The encrusted form is associated with warmer temperatures, nutrient-poor waters, and a well-stratified seasonal thermocline (Reynolds and Thunell, 1986). The distribution of surface texture morphs (Figure 8) correlates well with that of the coiling morphs except for sample S4, which appears significantly different from samples S1, S2, S3, and S5, and sample S10, which appears similar to S11 rather than to sample S9. In general, the curves support abrupt cooling between samples S5 and S6 and return to moderately warm conditions at the top of the section.

In general, benthic biofacies boundaries do not correspond to changes observed in the planktonic assemblage. Planktonic frequencies do not change significantly through the first transgressive cycle. The shift to cool surficial conditions corresponds to the deepening (1b/2a boundary) recorded by the benthic fauna in the upper transgressive cycle. The benthic assemblage is unresponsive to the surficial warming inferred from planktonic foraminifera at the top of the section. These data indicate that the transgressive cycles are inconsistent with glacial-driven changes in sealevel.

CONCLUSIONS

1. Strontium $^{87}\text{SR}/^{86}\text{SR}$ techniques indicate that the Bathhouse Beach locality of the Santa Barbara Formation was deposited between 0.9 and 0.4 MyBP.
2. R-Mode analysis of benthic foraminiferal fauna fractional

abundances delineated five associations similar to those found on present-day banks and ridges of the California Borderland.

3. Four biofacies were recognized based on a Q-mode cluster analysis of benthic foraminiferal fractional abundances. These biofacies are analogous to biofacies identified from shallow banks and terraces (≈ 50 m) and from offshore ridges and deep banks (≈ 150 m) on the present-day California Borderland.
4. Two transgressive cycles separated by an apparent discontinuity were recognized from the stratigraphic succession of benthic foraminiferal biofacies.
5. The proportion of coiling ratios and morphs of the planktonic foraminifer *Neogloboquadrina pachyderma* indicates a warm interval at the base of the section; a cooler interval between samples 5 and 6 to between samples 10 and 11; and an interval of intermediate paleotemperature in the topmost sample of the section.
6. The shift in *Neogloboquadrina pachyderma* coiling ratio between samples 5 and 6, from predominantly dextral to sinistral, is consistent with the CD9/CD8 boundary (0.6 MyBP) of the chronostratigraphic framework proposed by Lago and Thompson (1988) for the California Borderland.
7. Changes in the planktonic assemblage do not coincide with the transgressive cycles inferred from the benthic biofacies, suggesting that these sea level changes were most likely not glacial-driven.

SPECIES LIST

Species are listed alphabetically. Numbers preceding species names denote position in R-mode analysis dendrogram and in the benthic foraminiferal relative frequency chart. Planktonic species are not included in either of these charts and are thus not numbered. Those figured represent ≥ 1 percent of the fauna. Generic designations follow Loeblich and Tappan, 1987.

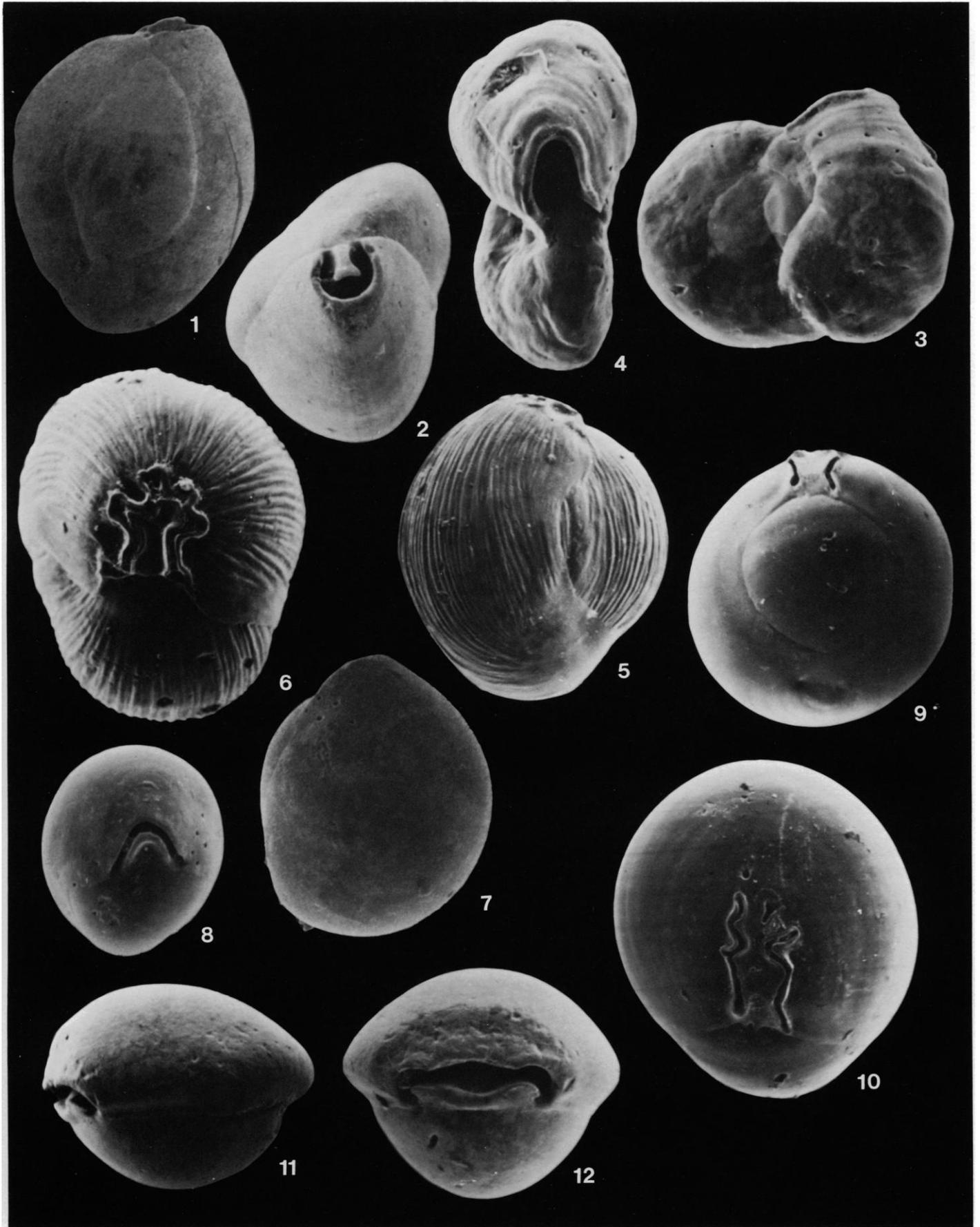
72. *ANGULODISCORBIS DUNCANI* Young, 1981
Angulodiscorbis duncani YOUNG, 1981, p. 905, Pl. 1, figs. 8–11.
60. *ANGULOGERINA BAGGI* (Galloway and Wissler, 1927)
Figure 16.12, 16.13
Uvigerina baggi GALLOWAY AND WISSLER, 1927a, p. 75, Pl. 11, fig. 19.
75. *ASTRONONION FIJIENSE* Cushman and Edwards, 1937
Astrononion fijiense CUSHMAN AND EDWARDS, 1937, p. 35, Pl. 3, figs. 15, 16.
76. *ASTRONONION VIRAGOENSE* Cushman and Edwards, 1937
Figure 13.11, 13.12
Astrononion viragoense CUSHMAN AND EDWARDS, 1937, p. 32, Pl. 3, fig. 12.
66. *BOLIVINA ACUMINATA* (Natland, 1946)
Bolivina subadvena Cushman var. *acuminata* NATLAND in Cushman and Gray, 1946b, p. 34, Pl. 5, fig. 46.
67. *BOLIVINA DECUSSATA* Brady, 1881
Figure 17.1, 17.2
Bolivina decussata BRADY, 1881, p. 58; 1884, p. 423, Pl. 53, figs. 12, 13.
68. *BRIZALINA* cf. *B. HUMILIS* (Cushman and McCulloch, 1942)
Bolivina seminuda Cushman var. *humilis* CUSHMAN AND MCCULLOCH, 1942, p. 211, Pl. 26, figs. 1–6.
69. *BRIZALINA PACIFICA* (Cushman and McCulloch, 1942)
Bolivina acerosa Cushman var. *pacifica* CUSHMAN AND MCCULLOCH, 1942, p. 185, Pl. 21, figs. 2, 3.
70. *BRIZALINA QUADRATA* (Cushman and McCulloch, 1942)
Figure 17.3, 17.4
Bolivina quadrata CUSHMAN AND MCCULLOCH, 1942, p. 205, Pl. 25, fig. 13.
62. *BUCCELLA FRIGIDA* (Cushman, 1922)
Figure 16.5–16.7
Pulvinulina frigida CUSHMAN, 1922, p. 470.
57. *BULIMINA MARGINATA* d'Orbigny, 1826
Bulimina marginata D'ORBIGNY, 1826, p. 269, Pl. 12, figs. 10–12.
92. *BULIMINELLA PUNCTATA* (d'Orbigny, 1826)
Bulimina punctata D'ORBIGNY, 1826, p. 270, no. 11.
93. *CASSIDULINA BRADSHAWI* Uchio, 1960
Figure 12.1, 12.2
Cassidulina bradshawi UCHIO, 1960, p. 68, Pl. 9, figs. 11, 12.
24. *CEREBRINA OBSCUROCOSTATA* (Galloway and Wissler, 1927)
Fissurina obscurocostata GALLOWAY AND WISSLER, 1927a, p. 52, Pl. 9, fig. 1.
23. *CEREBRINA* sp. 1
This species will be described in a forthcoming taxonomic treatment of the foraminifera of the Santa Barbara Formation.
89. *CRIBROELPHIDIUM MICROGRANULOSUM*
(Galloway and Wissler, 1927)
Figure 13.4, 13.5
Themeon decipiens GALLOWAY AND WISSLER, 1927a, p. 83, Pl. 12, figs. 15, 16 (not *Polystomella decipiens* Costa, 1856).
Themeon granulosis 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.
81. *DYOCIBICIDES BISERIALIS* Cushman and Valentine, 1930
Figure 14.1, 14.5
Dyocibicides biserialis CUSHMAN AND VALENTINE, 1930, p. 31, Pl. 10, figs. 1, 2.
90. *ELPHIDIELLA HANNAI* (Cushman and Grant, 1927)
Figure 13.6–13.8
Elphidium hannai CUSHMAN AND GRANT, 1927, p. 77, Pl. 8, fig. 1.
88. *ELPHIDIUM CRISPUM* (Linné, 1758)
Figure 13.9, 13.10
Nautilus crispus LINNÉ, 1758, p. 709.
59. *EUUVIGERINA JUNCEA* (Cushman and Todd, 1941)
Uvigerina juncea CUSHMAN AND TODD, 1941, p. 78, Pl. 20, figs. 4–11.
25. *FAVULINA SQUAMOSA* (Montagu, 1803)
Vermiculum squamosa MONTAGU, 1803, p. 526, Pl. 14, fig. 2.
26. *FISSURINA COPIOSA* McCulloch, 1977
Fissurina copiosa MCCULLOCH, 1977, p. 97, Pl. 63, fig. 1.
27. *FISSURINA EVOLUTIGUETRA* McCulloch, 1977
Fissurina evolutiquetra MCCULLOCH, 1977, p. 105, Pl. 58, figs. 21, 24.

28. FISSURINA FABIA (Balkwill and Millett, 1884)
Lagena faba BALKWILL AND MILLETT, 1884, p. 81, Pl. 2, fig. 10.
29. FISSURINA HABENIFERA (Buchner, 1940)
Lagena habenifera BUCHNER, 1940, p. 464, Pl. 11, figs. 184–188.
31. FISSURINA QUADRICOSTULATA Reuss, 1870
Lagena quadricostulata REUSS, 1870, p. 469, Pl. 4, figs. 25–30.
32. FISSURINA ROMETTENSIS Seguenza, 1862
Fissurina (Fissurina) romettensis SEGUENZA, 1862, p. 66, Pl. 2, fig. 24.
33. *Fissurina semimarginata* (Reuss, 1870)
Lagena marginata Williamson var. *semimarginata* REUSS, 1870, p. 468.
30. FISSURINA sp. 1
This species will be described in a forthcoming taxonomic treatment of the foraminifera of the Santa Barbara Formation.
34. FISSURINA VITREOLA (Buchner, 1940)
Lagena vitreola BUCHNER, 1940, p. 477, Pl. 13, figs. 256–258.
1. GAUDRYINA ARENARIA Galloway and Wissler, 1927
Gaudryina arenaria GALLOWAY AND WISSLER, 1927a, p. 68, Pl. 11, fig. 5.
2. GAUDRYINA SUBGLABRATA Cushman and McCulloch, 1939
Gaudryina subglabrata CUSHMAN AND MCCULLOCH, 1939, p. 92, Pl. 8, figs. 5–7.
64. GAVELINOPSIS CAMPANULATA (Galloway and Wissler, 1927)
Figure 16.1–16.4
Globorotalia campanulata GALLOWAY AND WISSLER, 1927a, p. 58, Pl. 9, fig. 14a–c.
80. GLABRATILLA ORNATISSIMA (Cushman, 1925)
Figure 15.7–15.10
Discorbis ornatissima CUSHMAN, 1925, p. 42, Pl. 6, figs. 11, 12.
91. GLABRATILLA sp. 1
This species will be described in a forthcoming taxonomic treatment of the foraminifera of the Santa Barbara Formation.
- GLOBIGERINA BULLOIDES d'Orbigny, 1826
Globigerina bulloides D'ORBIGNY, 1826, p. 277; 1839b, p. 132–133, Pl. 2, figs. 1, 3, 28.
- GLOBIGERINA FALCONENSIS Blow, 1959
Globigerina falconensis BLOW, 1959, p. 177, Pl. 9, figs. 40a–c, 41.
- GLOBIGERINA QUINQUELOBA Natland, 1938
Figure 18.10–18.12
Globigerina quinqueloba NATLAND, 1938, p. 149, Pl. 6, fig. 7a–c.
- GLOBIGERINITA UVULA (Ehrenberg, 1861)
Pyloedixia uvula EHRENBERG, 1861, p. 276, 277, 308; 1873, Pl. 2, figs. 24, 25.
- GLOBIGERINOIDES RUBER (d'Orbigny, 1839)
Globigerina rubra D'ORBIGNY 1839c, p. 82, (plates published separately) Pl. 4, figs. 12–14
- GLOBOROTALIA INFLATA (d'Orbigny, 1839)
Globigerina inflata D'ORBIGNY, 1839b, p. 134, Pl. 2, figs. 7–9.
61. GYROIDINA NEOSOLDANII Brotzen, 1936
Gyroidina neosoldanii BROTZEN, 1936, p. 158.

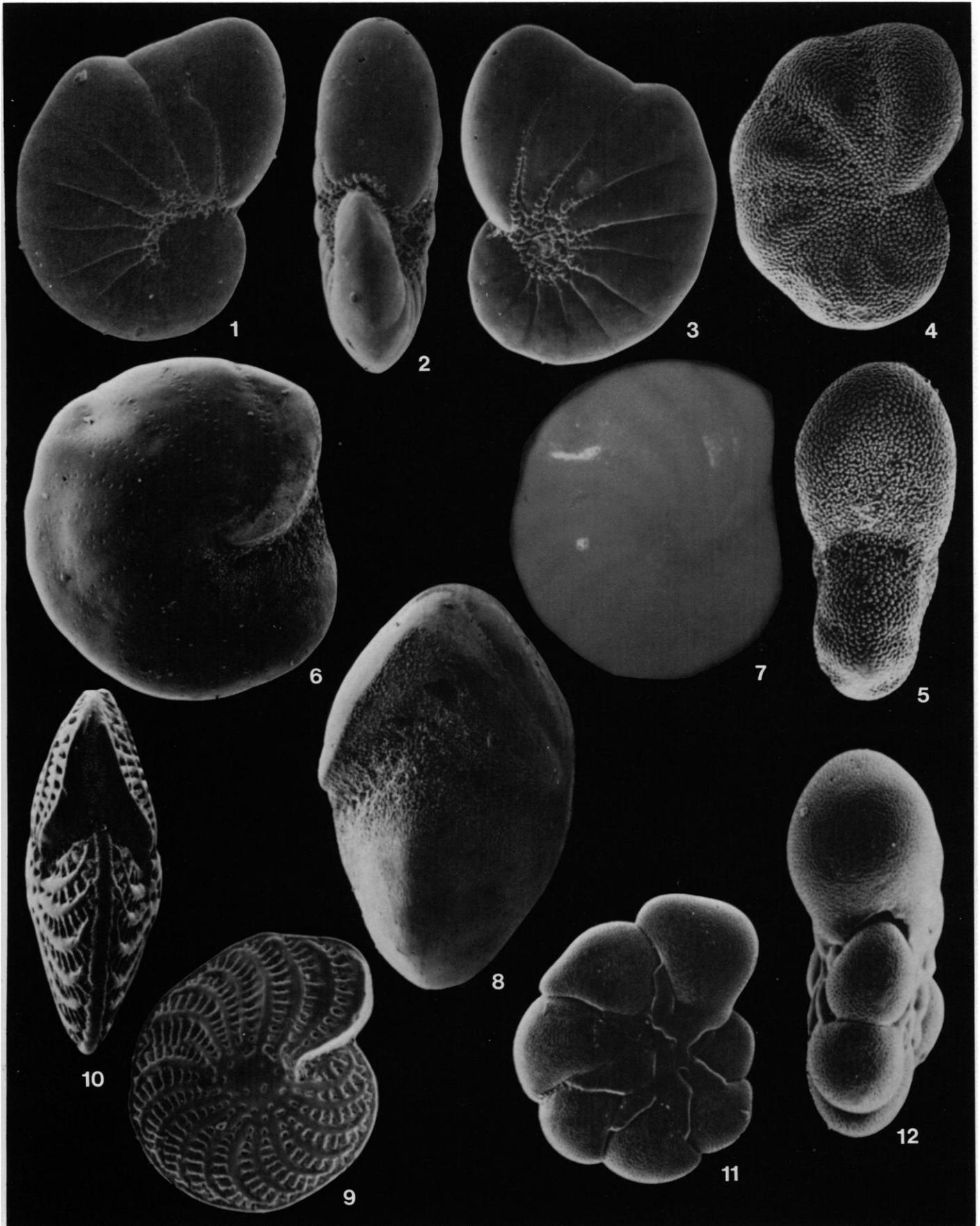
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FIGURE 11—1, 2, *Quinqueloculina triangularis* d'Orbigny. 1, side view of elongate hypotype, ×45, USNM 409048, (sample 1); 2, apertural view of same specimen showing bifurcate apertural tooth, ×50. 3, 4, *Pateoris hauerinoides* (Rhumbler). 3, side view of hypotype, ×160, USNM 409049, (sample 2); 4, apertural view of same specimen showing compressed test and non-toothed aperture, ×200. 5, 6, *Miliolinella sublineata* (Brady). 5, side view of striated hypotype, ×75, USNM 409050, (sample 2); 6, apertural view of same specimen showing irregular flaplike tooth constricting aperture, ×100. 7, 8, *Miliolinella californica* Rhumbler. 7, side view of smooth surfaced hypotype, ×230, USNM 409051, (sample 9); 8, apertural view of same specimen showing broad tooth constricting aperture, ×200. 9, 10, *Pyrgoella sphaera* (d'Orbigny). 9, side view of hypotype showing strongly overlapping biloculine chamber arrangement, ×50, USNM 409052, (sample 2); 10, apertural view of same specimen showing apertural tooth attached at both ends, ×60. 11, 12, *Pyrgo depressa* (d'Orbigny). 11, edge view of compressed hypotype showing biloculine chamber arrangement, ×40, USNM 409053, (sample 1); 12, apertural view of same specimen showing broad apertural tooth, ×50.

FIGURE 12—1, 2, *Cassidulina bradshawi* Uchio. 1, Side view of finely perforate hypotype, ×310, USNM 409054, (sample 5); 2, edge view of same specimen showing compressed test, ×370. 3–5, *Islandiella limbata* (Cushman and Hughes). 3, side view of hypotype showing slitlike aperture, ×80, USNM 409055, (sample 1); 5, edge view of same specimen showing compressed test and apertural tooth, ×100; 4, light photograph of side view of a different hypotype showing numerous narrow radiating chambers, ×90, USNM 409056, (sample 1). 6–8, *Islandiella californica* (Cushman and Hughes). 6, side view of hypotype, ×50, USNM 409057, (sample 1); 8, edge view of same specimen showing subglobular test shape, ×50; 7, light photograph of side view of a different hypotype showing large chambers, ×55, USNM 409058, (sample 1). 9–11, *Nonionella stella* Cushman and Moyer. 9, view of involute ventral side of hypotype showing final chamber overhanging umbilical region, ×190, USNM 409059, (sample 1); 10, view of spiral side of same specimen showing chambers rapidly increasing in size as added, ×160; 11, edge view of same specimen showing asymmetrical compressed test, ×190.

FIGURE 13—1–3, *Pseudononion basispinata* (Cushman and Moyer). 1, view of spiral side of hypotype showing chambers rapidly increasing in size as added, ×100, USNM 409060, (sample 3); 2, edge view of same specimen showing compressed asymmetrical test, ×100; 3, ventral view of same hypotype showing granular material partially infilling umbilicus and extending partway along sutures, ×100. 4, 5, *Criboelphidium microgranulosum* Galloway and Wissler. 4, side view of hypotype showing distinctive granular surface, ×100, USNM 409061, (sample 1); 5, edge view of same specimen showing planispiral chamber arrangement, ×150. 6–8, *Elphidiella hannai* (Cushman and Grant). 6, side view of hypotype showing double rows of apertural pores, ×65, USNM 409062, (sample 8); 8, edge and apertural view of same specimen, ×75; 7, light photograph of side view of a different hypotype showing numerous narrow radiating chambers, ×60, USNM 409063, (sample 10). 9, 10, *Elphidium crispum* (Linné). 9, side view of hypotype showing numerous cross-striated chambers, ×50, USNM 409064, (sample 1); 10, edge view of same specimen showing compressed test and large marginal carina, ×70. 11, 12, *Astrononion viragoense* Cushman and Edwards. 11, side view of hypotype showing characteristic umbilical flaps, ×110, USNM 409065 (sample 1); 12, edge view of same specimen showing interiomarginal slitlike aperture, ×150.





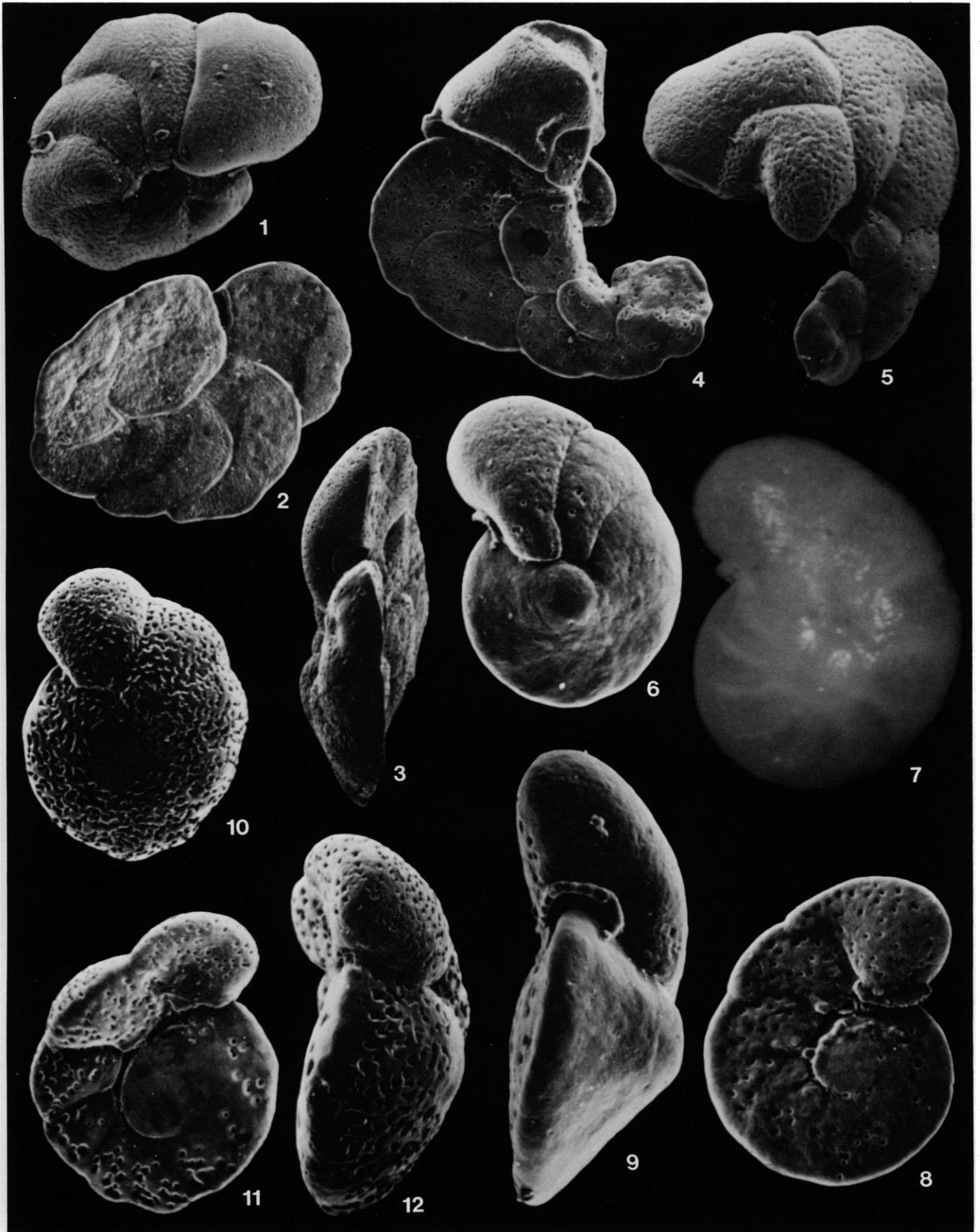


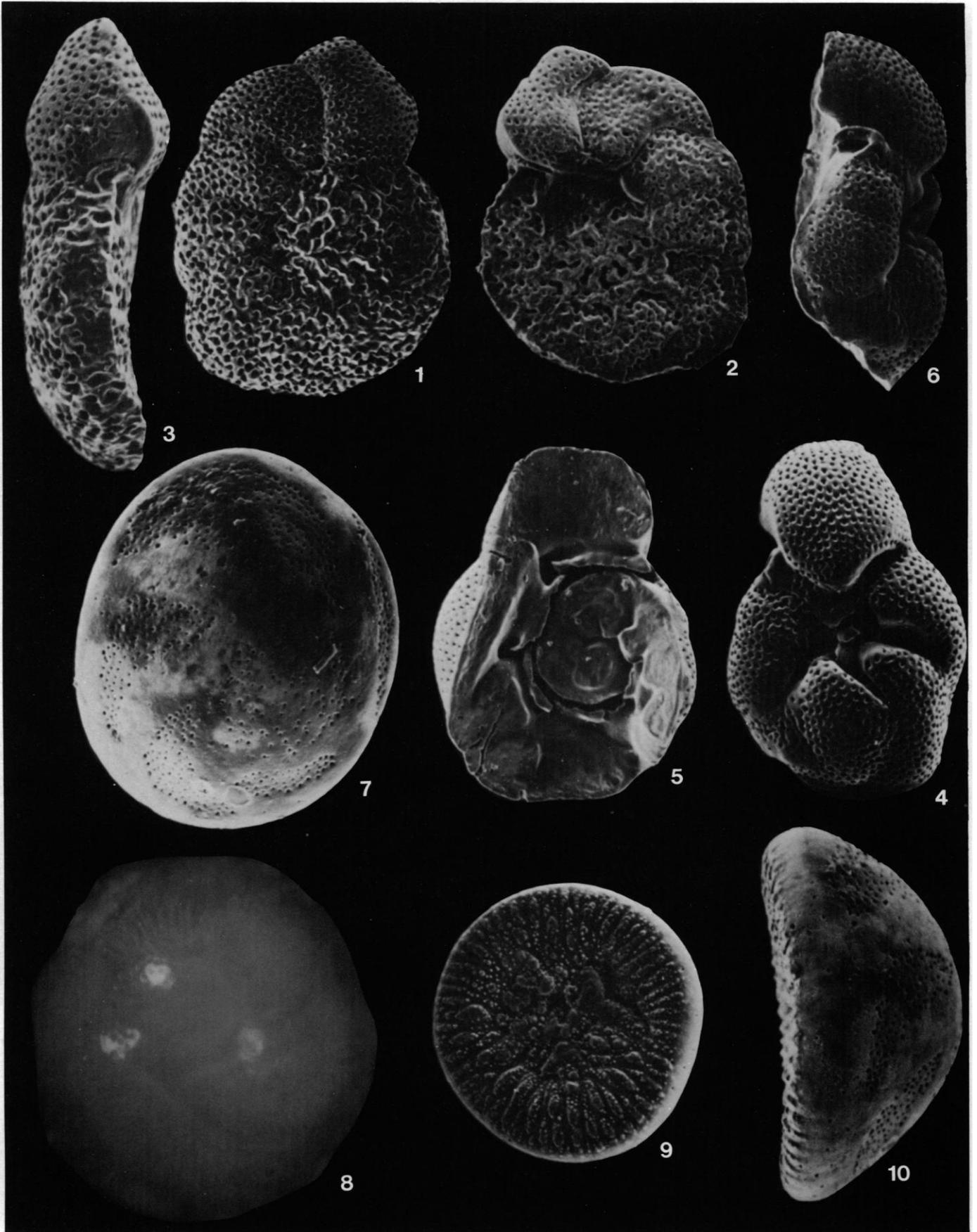
84. HANZAWAIA HAMADAENSIS Asano, 1951
Hanzawaia hamadaensis ASANO, 1951, p. 16, tfs. 21–23.
35. HOMALOHEDRA APIOPLEURA (Loeblich and Tappan, 1953)
Lagena apiopleura LOEBLICH AND TAPPAN, 1953, p. 59, Pl. 10, figs. 14, 15.
36. HOMALOHEDRA BOREALIS (Loeblich and Tappan, 1954)
Oolina borealis LOEBLICH AND TAPPAN, 1954, p. 384.
38. HOMALOHEDRA LINEATA (Williamson, 1848)
Entosolenia lineata WILLIAMSON, 1848, p. 18, Pl. 2, fig. 18.
39. HOMALOHEDRA NEOCOSTATA (McCulloch, 1977)
Lagena neocostata MCCULLOCH, 1977, p. 41, Pl. 55, fig. 4.
37. HOMALOHEDRA sp. 1
This species will be described in a forthcoming taxonomic treatment.
40. HOMALOHEDRA sp. 2
This species will be described in a forthcoming taxonomic treatment.
73. ISLANDIELLA CALIFORNICA (Cushman and Hughes, 1925)
Figure 12.6–12.8
Cassidulina californica CUSHMAN AND HUGHES, 1925, p. 12, Pl. 2, fig. 1.
74. ISLANDIELLA LIMBATA (Cushman and Hughes, 1925)
Figure 12.3–12.5
Cassidulina limbata CUSHMAN AND HUGHES, 1925, p. 12, Pl. 2, fig. 2.
3. KARRERIELLA BRADYI (Cushman, 1911)
Gaudryina bradyi CUSHMAN, 1911, p. 67, tf. 107.
19. LAGENA LAEVICOSTATA Cushman and Gray, 1946
Lagena sulcata (Walker and Jacob) var. *laevicostata* CUSHMAN AND GRAY, 1946a, p. 20, Pl. 3, figs. 47, 48.
20. LAGENA SPICATA Cushman and McCulloch, 1950
Lagena sulcata (Walker and Jacob) var. *spicata* CUSHMAN AND MCCULLOCH, 1950, p. 360, Pl. 48, figs. 4, 5, 7, (not 3, 6).
17. LAGENA sp. 1
This species will be described in a forthcoming taxonomic treatment.
18. LAGENA sp. 2
This species will be described in a forthcoming taxonomic treatment.
83. LOBATULA FLETCHERI (Galloway and Wissler, 1927)
Figure 14.6–14.9
Cibicides fletcheri GALLOWAY AND WISSLER, 1927a, p. 64, Pl. 10, figs. 8, 9.
82. LOBATULA MCKANNAI (Galloway and Wissler, 1927)
Figure 14.10–14.12
Cibicides mckannai GALLOWAY AND WISSLER, 1927a, p. 65, Pl. 10, figs. 5, 6.
4. MASSILINA PULCHRA Cushman and Gray, 1946
Massilina pulchra CUSHMAN AND GRAY, 1946a, p. 65, Pl. 12, fig. 1.
54. METAPOLYMORPHINA CHARLOTTENSIS (Cushman, 1925)
Polymorphina charlottensis CUSHMAN, 1925, p. 41, Pl. 6, fig. 9.
12. MILIOLINELLA CALIFORNICA Rhumbler, 1936
Figure 11.7, 11.8
Miliolinella californica RHUMBLER, 1936, p. 215.
13. MILIOLINELLA SUBLINEATA (Brady, 1884)
Figure 11.5, 11.6
Miliolina circularis (Bornemann) var. *sublineata* BRADY, 1884, p. 169, Pl. 4, fig. 7.

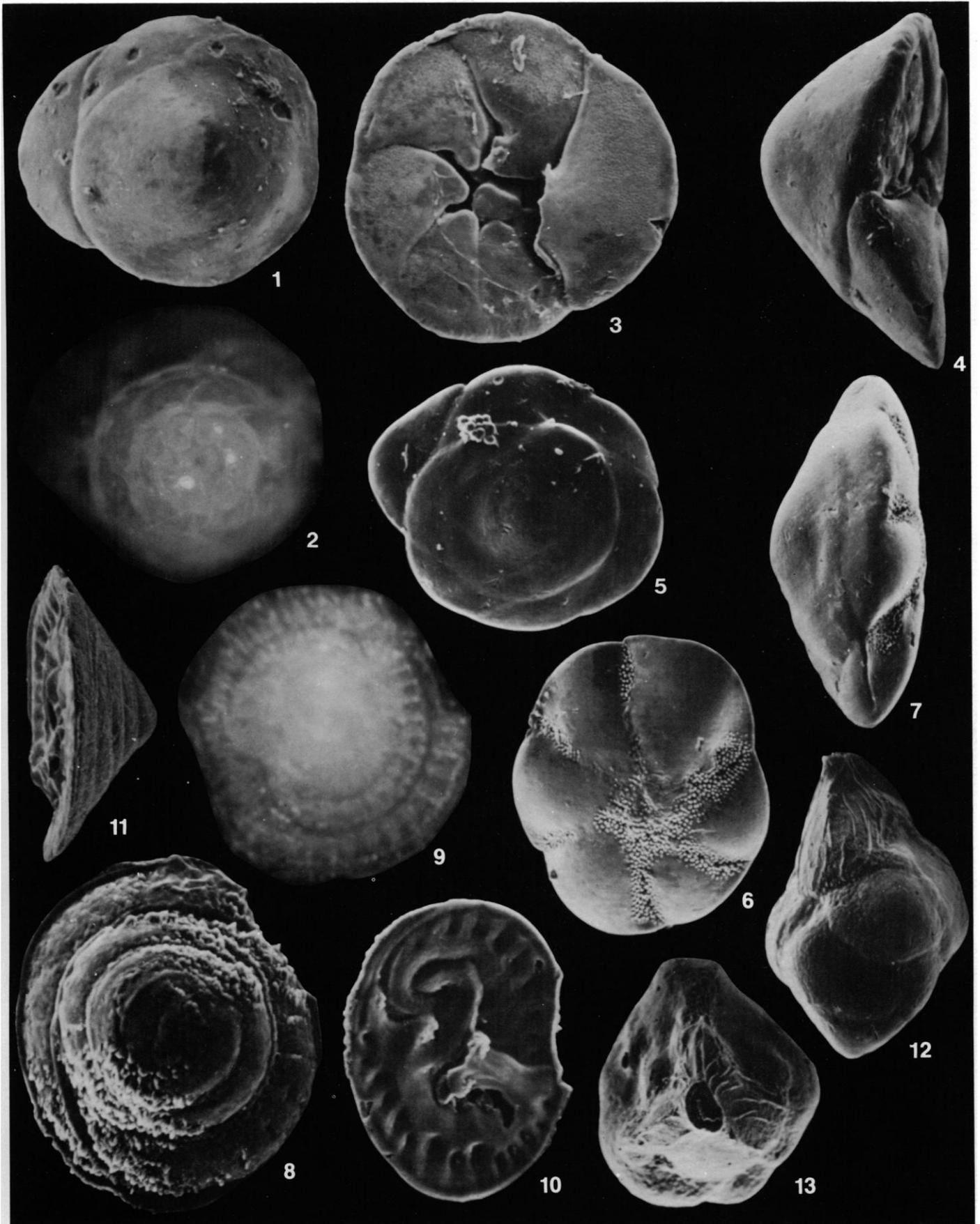
FIGURE 14—1–5, *Dyocibicides biserialis* Cushman and Valentine. 1, ventral view of hypotype prior to development of biserial stage, $\times 53$, USNM 409066, (sample 6); 2, view of flattened spiral side of same specimen, $\times 55$; 3, edge view of same specimen showing compressed test, $\times 70$; 4, view of flattened spiral side of a second hypotype showing well-developed biserial stage, $\times 70$, USNM 409067, (sample 1); 5, ventral view of same specimen, $\times 60$. 6–9, *Lobatula fletcheri* (Galloway and Wissler). 6, ventral view of hypotype showing slightly porous surface, $\times 150$, USNM 409068, (sample 1); 8, flattened ventral side of same specimen, $\times 160$; 9, edge view showing compressed test and lipped aperture, $\times 230$; 7, light photograph of the ventral side of a different hypotype showing translucent umbilical boss and radiating sutures, $\times 170$, USNM 409069, (sample 1). 10–12, *Lobatula mckannai* (Galloway and Wissler). 10, ventral view of coarsely perforate hypotype, $\times 50$, USNM 409070, (sample 1); 11, view of flattened spiral side of same specimen, $\times 55$; 12, edge view of same specimen showing compressed test, $\times 75$.

FIGURE 15—1–3, *Planulina ornata* (d'Orbigny). 1, ventral view of slightly lobulate hypotype showing reticulate ornamentation on early chambers and coarsely perforate test, $\times 75$, USNM 409071, (sample 3); 2, view of attached side of same specimen showing more flattened surface, $\times 70$; 3, edge view of same specimen showing compressed test, $\times 100$. 4–6, *Montfortella bramlettei* Loeblich and Tappan. 4, ventral view of hypotype showing deeply incised sutures, $\times 70$, USNM 409074, (sample 1); 5, flattened spiral side of same specimen showing well-developed intercameral openings, $\times 70$; 6, edge view of same specimen, $\times 70$. 7–10, *Glabratella ornatissima* (Cushman). 7, coarsely perforate spiral side of adult gamont, $\times 170$; USNM 409075, (sample 8); 9, flattened ventral side of same hypotype, $\times 145$; 10, edge view of same hypotype, $\times 185$; 8, light photograph of spiral side of a different hypotype showing chamber arrangement, $\times 165$, USNM 409076, (sample 8).

FIGURE 16—1–4, *Gavelinopsis campanulata* (Galloway and Wissler). 1, spiral side of hypotype, $\times 160$, USNM 409077, (sample 2); 3, view of flattened ventral side of same specimen showing openings along sutures, $\times 195$; 4, edge view of same subconical specimen, $\times 195$; 2, light photograph of different hypotype showing chamber arrangement on spiral side, $\times 160$, USNM 409078, (sample 2). 5–7, *Buccella frigida* (Cushman). 5, spiral view of hypotype, $\times 160$, USNM 409079 (sample 1); 6, ventral view of same specimen showing characteristic granular material along sutures and in umbilicus, $\times 165$; 7, edge view of same specimen, $\times 185$. 8–11, *Patellina corrugata* Williamson. 8, evolute spiral side of hypotype, $\times 480$, USNM 409081, (sample 7); 10, flattened involute ventral side of same specimen, $\times 390$; 11, edge view of same specimen showing conical shape, $\times 260$; 9, light photograph of spiral side of a different hypotype showing numerous incomplete transverse septa, $\times 400$, USNM 409082, (sample 6). 12, 13, *Angulogerina baggi* (Galloway and Wissler). 12, side view of hypotype showing compact nature of test, $\times 125$, USNM 409083, (sample 5); 13, apertural view of same specimen, $\times 160$.







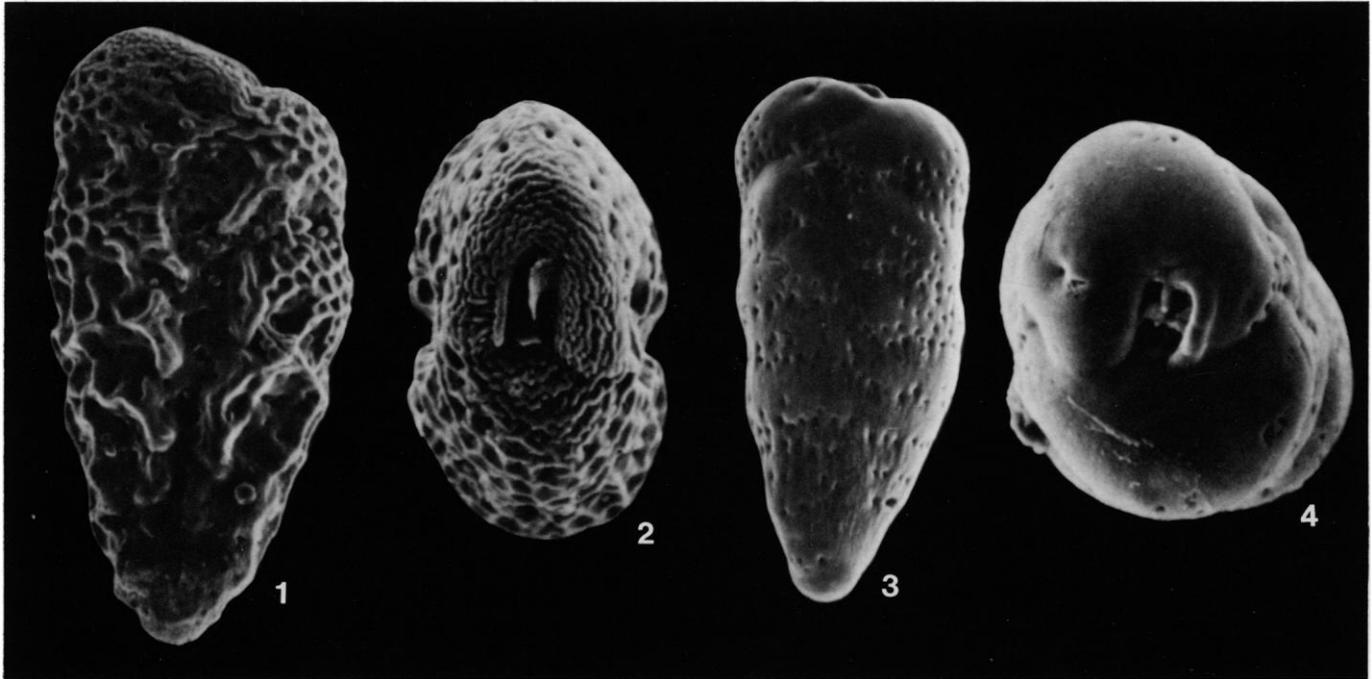


FIGURE 17—1, 2, *Bolivina decussata* Brady. 1, side view of hypotype showing coarsely perforate and reticulate surface, $\times 280$, USNM 409084, (sample 5); 2, apertural view showing apertural tooth, $\times 360$. 3, 4, *Brizalina quadrata* (Cushman and McCulloch). 3, side view of hypotype showing smooth surface and coarse pores concentrated along sutures, $\times 310$, USNM 409085, (sample 1); 4, apertural view showing slightly compressed test and apertural tooth arrangement, $\times 570$.

85. MONTFORTELLA BRAMLETTEI Loeblich and Tappan, 1963
Figure 15.4–15.6

Montfortella bramlettei LOEBLICH AND TAPPAN, 1963, p. 213, 214, tfs. 7, 8a–c, 9a, b.

NEOGLOBOQUADRINA PACHYDERMA (Ehrenberg, 1861)
Figure 18.1–18.9

Aristerspira pachyderma EHRENBURG, 1861, p. 276, 277, 303.
Aristerspira pachyderma EHRENBURG, 1873, Pl. 1, fig. 4.

78. NONIONELLA STELLA Cushman and Moyer, 1930
Figure 12.9–12.11

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

41. OOLINA CAUDIGERA (Wiesner, 1931)

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

ORBULINA UNIVERSA d'Orbigny, 1839

Orbulina universa D'ORBIGNY, 1839c, p. 3, Pl. 1, fig. 1.

42. PALLIOLATELLA FRANGENS (Buchner, 1940)

Lagena frangens BUCHNER, 1940, p. 504, Pl. 19, figs. 407–409.

44. PALLIOLATELLA LAGUNCULA (Buchner, 1940)

Lagena laguncula BUCHNER, 1940, p. 492, Pl. 17, figs. 314–342.

43. PALLIOLATELLA n. sp.

This species will be renamed in a forthcoming taxonomic study.

45. PALLIOLATELLA RONANI (Young, 1981)

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

46. PARAFISSURINA cf. P. CARINATA (Buchner, 1940)

Lagena lateralis Cushman forma *carinata* BUCHNER, 1940, p. 521, Pl. 23, figs. 497–500.

48. PARAFISSURINA LATERALIS (Cushman, 1913)

Lagena lateralis CUSHMAN, 1913, p. 9, Pl. 1, fig. 1.

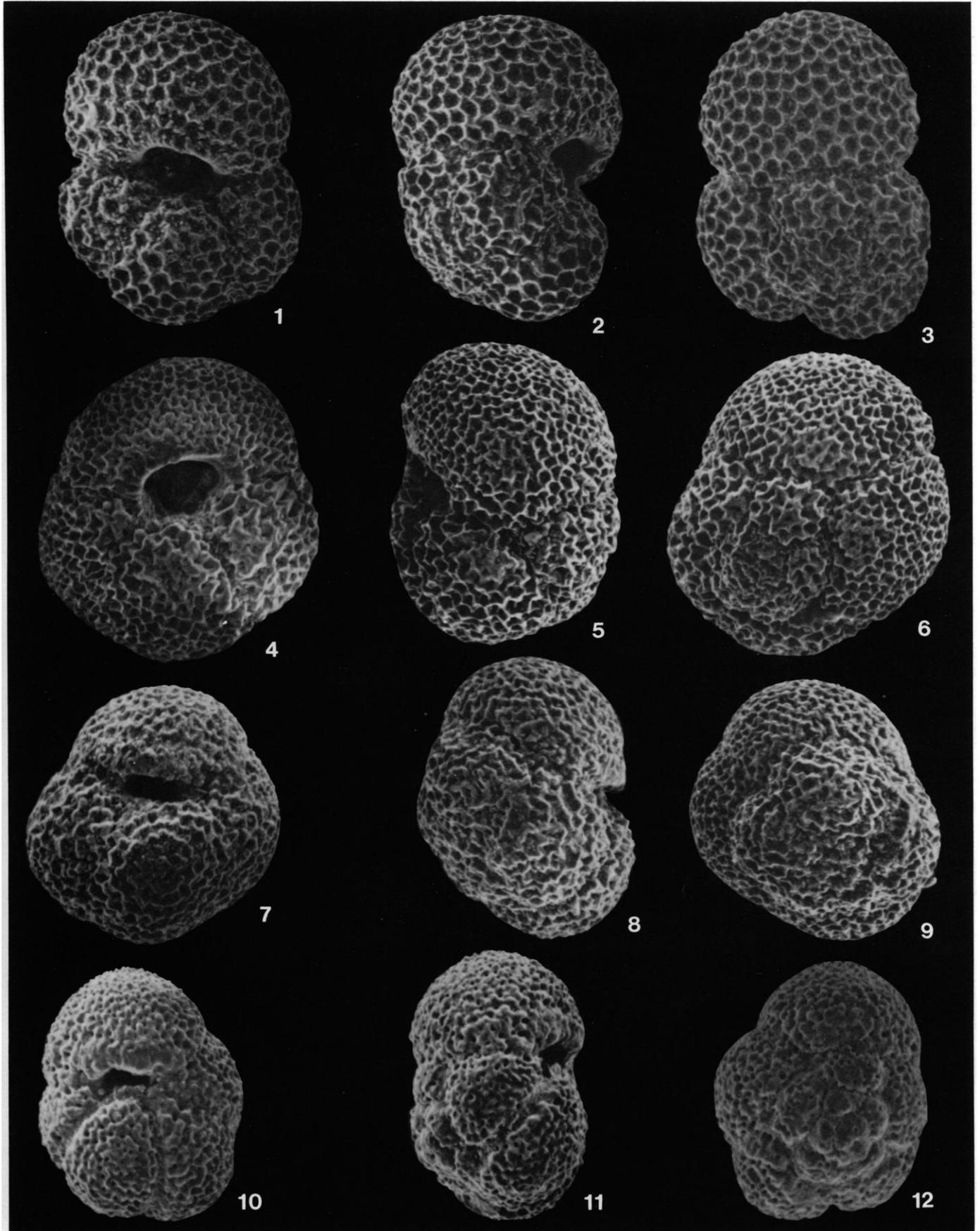
47. PARAFISSURINA REMOVENS Buchner, 1940

Lagena removens BUCHNER, 1940, p. 62, Pl. 28, figs. 601, 602, Pl. 29, fig. 620 (not figs. 614–619).

49. PARAFISSURINA SEMICARINATA (Buchner, 1940)

Lagena lateralis (Cushman) subsp. *semicarinata* BUCHNER, 1940, p. 520, Pl. 23, fig. 493, 494.

FIGURE 18—1–9, *Neogloboquadrina pachyderma* (Ehrenberg). 1, umbilical view of quadrate warm-water phenotype, $\times 250$, hypotype, USNM 409080, (sample 1); 2, edge view of same specimen showing reticulate surface sculpture, $\times 250$; 3, spiral view of same specimen showing dextral coiling; 4, umbilical view of compact cool-water phenotype, $\times 250$, hypotype, USNM 409092, (sample 7); 5, edge view of same specimen showing characteristic secondary calcite encrustation, $\times 250$; 6, spiral view of same specimen showing sinistral coiling, $\times 250$; 7, umbilical view of a second compact cool-water phenotype, $\times 250$, hypotype, USNM 409093, (sample 5); 8, edge view of same specimen showing secondary calcite encrustation, $\times 250$; 9, spiral view of same specimen showing dextral coiling, $\times 250$. 10–12, *Globigerina quinqueloba* Natland. 10, umbilical view of encrusted hypotype showing how this form can be sometimes confused with the cool-water phenotype of *Neogloboquadrina pachyderma*, $\times 250$, hypotype USNM 409096, (sample 3); 11, edge view of same hypotype, $\times 250$; 12, spiral view of same hypotype showing dextral coiling and secondary calcite encrustation, $\times 250$.



16. PATELLINA CORRUGATA Williamson, 1858
Figure 16.8–16.11
Patellina corrugata WILLIAMSON, 1858, p. 46, Pl. 3, figs. 86–89, 89a.
5. PATEORIS HAUERINOIDES (Rhumbler, 1936)
Figure 11.3, 11.4
Quinqueloculina subrotunda (Montagu) forma *hauerinoides* RHUMBLER, 1936, p. 206, 217, 226, tf. 167 (p. 205), tf. 208–212 (p. 225).
86. PLANORBULINA ACERVALIS Brady, 1884
Planorbulina acervalis BRADY, 1884, p. 657, Pl. 92, fig. 4.
53. PLANULARIA PLANULATA (Galloway and Wissler, 1927)
Astaculus planulatus GALLOWAY AND WISSLER, 1927a, p. 46, Pl. 8, fig. 5.
87. PLANULINA ORNATA (d'Orbigny, 1839)
Figure 15.1–15.3
Planulina ornata D'ORBIGNY, 1839a, p. 40, Pl. 6, figs. 7–9.
58. PRAEGLOBOBULIMINA PUPOIDES (d'Orbigny, 1846)
Bulimina pupoides D'ORBIGNY, 1846, p. 185, Pl. 11, figs. 11, 12.
21. PROCEROLAGENA DISTOMA (Parker and Jones, 1864)
Lagena distoma PARKER AND JONES in Brady, 1864, p. 467, Pl. 48, fig. 6.
22. PROCEROLAGENA MERIDIONALIS (Wiesner, 1931)
Lagena gracilis Williamson var. *meridionalis* WIESNER, 1931, p. 117, Pl. 218, fig. 211.
77. PSEUDONONION BASISPINATA (Cushman and Moyer, 1930)
Figure 13.1–13.3
Nonion pizarrensis Berry var. *basispinata* CUSHMAN AND MOYER, 1930, p. 54, Pl. 7, fig. 18.
10. PSEUDOTRILOCULINA OBLONGA (Montagu, 1803)
Vermiculum oblonga MONTAGU, 1803, p. 522, Pl. 14, fig. 9.
79. PULLENIA SALISBURYI R. E. and K. C. Stewart, 1930
Pullenia salisburyi STEWART AND STEWART, 1930, p. 72, Pl. 8, fig. 2.
6. PYRGO DEPRESSA (d'Orbigny, 1826)
Figure 11.11, 11.12
Biloculina depressa D'ORBIGNY, 1826, p. 298.
7. PYRGOELLA SPHAERA (d'Orbigny, 1839)
Figure 11.9, 11.10
Biloculina sphaera D'ORBIGNY, 1839a, p. 66, Pl. 8, figs. 13–16.
52. PYTINE sp. 1
This species will be described in a forthcoming taxonomic treatment.
9. QUINQUELOCULINA GIGAS Natland, 1938
Quinqueloculina gigas NATLAND, 1938, p. 141, Pl. 4, fig. 4.
8. QUINQUELOCULINA TRIANGULARIS d'Orbigny, 1846
Figure 11.1, 11.2
Quinqueloculina triangularis D'ORBIGNY, 1846, p. 288, Pl. 18, figs. 7–9.
71. RECTOBOLIVINA sp. 1
This species will be described in a forthcoming taxonomic treatment of the foraminifera of the Santa Barbara Formation.
56. ROBERTINOIDES CHARLOTTENSIS (Cushman, 1925)
Cassidulina charlottensis CUSHMAN, 1925, p. 41, Pl. 6, figs. 6, 7.
14. SCUTULORIS TEGMINIS Loeblich and Tappan, 1953
Scutuloris tegminis LOEBLICH AND TAPPAN, 1953, p. 41, Pl. 5, fig. 10.
65. SESTRONOPHORA ARNOLDI Loeblich and Tappan, 1957
Sestronophora arnoldi LOEBLICH AND TAPPAN, 1957, p. 229, Pl. 73, fig. 5.
55. SIGMOMORPHINA FRONDCULARIS (Galloway and Wissler, 1927)
Polymorphina frondicularis GALLOWAY AND WISSLER, 1927a, p. 55, Pl. 9, fig. 6.
50. SOLENINA TIMMSENSIS (Cushman and Gray, 1946)
Entosolenia sigmoidella (Cushman) var. *timmensis* CUSHMAN AND GRAY, 1946b, p. 30, Pl. 5, figs. 34–36.
15. SPIROLOCULINA CALIFORNICA Cushman and Todd, 1944
Spiroloculina depressa d'Orbigny var. *californica* CUSHMAN AND TODD, 1944, p. 30, Pl. 5, figs. 10–12.
11. SPIROSIGMOILINA TENUIS (Czjzek, 1848)
Quinqueloculina tenuis CZIZEK, 1848, p. 149, Pl. 13, figs. 31–34.
- TINOPHODELLA GLUTINATA (Egger, 1893)
Globigerina glutinata EGGER, 1893, p. 371, Pl. 13, figs. 19–21.
63. *Tretomphalus pacificus* Cushman, 1934
Tretomphalus pacificus CUSHMAN, 1934, p. 93, Pl. 11, fig. 7, Pl. 12, figs. 8–12.
51. VASICOSTELLA SEMIALATA (Balkwill and Millett, 1884)
Lagena quadrata (Williamson) var. *semialata* BALKWILL AND MILLETT, 1884, p. 81, Pl. 2, fig. 9.

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