

LATE PLEISTOCENE AND HOLOCENE MOLLUSKS AND FORAMINIFERS FROM NEAR CORDELL BANK, OFFSHORE CENTRAL CALIFORNIA; THEIR AGE AND ENVIRONMENTAL SIGNIFICANCE

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Abstract

Thirty-one molluscan and 73 foraminiferal taxa were recovered from three dredge samples collected at outer shelf to upper slope depths (89 to 215 m) near Cordell Bank, central California (38°N, 123°W). Sample CoBa-2-90 contained the most diverse fauna: 10 molluscan and 73 foraminiferal taxa. This sample was collected between 155 and 255 m depth, west of Cordell Bank, and ^{14}C dating of *Chlamys rubida* (Hinds) valves from the sample has resulted in an age of 15.26 ± 0.045 ka. The ^{14}C age determination, along with the presence of mollusks with modern ranges mostly north of the fossil locality and cool water foraminifers, indicate that this faunal assemblage was deposited around the last glacial maximum (oxygen isotope stage 2). Samples CoBa-3-90 Dredge 2 and CoBa-3-90 Dredge 3 were dredged from shallower depths (89 to 100 m), east of Cordell Bank. These samples contained 25 molluscan taxa and no foraminifers. ^{14}C dates on *Glycymeris septentrionalis* (Middendorff) and *Humularia kennerleyi* (Reeve) valves constrain the age of these samples to between ~ 10.8 and ~ 10.9 ka (early Oxygen Isotope Stage 1). The bivalve *Mya truncata* Linnaeus from these samples indicates that water temperatures were still cooler than present-day at Cordell Bank between ~ 10.8 and ~ 10.9 ka. In addition, the macrofauna from these samples indicates shallow water depths (1-10 m). This is much shallower than the 89 to 100 m depth from which the samples were collected.

Introduction

In the summer of 1990, field work was undertaken off the coast of San Francisco by the U.S. Geological Survey to: 1) obtain side scan sonar images and video transects to aid in locating some of the more than 47,000 containers of low-level radioactive waste that were dumped between 1946 and 1970 on the continental shelf and slope south of the Farallon Islands west of San Francisco (Figure 1).

<http://walrus.wr.usgs.gov/farallon/radwaste.html>; <http://pubs.usgs.gov/fs/farallones/index.html>); 2) provide high resolution images of the physiography of the central California coast and continental shelf (<http://walrus.wr.usgs.gov/gloria/gloria.html>); 3) obtain cores to document Quaternary paleoceanographic changes; and 4) collect granitic rocks from the seafloor in the vicinity of the Farallon Islands and Cordell Bank in order to characterize their strontium values and compare the chemical data from these Cretaceous Salinian block rock samples to rocks of similar age at Point Reyes, Tomales Bay, and Montara, Marin County, California.

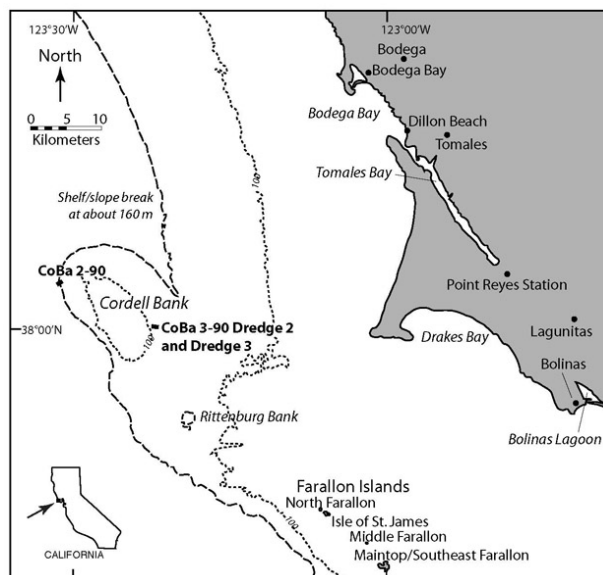


Figure 1. Index map showing the general location of Cordell Bank in relation to other geographic features of the central California coast. The dashed line is the approximate shelf/slope break at a depth of about 160 m near the Farallon Islands and Cordell Bank. The dotted contour indicates 100 m and outlines the position of Cordell Bank.

Dredge samples containing macro- and microfaunal specimens were concurrently collected with the granite samples by the U.S. Geological Survey R/V *Farnella* in the vicinity of Cordell Bank on August 16, 1990 (Figure 1). A cursory examination of the biota suggests that they are late Pleistocene age, that some were extra-limital (i.e., not found at the present-day latitude of Cordell Bank), and that several were not typical of the water depths from which the samples were collected. A similar fauna collected at comparable depths in Monterey Bay and ^{14}C dated at ~ 17 ka (Powell, 1994) led to speculation that the Cordell Bank samples were also from a late Pleistocene sea-level low stand and that the specimens warranted further investigation. All mollusks are deposited at the University of California, Museum of Paleontology (UCMP). The foraminiferal slides and processed residues are on file at the U.S. Geological Survey in Menlo Park, California.

Two other undocumented geographically and bathymetrically anomalous molluscan and foraminiferal faunas are known from the northeast Pacific Ocean: one offshore southern Oregon (Powell, unpublished data) and another from Islas Revillagigedo west of mainland Mexico (Powell, unpublished data; McGann, unpublished data). Both faunas are currently being studied.

Sample CoBa-2-90

Methods

Sample CoBa-2-90 is composed of material dredged on a single run, from 155 to 215 m depth, west of Cordell Bank. Most of the sediment and smaller, macro- and microfossils accompanying the larger *Chlamys* specimens were washed overboard when the pectens were cleaned with a shipboard hose. However, some sediment was retained and the smaller mollusks and foraminifers were recovered from the sediment adhering to the interior of a few *Chlamys* valves. ^{14}C age determinations on several of these *Chlamys rubida* valves were provided by the U.S. Geological Survey Radiocarbon Laboratory in Menlo Park, California. Conventional ^{14}C dating of this sample resulted in an age determination of 15.260 ± 0.045 ka (USGS 30-33; Powell, McGann & Trimble, 1992) correlating to the Oxygen Isotope Stage 2 sea-level lowstand.

Mollusca

Only ten molluscan taxa were present in this sample (Table 1); three were identified to the species level. Most of the taxa are found today north of Cordell Bank.

The bivalve *Nuculana minuta* (Fabricus), reported as extra-limital in preliminary results of this study (Powell, McGann & Trimble, 1992) is re-identified here as *N. pernula* (Müller, 1779). Hence, no extra-limital taxa were found. Because of the limited number of specifically identified mollusks in this sample, the geographic and depth ranges of these species, based on modern occurrences, is not precise (i.e., 35°N - 58°N ; 20 to 200 m; Figures 3, 4). However, since most taxa range north of the fossil locality, cooler water temperatures than off Cordell Bank today are suggested.

Foraminifera

The sediment washed from several *Chlamys* valves was wet-sieved through nested 63 μm , 150 μm and 1.0 mm screens to remove the clayey fraction. The remaining (>63 μm) sized fractions were then transferred onto filter paper and air-dried. A microsplitter was used to split the sample into an aliquot containing at least 300 benthic and 300 planktic foraminifers and all of the specimens were picked from this aliquot and identified. The relative abundances for benthic and planktic foraminiferal species were determined separately.

A diverse benthic foraminiferal assemblage of 63 species was recovered (Table 2). More than half of the fauna is comprised of species that today reside in the vicinity of the shelf break (Lankford & Phleger, 1973; Ingle, 1980; McGann, 2002) at depths similar to those where the sample was collected. The shelf break taxa include *Cassidulina limbata* Cushman & Hughes (18.2%), *C. tortuosa* Cushman & Hughes (16.4%), *C. californica* Cushman & Hughes (15.6%), and *Trifarina angulosa* (Williamson) (5.7%).

Nineteen percent of the fauna is characteristic of the inner shelf (0-50 m; Lankford & Phleger, 1973; Ingle, 1980; McCormick et al., 1994; McGann, 2002, 2007). These shallow-water species include *Buccella frigida* (Cushman), *Buliminella elegantissima* (d'Orbigny), *Cibicides fletcheri* Galloway & Wissler, *Dyocibicides biserialis* Cushman & Valentine, *Elphidium excavatum* var. *clavatum* Cushman, *Elphidium excavatum* var. *selseyensis* (Heron-Allen & Earland), *Glubratella californiana* Lankford, *Nonionella basispinata* (Cushman & Moyer), *Quinqueloculina akneriana* d'Orbigny, *Rosalina globularis* d'Orbigny, *Rotorbinella turbinata* (Cushman & Valentine) and *Trichohyalus ornatissima* (Cushman). The other 25% of the fauna is made up of the remaining 47 species.

Ten species of planktic foraminifera were also

covered (Table 2). The assemblage is dominated by *Globigerina bulloides* d'Orbigny (45.5%), a dissolution-resistant species (Berger, 1968; Thunell & Honjo, 1981), which prefers, but is not restricted to, cool waters that are associated with upwelling (Thunell & Reynolds, 1984; Reynolds & Thunell, 1985; Sautter & Thunell, 1989, 1991). The other dominant planktic foraminiferal species belongs to the *Neogloboquadrina* plexus as described by Kucera & Kennett (2000). Nearly 36% of the sample assemblage are the left-coiling *Neogloboquadrina pachyderma* B morphotype of the plexus (Kennett et al., 2000; Kucera & Kennett, 2000) which today dominates the colder waters (< 8°C) of the subpolar and polar regions (Bandy, 1972; Kennett, 1976; Keller, 1978; Sautter & Thunell, 1989) and are also resistant to dissolution (Parker & Berger, 1971; Malmgren, 1983; Reynolds & Thunell, 1986). The right-coiling morphotype, *Neogloboquadrina pachyderma pachyderma* (Ehrenberg), which commonly inhabits modern temperate waters and is less resistant to dissolution, occurs only rarely in the sample assemblage (2.3%). *Globigerinita glutinata* (Egger) (6.3%) and *Globigerina quinqueloba* Natland (5.6%) also were recovered. Both of these taxa are common in colder water masses in the eastern Pacific Ocean (Reynolds & Thunell, 1985; Sautter & Thunell, 1989, 1991).

The planktic foraminifers provide biostratigraphic information for CoBa-2-90 as well. Unless the two specimens recovered of *Globigerina umbilicata* Orr & Zaitzeff are contaminants, their presence is indicative of a Pliocene to Pleistocene (not Holocene) age for the sample (Orr & Zaitzeff, 1971; Rögl & Bolli, 1973; Saito et al., 1981; coiling direction zones CD15-CD11 of Lagoe & Thompson, 1988). The right-coiling form *Neogloboquadrina pachyderma pachyderma* first appears in the early Pliocene [California margin zone 7 (CM7) of Kennett et al., 2000; Kucera & Kennett, 2000] and ranges to the present day, whereas *Neogloboquadrina pachyderma* B is first seen in the early to middle Pleistocene (CM2 zone of Kennett et al., 2000) and is still seen in the modern oceans (Kucera & Kennett, 2000). The overlap of these stratigraphic ranges suggests a Pleistocene age for the sample, in agreement with the late Pleistocene ¹⁴C age of ~15.3 ka years determined from the *Chlamys* valves.

The foraminiferal planktic to benthic (P/B) ratio can be used as a bathymetric indicator since it generally increases with increasing water depth (Grimsdale & van Morkhoven, 1955). However, it is not a precise measure, due to the fact that the abundance of planktic

foraminifers can be influenced by depth, salinity, light and fluctuations in nutrients, as well as transport by currents (Murray, 1976; Gebhardt et al., 2003). In CoBa-2-90, nearly equal numbers of planktic and benthic specimens were recovered, suggesting the sample was deposited in open ocean conditions on the outer shelf to shelf break (Murray, 1976). More than half of the benthic foraminiferal assemblage of this sample is characteristic of these depths as well.

The CoBa-2-90 molluscan and foraminiferal assemblages suggest deposition in cooler water temperatures than present conditions where the sample was collected because: 1) most molluscan taxa range north of the fossil locality; and 2) cool water thriving planktic foraminifera dominate the microfaunal assemblage in abundances more typical of a planktic foraminiferal assemblage living in the Pacific Ocean off Washington today (Keller, 1978; Sautter & Thunell, 1989). In addition, foraminiferal assemblage dominance by benthic species that live near the shelf break, as well as the recovery of nearly equal number of benthic and planktic specimens, suggest deposition on the outer shelf to shelf break in open marine conditions. The abundance of inner shelf benthic foraminifers in CoBa-2-90 may be attributed to downslope transport or deposition during a period of lowered sea level. The faunal and chronological data of CoBa-2-90 suggest deposition during a late Pleistocene sea level lowstand, and that this sample correlates to age-constrained, fossiliferous deposits in Monterey Bay and at other locations along the coast of California (Powell, 1994). In Monterey Bay and the Cordell Bank area, significantly cooler water temperatures are postulated for the middle and late Pleistocene compared to present temperatures for this area.

Samples CoBa-3-90 Dredge 2 and CoBa-3-90 Dredge 3 Method

Samples CoBa-3-90 Dredge 2 and CoBa-3-90 Dredge 3 are composed of material from two dredge hauls traversing the same area between Cordell Bank and mainland California; one traveling eastward (CoBa-3-90 Dredge 2) and the other back to the west (CoBa-3-90 Dredge 3). Only larger molluscan specimens were recovered. No sediment was associated with these mollusk specimens; therefore, no smaller mollusks or foraminifers were recovered.

Twenty-five specimens of the bivalves *Glycymeris septentrionalis* (Middendorff) from CoBa-3-90 Dredge 2 and eight broken valves of *Humiliaria kennerleyi* (Reeve) from CoBa-3-90 Dredge 3 were ¹⁴C dated.

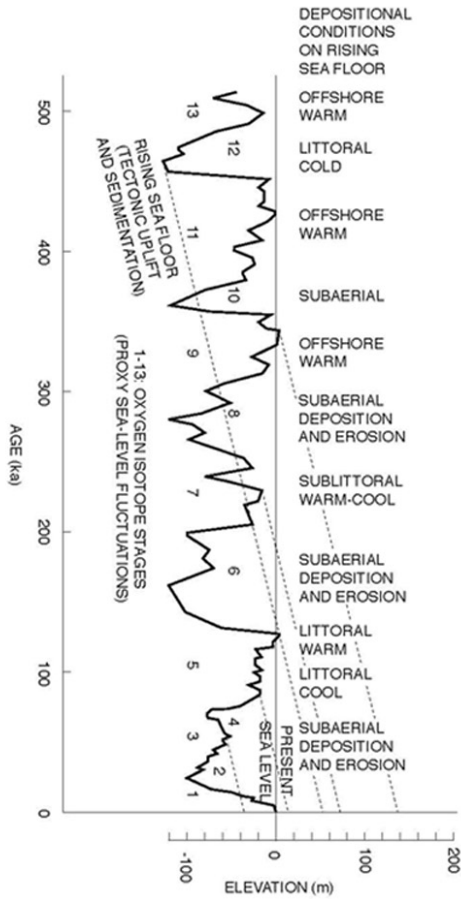


Figure 2. Generalized sea-level curve developed from the oxygen isotope record. Using sea-level as a proxy for water temperature expected molluscan faunas and associated depositional environments for the past 500 k.y. are shown. Lines ascending to the right assume a constant rate of uplift and suggest samples/deposits from the past three Oxygen Isotope Stages (1-3) are still underwater consistent with findings here with samples from Oxygen Isotope Stage (OIS) 2 found at depths between 89 and 215 m, and samples from OIS 1 found at depths between 89 and 100 m. Figure modified from Lajoie et al, (1991) and Powell et al. (2000).

Conventional ¹⁴C dating of CoBa-3-90 Dredge 2 and CoBa-3-90 Dredge 3 resulted in age determinations of 10.765 ± 0.040 ka and 10.890 ± 0.070 ka, respectively (USGS 30-34 and USGS 3-035; Powell, McGann & Trimble, 1992). These ages correlate to early Oxygen Isotope Stage 1, when sea-level was rising to its modern position (Figure 2).

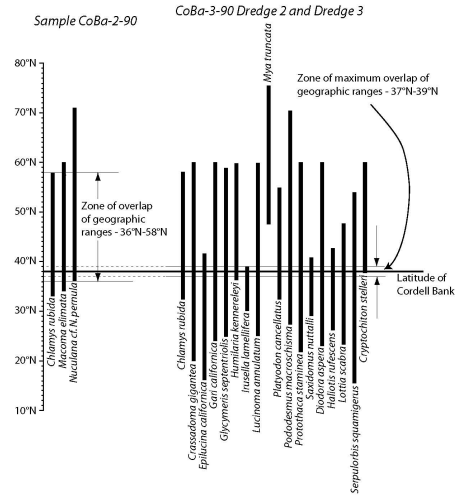


Figure 3. Latitudinal distribution of selected mollusks recovered from samples CoBa-2-90, CoBa-3-90 Dredge 2, and CoBa-3-90 Dredge 3. Data are from Bernard (1983), Coan, Scott & Bernard (2000), and McLean (2007). The heavier vertical line indicates the latitude of the Cordell Bank locality. CoBa-2-90 mollusks have an overlapping geographic range between 36°N and 58°N. CoBa-3-90, dredges 2 and 3 taxa have an overlapping geographic range between 37°N and 39°N.

Mollusca

Twenty-six molluscan taxa, 18 identified to species were collected from the two dredges at depths between 89 and 100 m, east of Cordell Bank (Table 1). Using modern latitudinal ranges, these mollusks show overlapping geographic ranges between 37°N to 39°N (Figure 3); that is, from about the latitude of Año Nuevo, San Mateo County, north to about Mendocino, Mendocino County, northern California. One of the bivalve species in both collections, *Mya truncata* Linnaeus, is an extra-limital northern species whose modern distribution does not extend south of Puget Sound, Washington today (Coan et al., 2000). This species indicates cooler water conditions existed at Cordell Bank in the Pleistocene.

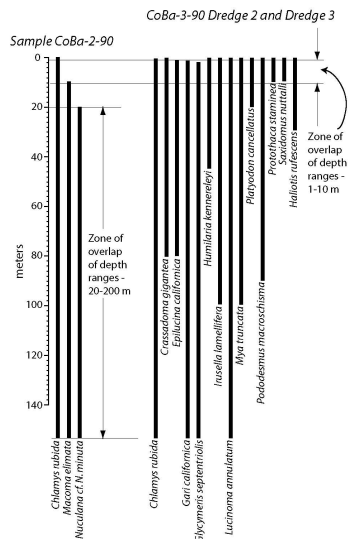


Figure 4. Depth distribution of selected mollusks recovered from samples CoBa-2-90, CoBa-3-90 Dredge 2, and CoBa-3-90 Dredge 3. Data from Coan, Scott & Bernard (2000) and McLean (2007). CoBa-2-90 mollusks have an overlapping depth range of between 20 and 200 m. Samples CoBa-2-90 and CoBa-3-90 dredges 2 and 3 taxa have an overlapping depth range of between 1 and 10 m.

The inferred paleobathymetry for the mollusks from these samples, based on modern depth data from Coan et al. (2000) and McLean (2007), is between 1 and 10 m (Figure 4). By subtracting the minimum and maximum inferred paleobathymetry from the minimum and maximum depths from which the samples were collected (89 and 100 m), sea level is determined to be between 79 and 99 m below present level about 10.8 ka. This is in general agreement with a sea-level determination of a minimum of 95 m below present at 10.5 ka in the vicinity of Vancouver and Queen Charlotte Islands in southern British Columbia (Luternauer et al., 1989), although local tectonics may influence this number.

Summary

The use of macro- and microfaunal analysis, and ^{14}C dating of mollusk shells, has made it possible to interpret the age, water depth, and environmental conditions under which three dredge samples collected

in the vicinity of Cordell Bank were originally deposited. The samples represent deposition during two different periods in the late Pleistocene and Holocene, around the last glacial maximum (approximately 20-15 ka years ago; Oxygen Isotope Stage 2) and when sea level was rising (about 10.8 ka years ago; early Oxygen Isotope Stage 1) towards its modern level. The biota of all three samples indicate water temperatures cooler than present today at the latitude of Cordell Bank. The results of this study emphasize the usefulness of integrating these methods to obtain information on paleobenthic and pelagic communities even with a limited sample size.

Acknowledgments

We wish to thank John Cannan (ship captain), Matthew Gilbey (chief engineer) and Albert Fuller (chief mate) of the R/V *Farnella* for their superb field effort, Herman Karl (USGS) for filling the role of chief scientist on the cruise, Duane E. Champion (USGS) for providing us the samples for this study, and Deborah Trimble (formerly USGS) for undertaking the ^{14}C analysis. Carol Reiss (USGS) is thanked for precisely plotting the location of the dredge hauls. We also want to thank Lindsey Groves (LACM), and Elmira Wan (USGS) for their helpful reviews of this manuscript.

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TABLE 1: Quantitative distribution of mollusks in Samples CoBa-2-90, CoBa-3-90 Dredge 2, and CoBa-3-90 Dredge 3 from around Cordell Bank, central California. Numbers in parentheses represent broken or partial specimens.

TAXA	LOCALITIES			COMMENTS
	CoBa- 2-90	CoBa-3-90 dredge 2	CoBa-3-90 dredge 3	
Mollusca				
Polyplacophora				
<i>Cryptochiton stelleri</i> (Middendorff, 1847)		(1)		
Bivalvia				
<i>Chlamys rubida</i> (Hinds, 1845)	78(29)	3(4)	2(2)	
<i>Clinocardium</i> sp.	(2)		(1)	
<i>Crassadoma gigantea</i> (Gray, 1825)			(2)	
<i>Epilucina californica</i> (Conrad, 1837)		1	4	
<i>Gari californica</i> (Conrad, 1849)		1(1)		
<i>Glycymeris septentrionalis</i> (Middendorff, 1849)		161	136 (16)	
<i>Humilaria kenerleyi</i> (Reeve, 1863)		5(10)	19(67)	
<i>Irus lamellifer</i> (Conrad, 1837)			1(1)	
<i>Lucinoma annulata</i> (Reeve, 1850)			1	
<i>Macoma elimata</i> Dunnill & Coan (1968)	1(3)			
<i>Macoma</i> sp.		1	1(2)	
<i>Modiolus</i> sp.		1	(2)	
<i>Mya truncata</i> Linnaeus, 1758		2	1(2)	It is an extra-limital northern taxon which today occurs only as far south as Neah Bay, WA (47° N). (pers. comm, P. Scott, 1991).
<i>Mytilus</i> sp.		(1)	(7)	
<i>Nuculana pernula</i> (Müller, 1779)	4			
<i>Nutricula</i> sp.	1			
<i>Platyodon cancellatus</i> (Conrad, 1837)		1		
<i>Pododesmus macrochisma</i> (Deshayes, 1839)		2(2)	2	
<i>Protothaca staminea</i> (Conrad, 1837)		9(3)	1(4)	The form found in these deposits is <i>P. s. ruderata</i> (Deshayes) an ecological morphotype usually associated with empty pholad burrows.
<i>Saxidomus nuttalli</i> (Conrad, 1837)		2(2)	cf.	
<i>Simomactra falcata</i> (Gould, 1850)		6(17)	1(12)	
Gastropoda				
<i>Bittium</i> sp.	14			
<i>Ceratostoma</i> sp.			(1)	
<i>Crepidula</i> sp.	(1)			
<i>Diodora aspera</i> (Rathke, 1833)		(1)		
<i>Epitonium</i> sp.	1			

<i>Haliotis rufescens</i> Swainson, 1822		(1)		
<i>Kurtziella</i> ? sp.	2			
<i>Lottia scabra</i> (Gould, 1846)			1	
Naticid indet		(2)	(2)	
<i>Oenopota</i> sp	1			
<i>Puncturella</i> sp.	1			
<i>Serpulorbis</i> cf. <i>S. squamigerus</i> (Carpenter, 1856)		2		

TABLE 2: Quantitative distribution (raw count and percent abundance) of benthic and planktic foraminifers > 0.63 mm in sample CoBa-2-90. Percentage of benthic and planktic foraminifers determined separately. X = rare specimens recovered in a qualitative (non-statistical) scan of the matrix not used in the quantitative study.

Species	Raw Count	Percentage Count
BENTHIC		
<i>Astrononion gallowayi</i> Loeblich & Tappan (1953)	3	0.6
<i>Bolivina pacifica</i> Cushman & McCulloch (1942)	4	0.8
<i>Bolivina spissa</i> Cushman (1926)	X	X
<i>Bolivina</i> sp.	1	0.2
<i>Buccella frigida</i> (Cushman, 1922)	31	6.3
<i>Buliminella elegantissima</i> (d'Orbigny, 1839)	3	1.6
<i>Cancris auricula</i> (Ficthel & Moll, 1798)	X	X
<i>Cancris inaequalis</i> (d'Orbigny, 1839)	X	X
<i>Cassidulina californica</i> Cushman & Hughes (1925)	77	15.6
<i>Cassidulina limbata</i> Cushman & Hughes (1925)	90	18.2
<i>Cassidulina tortuosa</i> Cushman & Hughes (1925)	81	16.4
<i>Cassidulina</i> sp.	5	1.0
<i>Cibicides fletcheri</i> Galloway & Wissler (1927)	15	3.0
<i>Cibicides lobatulus</i> (Walker & Jacob, 1798)	59	11.9
<i>Cibicides</i> spp.	2	0.5
<i>Cornuspira foliacea</i> (Philippi, 1844)	X	X
<i>Dentalina ittai</i> Loeblich & Tappan (1953)	X	X
<i>Dentalina</i> sp.	X	X
<i>Dyocibicides biserialis</i> Cushman & Valentine (1930)	1	0.2
<i>Elphidium excavatum</i> var. <i>clavatum</i> Cushman (1930)	3	0.6
<i>Elphidium excavatum</i> var. <i>selseyensis</i> (Heron-Allen & Earland, 1909)	19	3.8
<i>Epistominella pacifica</i> (Cushman, 1927)	10	2.0
<i>Fissurina lineata</i> Williamson (1848)	X	X
<i>Fissurina lucida</i> Williamson (1848)	4	0.8
<i>Fissurina marginata</i> (Montagu, 1803)	2	0.4
<i>Fissurina orbignyana</i> (Sequenza, 1862)	X	X
<i>Fissurina serrata</i> (Schlumberger, 1894)	X	X
<i>Florilus labradoricus</i> (Dawson, 1860)	X	X
<i>Fursenkoina</i> sp.	1	0.2
<i>Gaudryina arenaria</i> Galloway & Wissler (1927)	X	X

Species (cont'd)	Raw Count	Percentage Count
<i>Glabrattella californiana</i> Lankford (1973)	1	0.2
<i>Globobulimina auriculata</i> Bailey (1851)	3	0.6
<i>Globocassidulina subglobosa</i> (Brady, 1881)	X	X
<i>Lagena laevis</i> (Montagu, 1803)	X	X
<i>Lagena meridionalis?</i> Wiesner (1931)	1	0.2
<i>Lagena semistriata</i> Williamson (1848)	X	X
<i>Lagena striata</i> (d'Orbigny, 1839)	X	X
<i>Lagena</i> sp.	X	X
<i>Loxostomum bradyi</i> (Asano, 1938)	X	X
<i>Miliolinella californica</i> Rhumbler (1936)	X	X
<i>Miliolinella oblonga</i> (Montagu, 1803)	1	0.2
<i>Neoconorbina terquemii</i> (Rzehak, 1888)	X	X
<i>Nodosaria</i> sp.	X	X
<i>Nonionella basispinata</i> (Cushman & Moyer, 1930)	1	0.2
<i>Nonionella digitata</i> Nervang (1945)	X	X
<i>Nonionella stella</i> Cushman & Moyer (1930)	4	0.8
<i>Oolina acuticosta</i> (Reuss, 1862)	X	X
<i>Oolina melo</i> d'Orbigny (1839)	1	0.2
<i>Oolina striatopunctata</i> (Parker & Jones, 1865)	X	X
<i>Oolina</i> sp.	X	X
<i>Planulina exorna</i> Phleger & Parker (1951)	3	0.6
<i>Polymorphina charlottensis</i> Cushman (1925)	X	X
<i>Poroeponides cribrorepandus</i> Asano & Uchio (1951)	X	X
<i>Pullenia salisburyi</i> Stewart & Stewart (1930)	X	X
<i>Pyrgo depressa</i> (d'Orbigny, 1826)	X	X
<i>Pyrgo murrhina</i> (Schwager, 1866)	X	X
<i>Quinqueloculina akneriana</i> d'Orbigny (1846)	2	0.4
<i>Quinqueloculina elongata</i> Natland (1938)	4	0.8
<i>Quinqueloculina stalkerii</i> Loeblich & Tappan (1953)	3	0.6
<i>Quinqueloculina</i> spp.	4	0.8
<i>Robertina charlottensis</i> (Cushman, 1925)	1	0.2
<i>Rosalina globularis</i> d'Orbigny (1826)	9	1.8
<i>Rotorbinella turbinata</i> (Cushman & Valentine, 1930)	5	1.0
<i>Sigmomorphina trilocularis</i> (Bagg, 1912)	X	X
<i>Tricohyalus ornatissima</i> (Cushman, 1925)	1	0.2
<i>Trifarina angulosa</i> (Williamson, 1858)	28	5.7
<i>Triloculina tricarinata</i> d'Orbigny (1826)	1	0.2
<i>Ovigerina juncea</i> Cushman & Todd (1941)	5	1.0
<i>Ovigerina peregrina</i> Cushman (1923)	X	X
Others	5	1.0
Total benthic specimens	494	
PLANKTIC		
<i>Globigerina bulloides</i> d'Orbigny (1826)	194	45.5
<i>Globigerina quinqueloba</i> Natland (1938)	24	5.6
<i>Globigerina umbilicata</i> Orr & Zaitzeff (1971)	2	0.5
<i>Globigerinita glutinata</i> (Egger, 1893)	27	6.3
<i>Globigerinita uvula</i> (Ehrenberg, 1861)	X	X

Species (cont'd)	Raw Count	Percentage Count
<i>Globorotalia inflata</i> (d'Orbigny, 1839)	X	X
<i>Globorotalia scitula</i> (Brady, 1882)	3	0.7
<i>Globorotalia truncatulinoides</i> (d'Orbigny, 1839)	X	X
<i>Neogloboquadrina pachyderma</i> B. Kennett, Rozo-Vera & Machain Castilio (2000)	153	35.9
<i>Neogloboquadrina pachyderma pachyderma</i> (Ehrenberg, 1861)	10	2.3
<i>Orbulina universa</i> d'Orbigny (1839)	X	X
Others	5	1.2
Total planktic species	426	

Appendix: Locality data

Field Sample No.: CoBa-2-90, USGS Cruise Locator F-8-90-NC, Station 49-7. Dredge between 215 m and 155 m, from west to east on the west flank of Cordell Bank, Marin Co., California. Latitude: 38.5383°N to 38.0565°N, longitude 123.5218°W to 123.5140°W.

Field Sample No.: CoBa-3-90 dredge 2, USGS Cruise Locator F-8-90-NC, Station 49-2. Dredge between 100 m and 89 m, from east to west on the east flank of Cordell Bank, Marin Co., California. Latitude: 37.9988°N to 37.9995°N, longitude 123.3720°W to 123.3822°W.

Field Sample No : CoBa-3-90 dredge 3. USGS Cruise locator F-8-90-NC, Station 49-2. Dredge between 100 and 89 m, from west to east on the east flank of Cordell Bank, Marin Co., California. Latitude: 37.9995°N to 37.9988°N, longitude 123.3822°W to 123.3720°W.

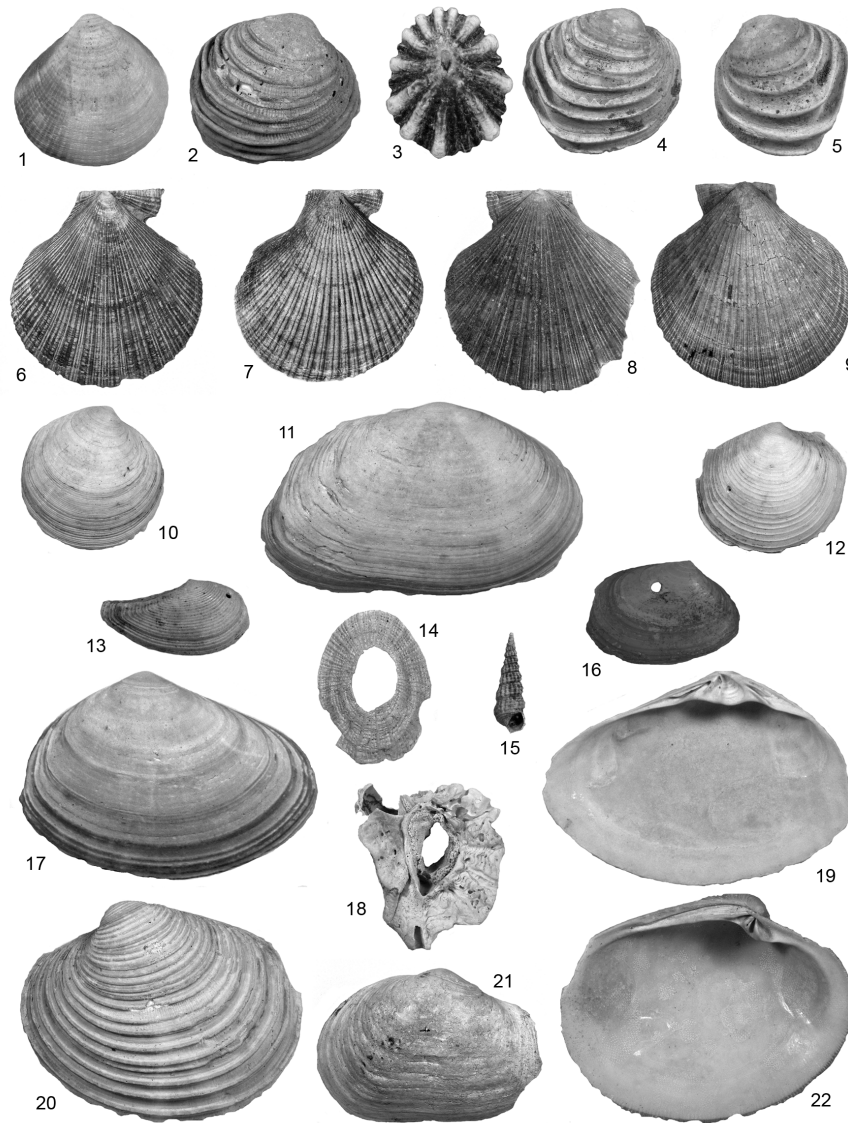


Plate 1. Figures 1-22. Mollusks (1) *Glycymeris septentrionalis*. Exterior, left valve. UCMP locality IP 367. UCMP hypotype 56040; height 28.4 mm, length 28.6 mm. (2) *Protothaca staminea*. Exterior, right valve. UCMP locality IP 367. UCMP hypotype 56057; height 40.7 mm, length 45.8 mm. (3) *Lottia scabra*. Exterior. UCMP locality IP 367. UCMP hypotype 56028; height 28.9 mm, width 24.5 mm. (4-5) *Irus lamellifer*. (4) Exterior, right valve. UCMP locality IP 637. UCMP hypotype 56058; height 36.4 mm, width 40.4 mm. (5) Exterior, left valve. UCMP locality IP 367. UCMP hypotype 56058, height 26.1 mm, length 25.7 mm. (6-9) *Chlamys rubida*. (6) Exterior, right valve. UCMP locality IP 636. UCMP hypotype 56095, height 56.7 mm, width 55.3 mm. (7) Exterior, right valve. UCMP locality IP 636. UCMP hypotype 56094; height 69.8 mm, width 68.6 mm. (8) Exterior, left valve. UCMP locality 636. UCMP hypotype 56096; height 59.1 mm, width 56.6 mm. (9). Exterior, left valve. UCMP locality IP 636. UCMP hypotype 56097, height 67.8 mm, width 65.9 mm. (10) *Epilucina californica*. Exterior, right valve. UCMP locality IP 367. UCMP hypotype 56038; height 34.6 mm, length 34.2 mm. (11) *Gari californica*. Exterior, right valve. UCMP locality IP 367. UCMP hypotype 56053; height 41.9 mm, length 69.4 mm. (12) *Lucinoma annulata*. Exterior, right valve. UCMP locality IP 637. UCMP hypotype 56024; height 25.3 mm, length 29.2 mm. (13) *Nuculana pernula*. Exterior, left valve. UCMP locality IP 636. UCMP hypotype 56091; height 6.1 mm, length 11.6 mm. (14) *Diodora aspera*. UCMP locality IP 367. UCMP hypotype 56052; height 33.8 mm, width 25.0 mm. (15) *Bittium* sp. Apertural view. UCMP locality IP 636. UCMP hypotype 56078; height 11.4 mm, width 3.4 mm. (16) *Macoma elimata*. Exterior, right valve. UCMP locality IP 636. UCMP hypotype 56090; height 10.7 mm, length 15.6 mm. (17, 19) *Simomactra falcata*. (17) Exterior, left valve. (19) Interior, right valve. UCMP locality UCMP IP 637. UCMP hypotype 56034; height 43.6 mm, length 62.2 mm. (18) *Ceratostoma* sp. Apertural view. UCMP locality IP 637. UCMP hypotype UCMP 56025; height 31.4 mm, width 27.8 mm. (20, 22) *Humiliaria kenneleyi*. (20). Exterior, left valve. (22) Interior, left valve. UCMP locality IP 637. UCMP hypotype 56042; height 43.3 mm, length 55.8 mm. (21) *Mya truncata*. Exterior, right valve. UCMP locality IP 637. UCMP hypotype 56036; height 52.5 mm, length 77.5 mm.

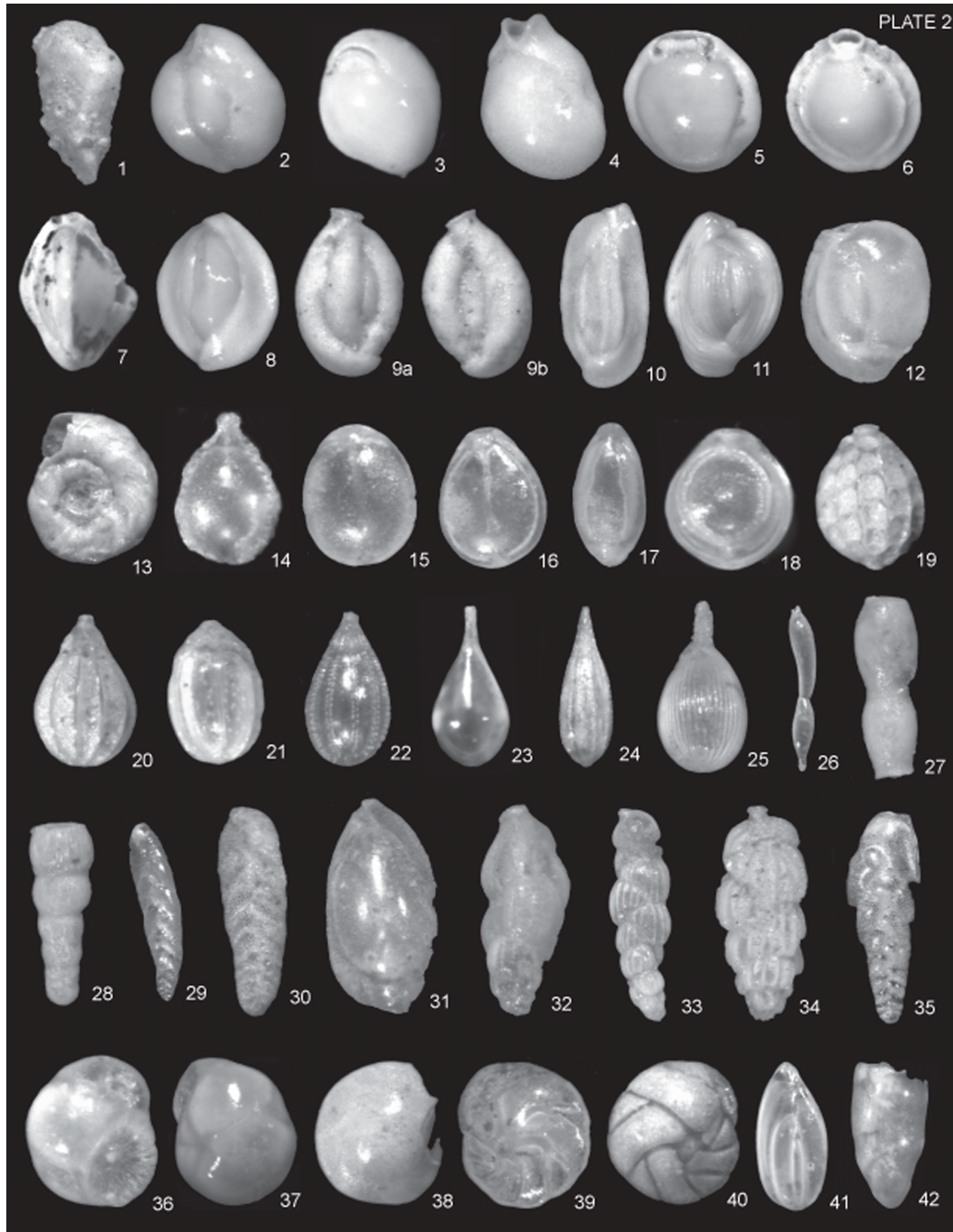


Plate 2. Figures 1-42. Benthic foraminifera. All specimens from sample CoBa-2-90. (1) *Gaudryina arenaria*, x41. (2) *Miliolinella californica*, side view, x66. (3) *Miliolinella californica*, apertural view, x66. (4) unknown calcareous imperforate, x79. (5) *Pyrgo depressa*, x55. (6) *Pyrgo murrhina*, x53. (7) *Triloculina tricarinata*, x74. (8) *Quinqueloculina akneriana*, x48. (9a) *Quinqueloculina stalkerii*, front view, x64. (9b) *Quinqueloculina stalkerii*, back view, x64. (10) *Quinqueloculina elongata*, x97. (11) *Quinqueloculina* sp., x49. (12) *Quinqueloculina* sp., x64. (13) *Cornuspira foliacea*, x41. (14) *Fissurina serrata*, x82. (15) *Fissurina marginata*, x96. (16) *Fissurina marginata*, x93. (17) *Fissurina lucida*, x63. (18) *Fissurina orbignyana*, x118. (19) *Oolina melo*, x169. (20) *Oolina acuticosta*, x100. (21) *Oolina* sp., x87. (22) *Oolina striatopunctata*, x82. (23) *Lagena laevis*, x50. (24) *Lagena meridionalis?*, x83. (25) *Lagena striata*, x69. (26) *Dentalina ittai*, x46. (27) *Dentalina* sp., x61. (28) *Nodosaria* sp., x57. (29) *Bolivina pacifica*, x56. (30) *Bolivina spissa*, x55. (31) *Globobulimina auriculata*, x49. (32) *Trifarina angulosa*, x78. (33) *Uvigerina juncea*, x42. (34) *Uvigerina peregrina*, x61. (35) *Loxostomum bradyi*, x44. (36) *Globocassidulina subglobosa*, x100. (37) *Cassidulina californica*, x33. (38) *Cassidulina tortuosa*, x46. (39) *Cassidulina limbata*, x52. (40) *Cassidulina* sp., x60. (41) *Sigmomorphina trilocularis*, x44. (42) *Polymorphina charlottensis*, x29.

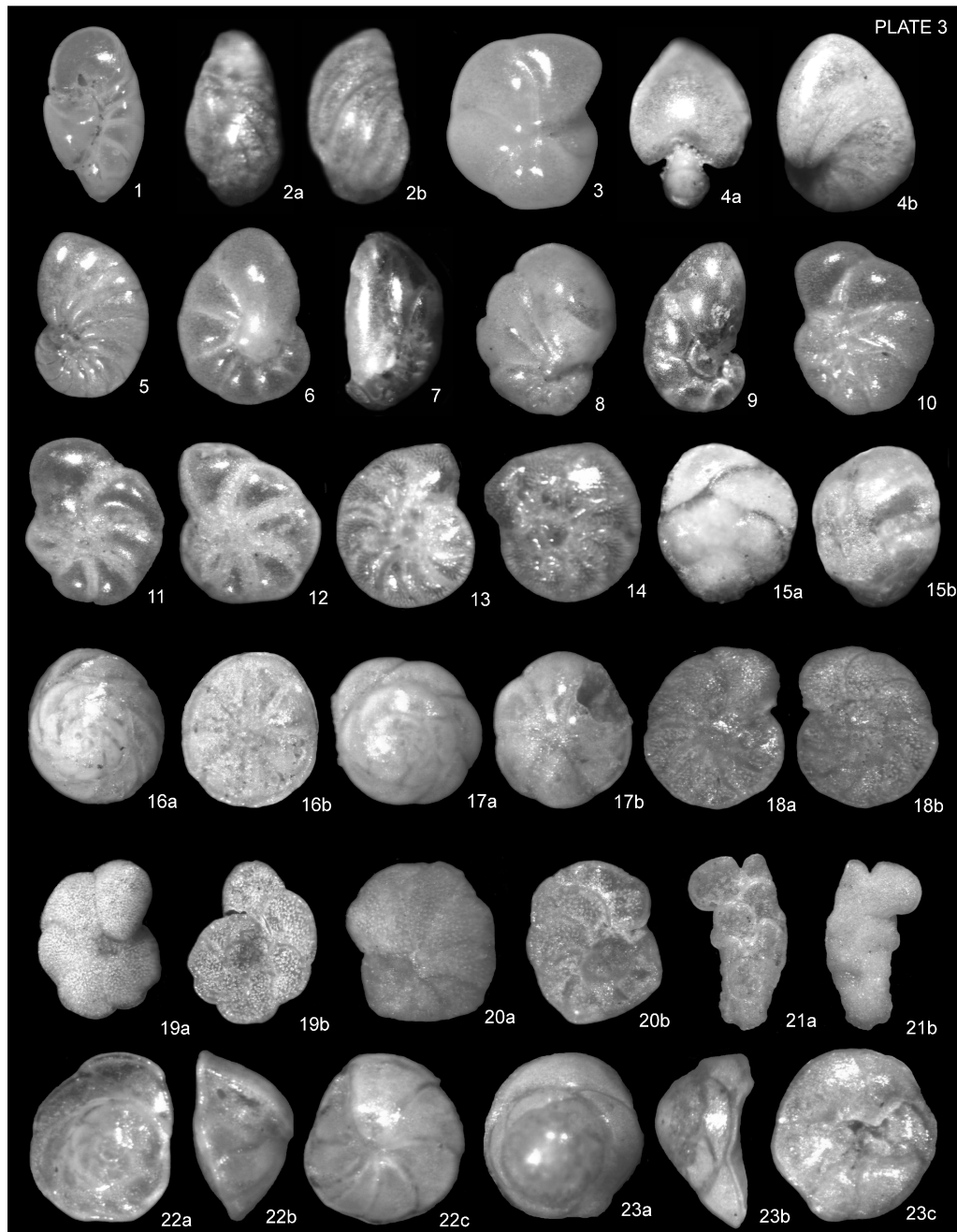


Plate 3. Figures 1-23c. Benthic foraminifera. All specimens from sample CoBa-2-90. (1) *Robertina charlottensis*, x78. (2a) *Buliminella elegantissima*, front view, x160. (2b) *Buliminella elegantissima*, back view, x160. (3) *Pullenia salisburyi*, x71. (4a) *Florilus labradoricus*, apertural view, x64. (4b) *Florilus labradoricus*, side view, x64. (5) *Nonionella basispinata*, x60. (6) *Nonionella stella*, x84. (7) *Nonionella digitata*, with collapsed last chamber, x84. (8) *Cancris auricula*, x56. (9) *Cancris inaequalis*, x23. (10) *Astrononion gallowayi*, x68. (11) *Elphidium excavatum* var. *selseyensis*, x55. (12) *Elphidium excavatum* var. *selseyensis*, x58. (13) *Elphidium excavatum* var. *clavatum*, x107. (14) *Elphidium excavatum* var. *clavatum*, x121. (15a) *Poroepionides cribrorrepandus*, dorsal view, x63. (15b) *Poroepionides cribrorrepandus*, ventral view, x63. (16a) *Buccella frigida*, dorsal view, x52. (16b) *Buccella frigida*, ventral view, x52. (17a) *Buccella frigida*, dorsal view, x81. (17b) *Buccella frigida*, ventral view, x81. (18a) *Cibicides* sp., dorsal view, x49. (18b) *Cibicides* sp., ventral view, x49. (19a) *Cibicides lobatulus*, dorsal view, x30. (19b) *Cibicides lobatulus*, ventral view, x30. (20a) *Cibicides lobatulus*, dorsal view, x54. (20b) *Cibicides lobatulus*, ventral view, x54. (21a) *Dyocibicides biserialis*, ventral view, x28. (21b) *Dyocibicides biserialis*, dorsal view, x28. (22a) *Epistominella pacifica*, dorsal view, x82. (22b) *Epistominella pacifica*, edge view, x82. (22c) *Epistominella pacifica*, ventral view, x82. (23a) *Rotorbinella turbinata*, dorsal view, x88. (23b) *Rotorbinella turbinata*, edge view, x91. (23c) *Rotorbinella turbinata*, ventral view, x91.

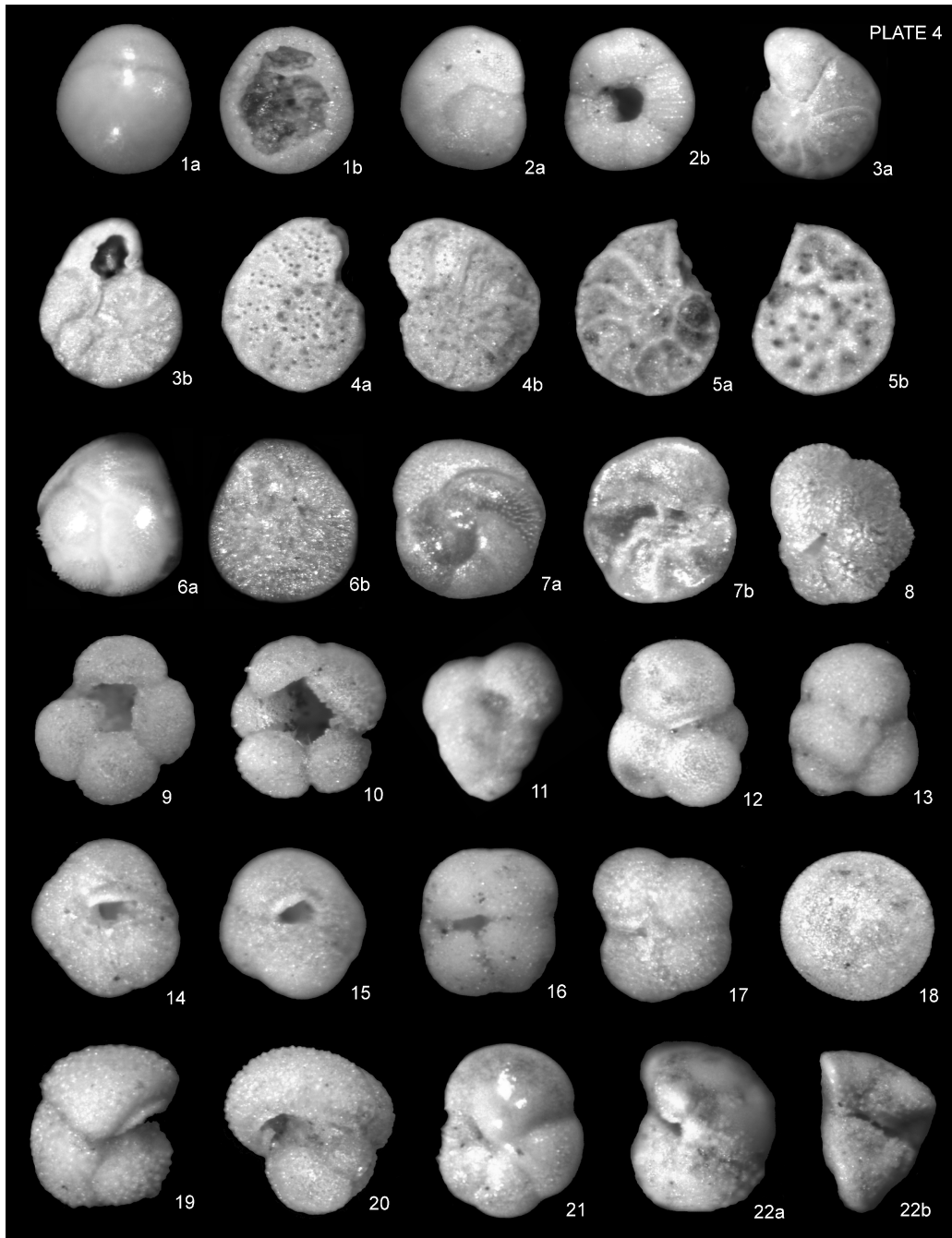


Plate 4. Figures 1a-22b. Benthic foraminifera (1-7), Planktic foraminifera (8-22). All specimens from sample CoBa-2-90. (1a) *Glabratella californiana*, dorsal view, x75. (1b) *Glabratella californiana*, ventral view, x75. (2a) *Glabratella californiana*, dorsal view, x100. (2b) *Glabratella californiana*, ventral view, x100. (3a) *Cibicides fletcheri*, dorsal view, x53. (3b) *Cibicides fletcheri*, ventral view, x59. (4a) *Planulina exorna*, ventral view, x72. (4b) *Planulina exorna*, dorsal view, x72. (5a) *Planulina exorna*, dorsal view, x100. (5b) *Planulina exorna*, ventral view, x100. (6a) *Trichohyalus ornatissima*, dorsal view, x83. (6b) *Trichohyalus ornatissima*, ventral view, x83. (7a) *Rosalina globularis*, dorsal view, x59. (7b) *Rosalina globularis*, ventral view, x61. (8) *Globigerina quinqueloba*, x112. (9) *Globigerina bulloides*, x74. (10) *Globigerina umbilicata*, x64. (11) *Globigerinita uvula*, x264. (12) *Globigerinita glutinata*, x100. (13) *Globigerinita glutinata*, with bullae covering umbilicus, x122. (14) *Neogloboquadrina pachyderma* B, x104. (15) *Neogloboquadrina pachyderma* B, x96. (16) *Neogloboquadrina pachyderma pachyderma*, x100. (17) *Neogloboquadrina pachyderma pachyderma*, x108. (18) *Orbulina universa*, x59. (19) *Globorotalia inflata*, x85. (20) unknown, x76. (21) *Globorotalia scitula*, x131. (22a) *Globorotalia truncatulinoidea*, ventral view, x79. *Globorotalia truncatulinoidea*, edge view, x74.