Fossil Invertebrates and Geology of the Marine Cliffs at Capitola, California

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Santa Cruz Museum Association

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Introduction

The rocks that form the cliffs between Capitola and New Brighton beaches preserve an important chapter in the geologic history of the northern Monterey Bay area. During much of the geologic past, this region was covered by the ocean. Nearby rivers emptied sand, mud, and other sediments into the sea where they were deposited in layers on the ocean floor along with ocean sediments. These deposits gradually hardened into rock, and were later uplifted to form the mountains and coastal cliffs of Santa Cruz County. Preserved within these rocks are the fossil remains of marine mollusks, crustaceans, fish, whales, marine birds, and other animals from long ago.

A walk along the cliffs between Capitola and New Brighton beaches is a walk back in time. Here we can view layer upon layer of the sea bottom, looking much as they did when deposited 3 to 5 million years ago during the Pliocene epoch. What we see is not quite the same as it would be if we could put on a diving suit and swim in the Pliocene sea, but with a little knowledge of modern marine animals and a small amount of imagination, it is not difficult to envision just such a dive.

My interest in the fossils along the cliffs at Capitola began in early 1967 while I was in the sixth grade. The *Santa Cruz Sentinel* published an article about them, and Jack Kepper, then geology instructor at Cabrillo College, set up a temporary fossil exhibit at the Santa Cruz City Museum. I studied the display intently, memorizing the scientific names and sketching what each kind looked like. With rock hammer in hand and knapsack over my shoulder, I then set out exploring for myself. Ten years later, some of these fossils became the subject of my senior thesis at the University of California, Santa Cruz. That same year the Santa Cruz City Museum published my booklet titled *Fossils of Santa Cruz County*. Now, ten more years have passed, and it is with pleasure that I share some of what I have learned over the years about this locality.

This booklet explores the origin and geologic context of the fossils in the Capitola cliffs. Invertebrates, excluding microscopic forms, are emphasized. I hope it will launch the reader on many happy hours studying and learning more about the fossils and geologic history of the northern Monterey Bay area.

Location

This fossil locality lies within the city of Capitola in the cliffs between Capitola City Beach and New Brighton State Beach—a stretch of about 3,500 feet. The cliffs are accessible at low tide, preferably a minus tide, though accessibility also depends on the height of the beach and the size of the waves. The cliffs trend northeast-southwest. People are often confused about directions here since these cliffs lie on the east side of a point (Soquel Point) which projects southward into Monterey Bay. Thus, if you walk from New Brighton "up the coast" towards Capitola, you are walking southwest. The coastline northeast of Escalona Gulch lies within New Brighton State Beach. Collecting of fossils and other natural features is prohibited from state beaches and parks without special permit.

A word of warning: because the cliffs are actively eroding and prone to sudden collapse, it can be dangerous to walk too close to them. Always keep a safe distance from the cliffs and, in particular, give a wide berth to overhangs. Those who choose to walk along these cliffs must recognize this danger and assume responsibility for any injury.

Regional Geologic Setting

The fossils occur in gray to brown sandstone and siltstone in a geologic unit called the Purisima Formation. This formation composes the bulk of the cliffs and is overlain by 10 to 15 feet of Pleistocene marine terrace deposits of loosely consolidated sand and gravel.

Formations are units of related rock grouped together for the purpose of geologic mapping. Many different formations occur in the Santa Cruz Mountains. Each represents a particular rock type (or suite of rocks) of a particular age. The Purisima Formation takes its name from Purisima Creek in San Mateo County. The unit was named and formally described from exposures at this *type locality* by H. L. Haehl and Ralph Arnold in 1904.

The Purisima Formation is exposed in western San Mateo County, in the southern half of Santa Cruz County, and on the sea floor beneath Monterey Bay. Joseph Clark and others (1984) presented convincing evidence that this and several other rock

Era	Period	Epoch	Years before present	Rock units in the Santa Cruz area
CENOZOIC	Quaternary	Holocene		beach, river, & sand dune deposits
			11,000	
		Pleistocene		Aromas Formation and marine terrace deposits
			1,800,000	
	Tertiary	Pliocene		Purisma Formation
			5,200,000	
		Miocene		Santa Cruz Mudstone
				Santa Margarita Formation
				Monterey Formation
				Lompico Sandstone
				Lambert Shale
			25,000,000	

Figure 1. Abbreviated geologic time scale.

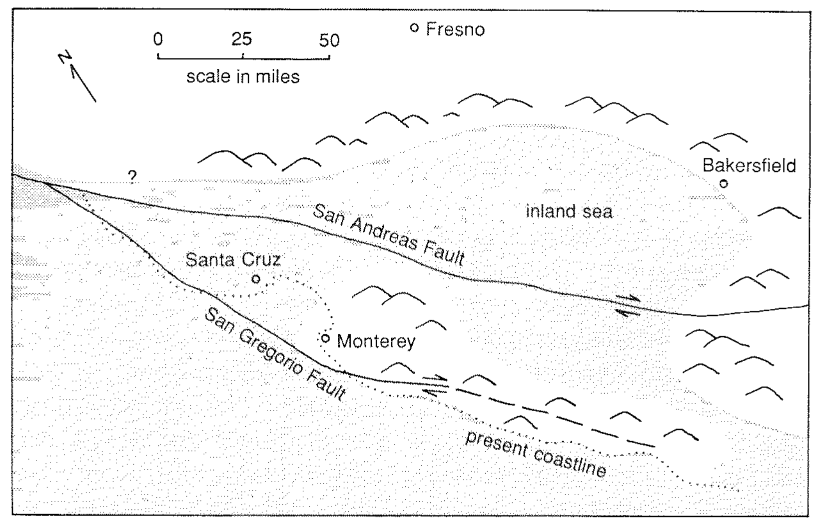

Figure 2. Distribution of the sea over central California during the Pliocene (modified from Greene and Clark, 1979).

units of the Santa Cruz Mountains are also exposed on the Point Reyes Peninsula. They proposed that westward extensions of the Purisima Formation, Santa Cruz Mudstone, and Santa Margarita Formation have been displaced about 90 miles to the north along the San Gregorio Fault zone, comprising what previously has been called the Drakes Bay Formation.

During the late Miocene and Pliocene a large inland sea extended across what are now Santa Cruz and San Benito counties and also blanketed the southern San Joaquin Valley (Greene and Clark, 1979). Many of the marine fossils present in the Purisima Formation have also been found in San Benito County and in the Jacalitos and Etchegoin formations of the Kettleman Hills. This sea became smaller and disappeared during the late Pliocene and Pleistocene (about 1 to 3 million years ago) as the central Coast Ranges gradually emerged and the present landscape took shape (see Howard, 1979).

Along the northern edge of Monterey Bay, the Purisima Formation crops out between Merced Avenue below West Cliff Drive in Santa Cruz and the cliffs just west of the entrance road at Seacliff State Beach. The Purisima is underlain by the Santa Cruz Mudstone, but this unit is not exposed at Capitola. Both, however, can be seen along the cliffs below West Cliff Drive between Swift and Almar streets, where the Santa Cruz Mudstone (which is more resistant to erosion) has formed a bench extending seaward from the lower part of the cliffs. At Seacliff Beach the Purisima disappears, dipping below beach level. It is replaced by the Pleistocene Aromas Formation composed of sand and gravel which overlies the Purisima and forms the cliffs east of the Seacliff entrance road (see Dupré, 1975).

Although formations are often composed of units of similar rock, the Purisima varies in appearance and composition. The lower part of the formation, as exposed along West Cliff Drive, is a diatomite (composed largely of the microscopic "shells" of single-celled plants called diatoms). Elsewhere it is a coarse-grained sandstone or sandy siltstone. Fossil shells are most common in the upper (younger) part of the formation exposed between Capitola and Seacliff. These differences between the older and younger parts of the Purisima reflect changes in the source areas for the sediments as well as changes in the marine

environment in which the sediments were deposited. Studies by the author of fossils and other evidence suggests that the Purisima in the Santa Cruz region records a gradual shift through time from offshore, deeper water conditions to shallow, near-shore waters.

Although the cliffs bordering northern Monterey Bay do not expose more than about an 80-foot-thick section of the Purisima at any one locality, some 800 feet are exposed altogether. This is because the formation dips gently (3 to 6 degrees) to the southeast. If you walk the entire length of the exposure from West Cliff Drive to Seacliff Beach, you will see successively younger beds as you walk east.

During the Pleistocene the ocean eroded a substantial portion of this region's geologic record. As the Santa Cruz Mountains were pushed up, wind and rain also contributed to the erosion. In the Scotts Valley area only a few remnants of the Purisima remain, capping hilltops. In the Pajaro Valley the formation remains intact, but is buried beneath hundreds of feet of river and lake deposits. Therefore, it is only in the mid-county area, particularly along the coastal cliffs, that we have ready access to the geologic record of the late Miocene and Pliocene for this region.

Previous Studies

Although the Capitola cliffs are rich in fossils, until recently this locality had received only cursory study by paleontologists. In 1895 George Ashley published the first faunal list for this locality, listing 33 invertebrate species. Unfortunately, the next three-quarters of a century brought little in the way of additional studies. Capitola lies just outside the Santa Cruz Quadrangle and thus escaped all but brief mention in what was for many years the principal reference work on Santa Cruz area geology (see Branner et al., 1909). Studies in the Santa Cruz Mountains by Stanford University students during the 1950s and 1960s focused on refinements within this quadrangle, while paleontologists at U.C. Berkeley studying fossils of this age focused their attention on localities bordering the San Joaquin Valley. Except for brief mention by Arnold (1908), Carson (1926), Grant and Gale (1931), and a few other authors, little was published on this locality until the popular account by Perry (1977b) and the report by Addicott and others (1978). Recently, the age of the deposit was studied by Madrid and others (1986) and its origin investigated by Norris (1986) and Friede (1987).

Age

Paleontologists have established the age of the Purisima Formation in the Monterey Bay area based on several criteria: percentage of the fauna that is extinct, correlation of the fossils with deposits elsewhere, radiometric dating, and paleomagnetic dating. The Purisima Formation is late Miocene and Pliocene in age based on these criteria. As used in this paper, the Miocene-Pliocene boundary is placed at 5.2 million years ago, and the Pliocene-Pleistocene boundary at 1.8 million years ago. (In the 1970s these dates were generally agreed upon; prior to this, many different dates were used for these boundaries. These dates differ from those used by Perry, 1977b.)

Of the fossil mollusks at this locality identified to species, about two thirds are modern forms, the rest extinct. Quite appropriately, this ratio falls within the percentage given by the famous British geologist Charles Lyell in his original definition of the Pliocene. In 1833 Lyell defined marine Pliocene rocks as those in which 50 to 90 percent of the shelled invertebrates are modern forms.

Many species from the Purisima Formation have been correlated with latest Miocene and Pliocene strata elsewhere in California. Some are fairly indicative of rocks of this age, including the ark clam, *Anadara trilineata*, the nassa snail, *Nassarius grammatus*, and the cockle, *Clinocardium meekianum*.

The only radiometric age determination for the Purisima in this region was made in the early 1960s. In this dating method, the age of rock is calculated by measuring the relative amounts of a naturally occurring radioactive element and its decay product. For the Purisima, sediment samples containing the mineral glauconite were collected from the base of the formation and analyzed using the potassium-argon method. Glauconite is a greenish-colored silicate mineral which contains potassium. By determining how much potassium had decayed to argon, the rock was dated at 6.7 ± 0.6 million years (Clark, 1981).

Paleomagnetism studies of the Purisima Formation were conducted in the late 1970s and early 1980s (see Madrid et al., 1986). Through geologic time the earth's magnetic field has periodically reversed, roughly every one half million years (though at irregular intervals). When this happens, magnetic north becomes south, and south becomes north. Magnetic minerals in sedimentary rocks preserve this normal or reversed magnetic direction from the time they were deposited. Analysis of the remnant magnetism in the Purisima Formation and correlation of it with the earth's magnetic polarity time scale has shed additional light on the age of these rocks. The base of the formation is interpreted as dating from 6.07 million years ago, somewhat younger than the age determined radiometrically. The top of the Purisima at Seacliff State Beach is believed to date from about 2.5 million years ago. The section of the Purisima Formation (and its fossils) preserved in the cliffs between Capitola and New Brighton beaches records the interval from approximately 5 to 3 million years ago.

This may seem straight forward, but there is one complication. It appears that there is a gap in the geologic record here between 3.5 and 4.5 million years ago (Madrid et al., 1986). Either there was a pause in deposition, or sediment was deposited and later eroded away, or a combination of the two. In any event, the lower beds at this locality are thought to date from 5 to 4.5 million years ago, and the upper beds from 3.5 to 3 million years ago.

Geology

Although fossils are what most people come to these cliffs to see, there are some additional geologic features worth noting. The cliffs are eroding quite rapidly: about a foot per year in some places (Griggs and Johnson, 1979). For example, turn-of-the-century photos show several rows of trees between the cliff edge and Grand Avenue. Not only are the trees now gone, but in several places the street has been undermined and destroyed. Erosion at the top of the cliffs occurs episodically. The waves gradually undermine the cliffs at their base over a period of years until the upper portions are no longer adequately supported and collapse. The slumped material temporarily protects the cliffs from the waves, but gradually the boulders erode away and the cycle begins again.

The rock that makes up the cliffs varies mostly from mudstone to medium-grained sandstone, though some beds contain pebbles. The mudstone grains are too small to be seen individually except with the aid of a hand lens. The medium sandstone grains are defined as being from 1/4 to 1/2 millimeter in diameter. The grains are made of quartz, feldspar, biotite mica, and hornblende. In some places small fragments of carbon dispersed through the sediment give it a black speckled appearance.

Beds of fossil shells dominate most of the cliff exposures. These beds vary in species composition and shell preservation. Some have shells in excellent condition; in others the shells are water-worn and fragmented. Some of the layers are called graded beds. These beds contain shells and other coarse material at their base and grade upward into increasingly finer sandstone, and finally mudstone. The total sequence commonly measures from 1 to 3 feet in thickness and is repeated in cycles.

Some of the beds can be traced for nearly the entire exposure —about two-thirds of a mile. Following individual beds along the cliffs takes practice and is complicated by faults. A fault is a fracture in the rock along which movement has taken place. The faults here show vertical displacement ranging from less than an inch to 33 feet. Seven have a displacement greater than three feet (figure 7). In some places the slickened surfaces of the fault planes are visible. Look for striations along these planes (clues to the direction of fault movement).

It is unlikely that these small faults were directly associated with earthquakes. Movement along these faults probably took place very slowly as this region was unevenly uplifted by forces deep below the earth's surface.

Although in most places the sediment is soft and easily scratched with a pick, in some areas it is very hard. These hard areas are concretions or concretionary beds. Their hardness results from calcium carbonate gluing the sediment grains together. Groundwater dissolved some of the calcium carbonate from the fossil shells and redeposited it elsewhere, either along beds or around objects such as fossils. Along the upper part of the cliffs near New Brighton, concretions formed in many odd

Figure 3. Shell beds offset by fault.

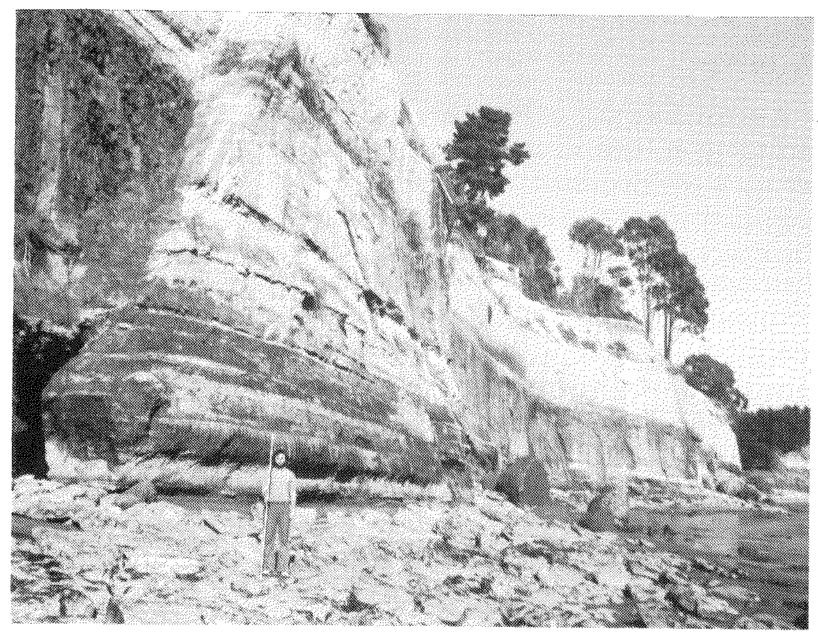

Figure 4. View along cliffs near New Brighton Beach.

shapes and sizes. Here, the shapes were influenced by fossil burrows (see section on trace fossils).

It is useful to divide the Capitola-New Brighton section of the Purisima Formation into several discrete units, each of which can be characterized by the composition and appearance of its sediment and fossils. Geologists use the term *facies* to describe the composition and appearance imparted on sedimentary rock by the environment in which it was deposited. For example, a unit of rock that is characterized by abundant fossil sand dollars might be termed the "sand dollar facies." Or a group of beds of fine-grained, gray sandstone might be called the "gray sandstone facies." The roughly 145 feet of the Purisima Formation exposed along the Capitola-New Brighton cliffs can be divided into four sedimentary facies. They are (from bottom to top): (1) the lower shell bed facies, (2) the *Clinocardium* facies, (3) the upper shell bed facies, and (4) the *Crepidula* facies. The second is named for the fossil cockle, *Clinocardium meekianum*, which is abundant in this unit, and the upper most facies is named for the fossil slipper shell, *Crepidula princeps*, which is abundant there. See figures 5 and 7 for distribution and description of each facies.

Fossils

A great diversity of invertebrate fossils occur at this locality including at least 55 species of mollusks, 6 species of crustaceans, 2 echinoderms, a brachiopod, and numerous microscopic invertebrate fossils including foraminifera and bryozoa. The checklist on page 28 lists the larger invertebrate species and their relative abundance in the four facies.

In most areas, the actual mollusk shells are preserved. For some bivalve specimens the level of preservation is truly remarkable, revealing traces of periostracum, ligament, and coloration. The shells are still composed of calcium carbonate, as in life, but the chemical has been recrystallized. Some shells do not show the recrystallization in an obvious fashion, but others, when broken, reveal calcite cleavage planes. Sometimes the interiors of bivalves are lined with well-formed crystals of honey-colored calcite.

In contrast to the whitish shells of mollusks, crustacean remains, with the exception of barnacles, are usually very dark

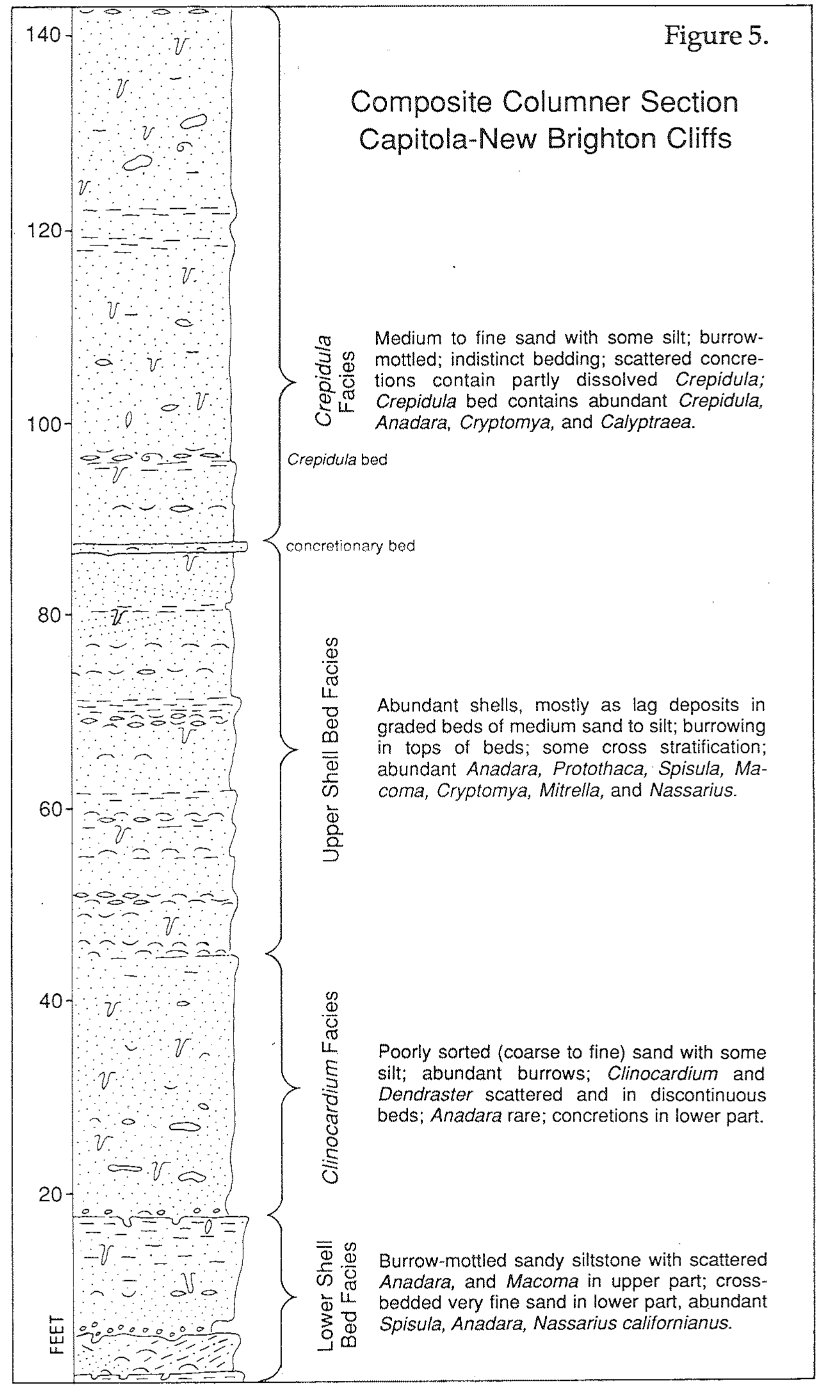

Figure 5.

Composite Columner Section
Capitola-New Brighton Cliffs

brown or black. The exoskeletons of crabs and shrimp are composed of chitin, a material similar in composition to fingernails.

The fossil invertebrates preserved at this locality are generally indicative of a near-shore, shallow-water, sandy-bottom environment, with water temperatures similar to the present central California coast. Conspicuously absent are rocky-substrate animals such as chitons, abalones, limpets and sea urchins. Some of the fossils, such as plant remains, presumably washed into the marine environment from nearby rivers.

To better understand how these creatures once lived, it is useful to compare them to modern organisms. This can be accomplished quite easily since these fossils are geologically young and most are therefore closely related or identical to modern West Coast marine invertebrates. Three references on modern marine animals particularly helpful for this comparison are MacGinitie and MacGinitie (1968), Morris and others

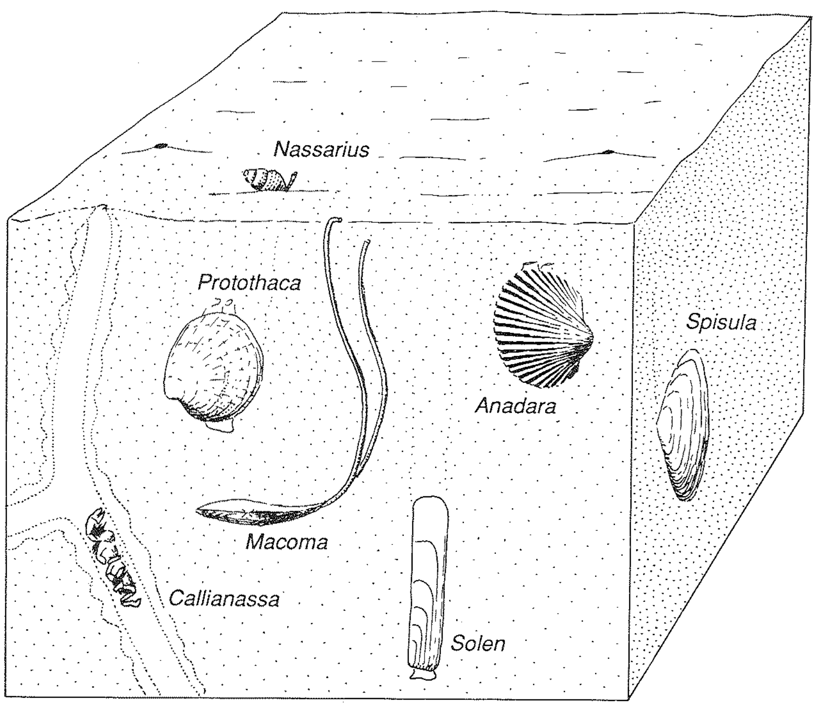

Figure 6. Cross-section of the Pliocene sea floor.

(1980), and Ricketts and others (1985).

Most of the bivalves were types which lived buried below the surface of the sandy bottom. From the safety of their burrows, they fed by extending their siphons to the surface of the bottom and filtering plankton from the water. Many of the snails lived on or near the bottom where they fed on detritus or algae—though some were carnivorous.

Fossil bivalves are much more common than snails, primarily because they were more common in life. Most occupied a lower link in the food chain than the snails and were therefore more abundant.

It is beyond the scope of this guide to discuss in detail each species listed in the checklist. However, some deserve elaboration.

The ark clam, *Anadara trilineata*, is one of the most abundant and distinctive bivalves here. Each of its flattened ribs is divided by three radiating, depressed lines, thus the species name *trilineata*, meaning three-lined. This is one way of distinguishing it from the cockle, *Clinocardium meekianum*, which also has coarse radiating ribs, though rounded and not divided. *Anadara* is further distinguished by its taxodont hinge teeth, a characteristic of the ark clam family. The numerous tiny interlocking teeth occur in a long and fairly uniform row. Some specimens show alternating light and dark concentric bands—remnants of original coloration.

The dish or surf clams, family Mactridae, are represented by three species: *Spisula coosensis*, *Tresus pajaroanus*, and an unidentified species of *Spisula*. *Tresus pajaroanus* was named in 1856 by Timothy Conrad of the Academy of Natural Sciences of Philadelphia, based on a specimen sent to him from the Pajaro River. Exposures of the Purisima Formation occur along the Pajaro River at Chittenden Pass. The clam is a close relative of the modern gaper clam, *Tresus nuttallii*, but is smaller and has a less pronounced siphonal gape.

Macoma addicotti was named and described in part from specimens collected at New Brighton Beach (Nikas, 1977). The species is very similar to the modern bent-nosed clam, *Macoma nasuta*. The latter, besides occurring in the Purisima, also lives just offshore and often washes up on the beach here. Distinguishing the two species can be difficult at first, but the posterior end of *Macoma addicotti* is broader and more truncated.

When feeding, the bent-nosed clam acts like a tiny vacuum cleaner. The clam lies on its side, several inches below the bottom, and extends its incurrent siphon up through the sand or mud. This is facilitated by the upward bend of the posterior end of the shell. The siphon moves back and forth over the surface of the bottom, sucking in detritus and other goodies plus a good deal of sediment. The latter is eventually ejected from the siphon and the rest consumed (Morris et al., 1980).

The littleneck clam, *Protothaca staleyi,* closely resembles its living relative, *Protothaca staminea,* which is common on the beach here. Comparing the two will test your powers of observation. Look for differences in outline, concentric sculpture, and the shape of the cardinal hinge teeth.

The geoduck, *Panopea generosa,* is the largest of California burrowing clams and has both an interesting natural history and an extensive fossil record. Its modern range is from Alaska to Baja California. A resident of the low intertidal zone and offshore waters, the geoduck lives in semipermanent burrows to a depth of 4 feet. With its massive siphons it reaches to the surface of the sand or mud to filter feed. The siphons are so large that the clam cannot fully retract them into its shell. Geoducks may live 15 to 16 years, attain a shell length of 7 inches, and weigh over 13 pounds. This or closely related species have been found in rocks as old as early Miocene.

Among the gastropods or snails, *Mediargo mediocris* is one of the rarest. This snail with the unusual name is a triton, family Cymatiidae (see Terry, 1968). The only specimen I know of from this locality was collected in 1914 by Harold Hannibal and is now in the collection of the California Academy of Sciences.

Another rare gastropod is *Searlesia portolaensis,* first described by Ralph Arnold in 1908 from the Purisima Formation of San Mateo County. I have found only one complete specimen of it at Capitola.

The nassa, *Nassarius grammatus,* is common to abundant in many shell beds. This species is probably the evolutionary ancestor of the channeled nassa, *Nassarius fossatus,* which ranges today from British Columbia to Baja California and lives just offshore from Capitola (see Addicott, 1965). *Nassarius fossatus* is primarily a scavenger, crawling along the sand or plowing just below the surface as it searches for dead animal debris.

One of the loveliest of Purisima gastropods is the delicately

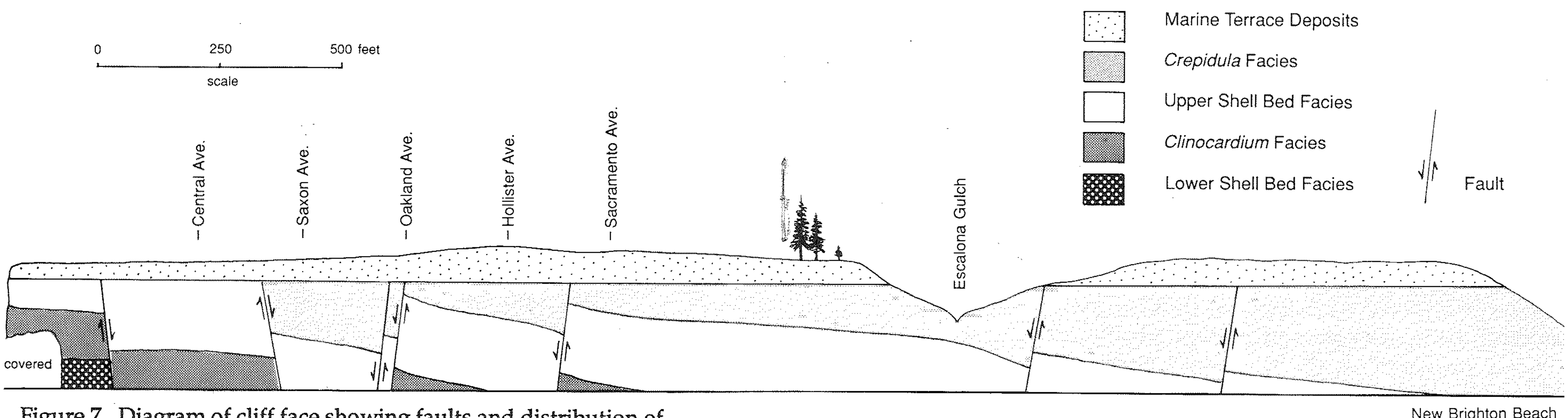

Figure 7. Diagram of cliff face showing faults and distribution of rock units. Vertical scale exaggerated 4 to 1.

sculptured *Cancellaria arnoldi*. It is not common, making it an added treat to find. Addicott (1969) stated that it had been previously reported only from several southern California localities and that its presence at Capitola and at a Santa Clara County locality represented northern extensions of its range. It belongs to the family Cancellariidae, popularly called the nutmeg shells.

A larger member of the nutmeg family is *Cancellaria tritonidea*. This species is quite variable and consequently led early-day paleontologists to name several species and varieties based on specimens of differing appearance. Grant and Gale (1931) concluded that although single specimens of the named varieties seem distinct, large collections show intergradation between all of them. Carson (1926) believed specimens from Capitola represented a species he called *Cancellaria palmeri*. Grant and Gale, however, dismissed Carson's new species as a synonym for a variety of *Cancellaria tritonidea*.

Of the three species of moon snails present, the Lewis moon snail, *Polinices lewisii*, is the largest. It is an extant species and a carnivore. It feeds by grasping clams such as *Macoma* with its muscular foot and drilling a small counter-sunk hole in the clam's shell with its file-like tongue. It then sucks the meat out of the clam. Some of the fossil *Macoma* clams bear this tell-tale hole.

Another large shell is the slipper shell, *Crepidula princeps*. Slipper shells are filter feeders and need a hard substrate on which to anchor themselves. These, having lived in a sandy-bottom environment, attached to each other, forming clusters on the sea floor. These clusters also formed a substrate for other animals including barnacles and a limpet like snail called *Calyptraea fastigiata*. Attaching to one another also helped the slipper shells in mating. Modern slipper shells begin life mostly as males, turning into females as they grow older. Look for fossil slipper shells with small ones still fastened to them. The large ones were females, the smaller ones males, and the medium sized ones were probably both.

Only one brachiopod has been found: a fragment of the genus *Discinisca*. The Santa Cruz City Museum has some well-preserved specimens of this genus collected in the late 1930s, supposedly from the Purisima Formation of Santa Cruz

County. Unfortunately, the locality has not been relocated.

The extinct fossil sand dollar, *Dendraster gibbsii*, differs from the modern *Dendraster excentricus* in its more eccentric petals and in many more subtle ways. There has been some confusion in the identification of these sand dollars. I previously assigned them to *Dendraster ashleyi*, but Dr. J. Wyatt Durham of University of California, Berkeley, who kindly examined a large number of specimens for me, concluded that, despite their variation, they are best called *Dendraster gibbsii* (Durham, written communication, 1982).

Barnacles are most often found in the *Crepidula* facies, especially the *Crepidula* bed. The variability of their conical shells, due to differences in substrate and environment, make them tricky to identify. More diagnostic are the scuta and terga—the movable plates at the top of the shell. Several detached scuta collected from the *Crepidula* bed appear to be from *"Balanus" gregarius* (Zullo, written communication, 1987).

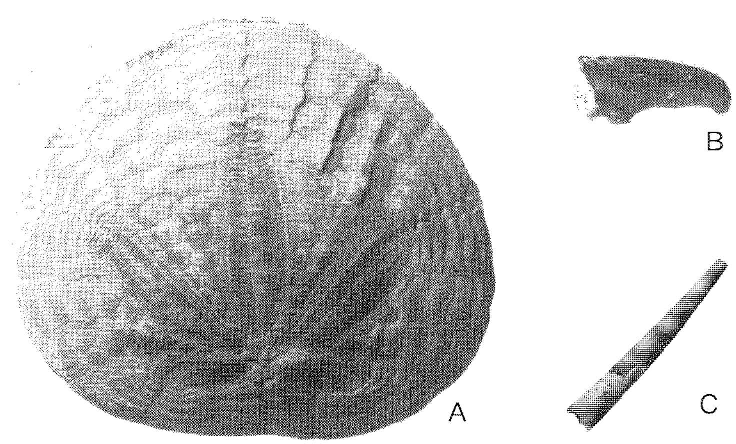

Figure 8. (A) *Dendraster gibbsii*, x1. (B) *Callianassa longimana*, movable finger from left claw, x1. (C) *Dentalium* sp., x1. Note: sizes of all figures are approximate.

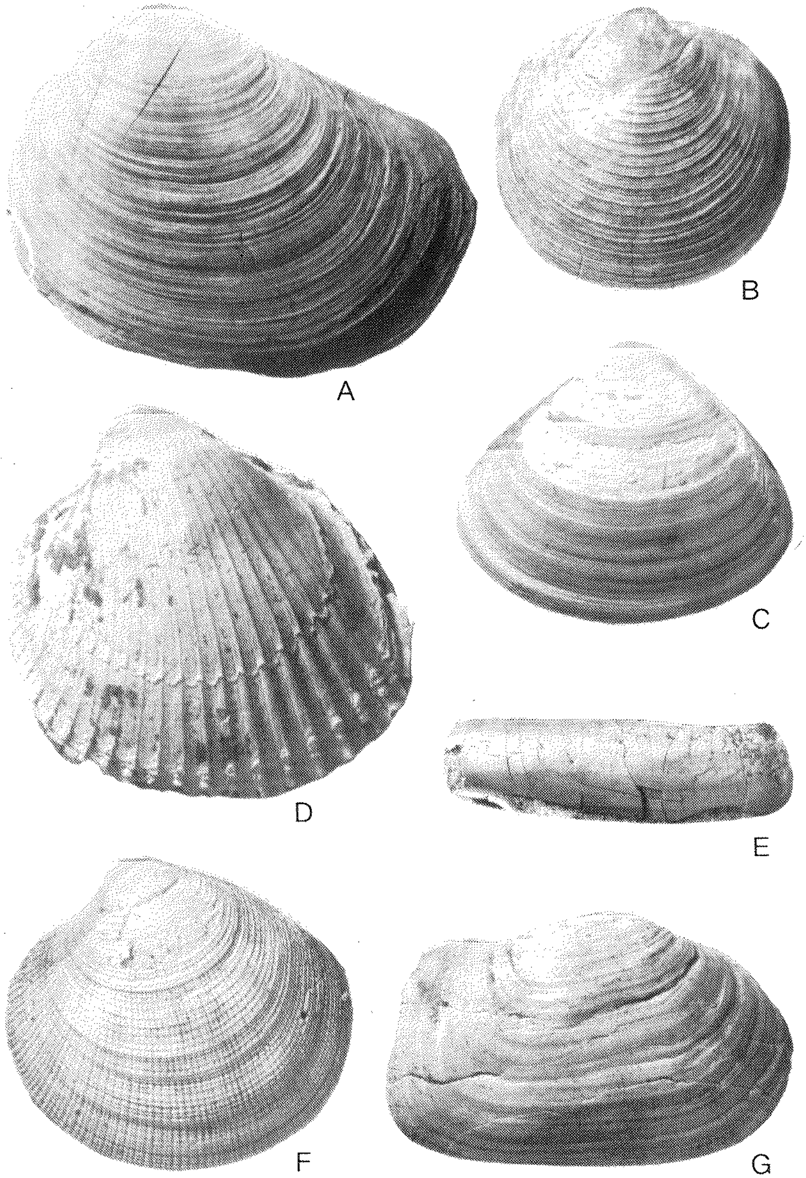

Figure 9. (A) *Tresus pajaroanus*, x2/3. (B) *Lucinoma annulata*, x2/3. (C) *Spisula coosensis*, x2/3. (D) *Clinocardium meekianum*, x2/3. (E) *Solen sicarius*, x2/3. (F) *Protothaca staleyi*, x1. (G) *Panopea generosa*, x1/2.

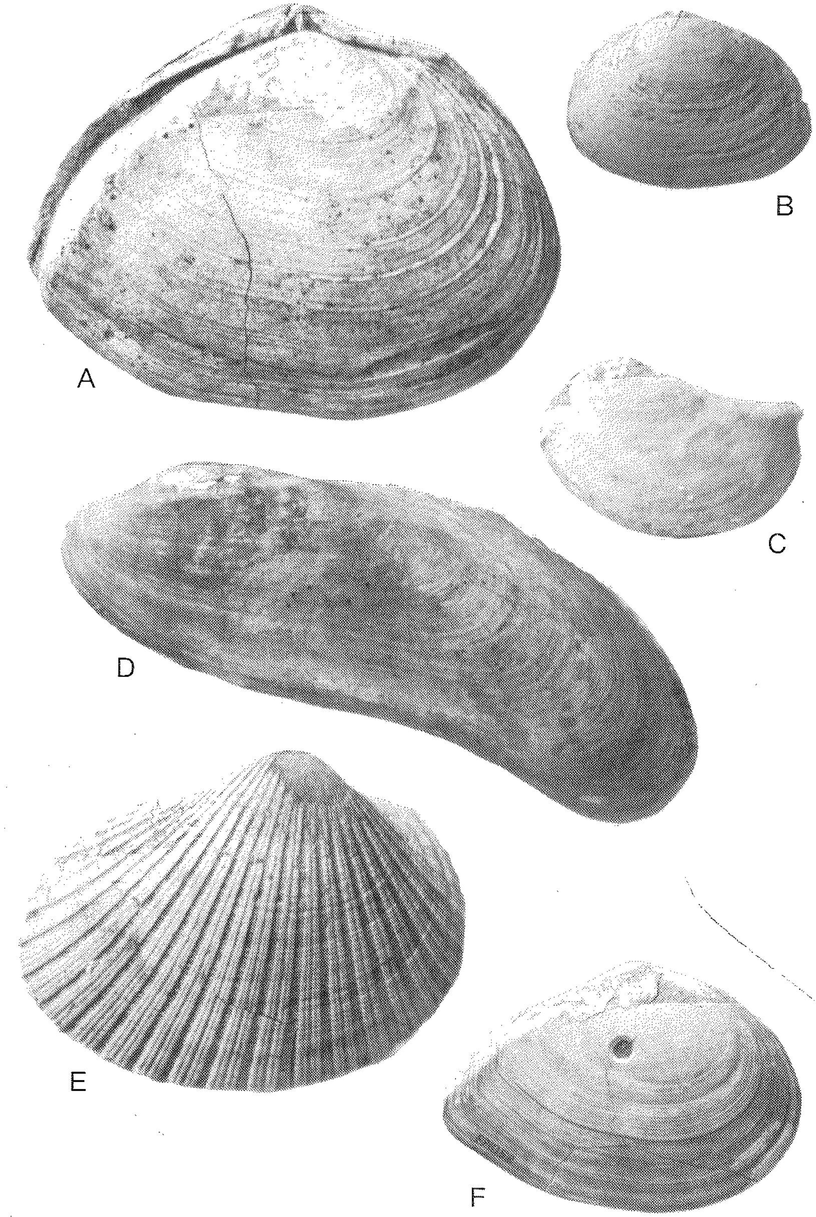

Figure 10. (A) *Macoma addicotti*, x3/4. (B) *Cryptomya californica*, x1. (C) *Pandora punctata*, x1. (D) *Modiolus rectus*, x2/3. (E) *Anadara trilineata*, x1. (F) *Macoma nasuta* with *Polinices* boring, x2/3.

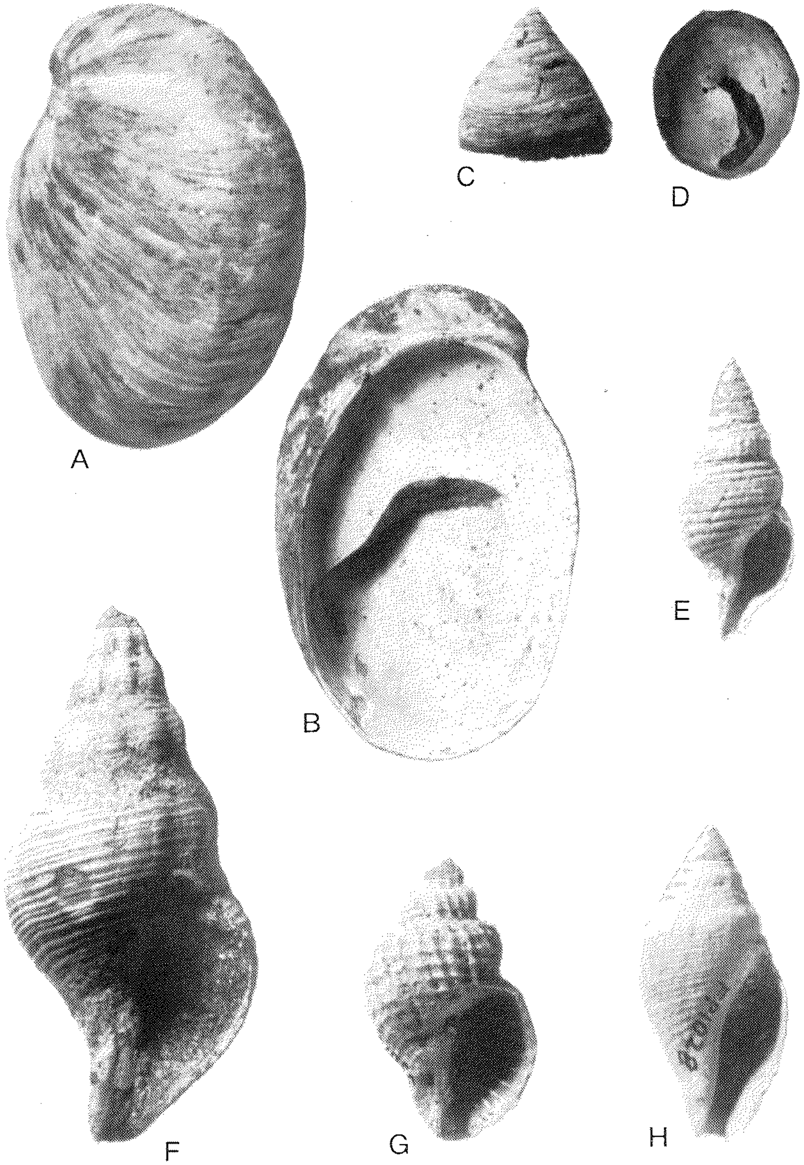

Figure 11. (A,B) *Crepidula princeps*, exterior and interior, x1. (C,D) *Calyptraea fastigiata*, exterior and interior, x1. (E) *Ophiodermella graciosana*, x2. (F) *Searlesia portolaensis*, x1.5. (G) *Cancellaria arnoldi*, x1.5. (H) *Megasurcula remondii*, x1.5.

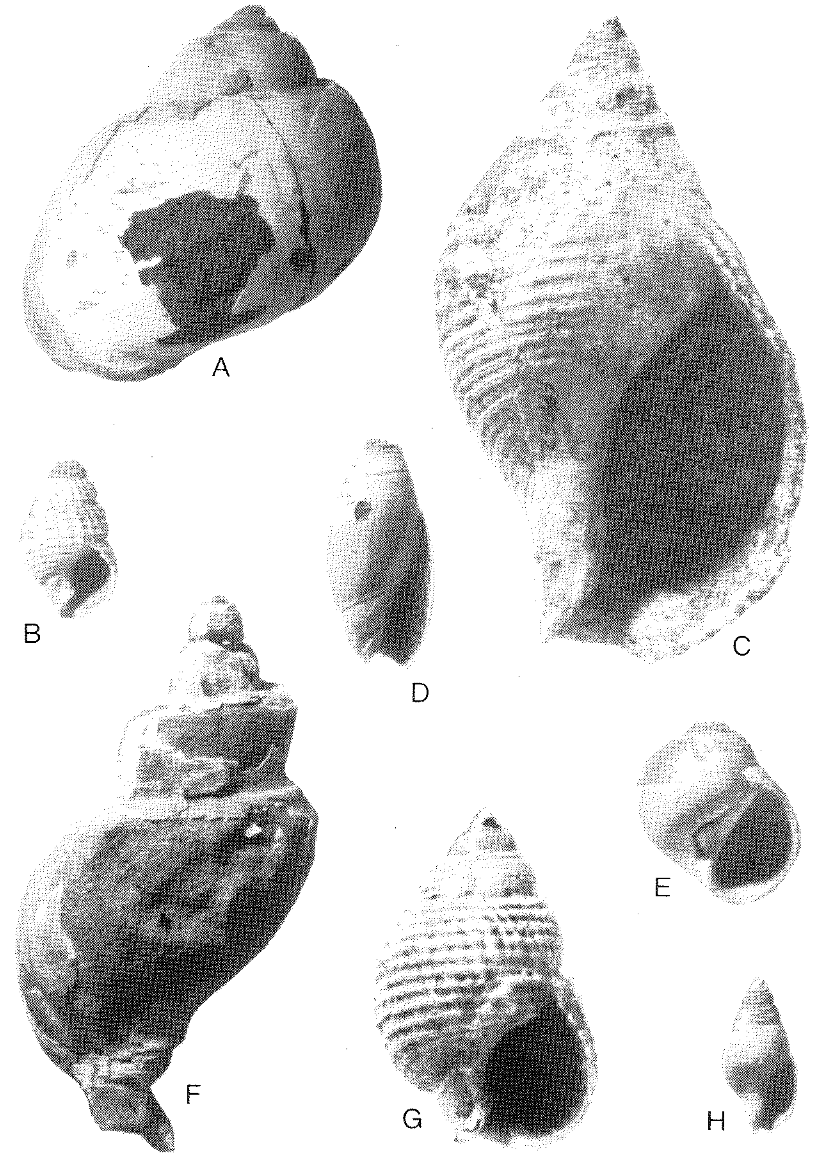

Figure 12. (A) *Polinices lewisii*, x1/2. (B) *Nassarius californianus*, x2. (C) *Cancellaria tritonidea*, x1. (D) *Olivella pedroana*, x2. (E) *Natica clausa*, x1.5. (F) *Beringius stantoni*, x2/3. (G) *Nassarius grammatus*, x1.5. (H) *Mitrella gausapata*, x2.

Trace Fossils

In addition to hard parts, mollusks and crustaceans have also left behind indirect evidence of their existence in the form of borings and burrows. These trace fossils offer a separate and significant line of evidence for understanding the Purisima's depositional history. They can also tell us something about the animals' feeding and burrowing behavior.

By definition, borings occur in hard matrix such as rock or shell. Most specimens of the slipper shell, *Crepidula princeps*, are honeycombed by borings from the boring sponge, *Cliona*. Though I have not found remains of the sponge itself, its distinctive borings show that it lived here. The shells of the ark clam, *Anadara trilineata*, often contain borings by polychaete worms of the family spionidae (Thompson, 1984). Fossil *Macoma* clams sometimes have a small, counter-sunk hole in their shell drilled by moon snails, as discussed earlier.

Unlike borings, burrows are made in soft substrate such as sand or mud. Several types of fossil burrows have been reported from the Purisima Formation and are abundant in many areas (Perry, 1977a). These burrows were made by worms, crustaceans, and other organisms that dwelled in the sea floor after the sediment was deposited. The *Crepidula* facies, for example, has been so extensively burrowed that bedding is only vaguely discernable. The rock shows the irregular mottled pattern of thousands of burrows.

Many of the burrows can be attributed to the ghost shrimp, *Callianassa*, a creature dear to the hearts of those who study marine trace fossils. Numerous studies have been made comparing fossil burrows with those made by a modern ghost shrimp of the Gulf Coast, *Callianassa major*. This shrimp measures 2 to 3 inches long and lives in the sandy substrate of beaches, estuaries, and other shallow, near-shore, marine environments (Frey et al., 1978). To reinforce the wall of its burrow, it shapes pellets of mud and packs them into the wall. Though the interior surface of the wall is smooth, the exterior has a knobby appearance due to its mode of construction. Fossil burrows of this type have been found in rocks as old as the early Permian and in marine sediments deposited at depths ranging from intertidal to several thousand feet. Obviously,

more than one species has been at work to leave behind such a long record, even though the best known modern constructor of such burrows is *Callianassa major*.

Not all modern ghost shrimp construct knobby-walled burrows. The species common in the intertidal sand flats of California's bays and sloughs, *Callianassa californiensis*, apparently does not. However, its relative and neighbor, the blue mud shrimp (*Upogebia pugettensis*), does. Some of the larger burrows in the Purisima have been attributed to *Upogebia* (Perry, 1977a). Claw fragments of another modern West Coast species, *Callianassa longimana*, have been found in the Purisima near New Brighton Beach. This suggests that the knobby-walled burrows preserved in that vicinity were made by this species, though the burrowing habits of living individuals have apparently not been studied. *Callianassa longimana* lives most commonly today in shallow water offshore.

The ghost shrimp is represented not only by hard parts and burrows, but also by fossil fecal pellets. These distinctive pellets measure about 1/8 inch long and, when well preserved, are rectangular in cross-section with rounded edges. Several channels,]-shaped in cross-section, run longitudinally through each pellet making their identity unmistakable. Deposits of

Figure 13. Fossil burrows probably made by *Callianassa*.

fossil pellets sometimes occur in the lower parts of fossil burrows. Modern pellets for comparison can be found in abundance on the sand flats of nearby Elkhorn Slough at low tide.

Origin of the Deposit

Many of the invertebrate species are types which still live in Monterey Bay, making them so-called living fossils. Their presence makes it possible to paint a detailed picture of the marine environment in which they lived long ago. For example, several of the mollusks (*Yoldia cooperii, Lucinoma annulata, Calyptraea fastigiata, Natica clausa*, and the genus *Megasurcula*) live at water depths of at least 30 to 60 feet. Others (*Modiolus rectus, Macoma nasuta, Pandora punctata*, and *Panopea generosa*) do not occur in waters deeper than about 150 feet. Thus, the fossil invertebrates probably lived at a depth of between 30 and 150 feet. These same depths occur today in northern Monterey Bay 1 to 8 miles from shore on the continental shelf.

Paleontologists have observed for many years that fossils are seldom, if ever, evenly distributed through a deposit. Indeed, the exposures at Capitola are no exception, as the fossils generally occur concentrated in layers. Many different theories have been proposed for the origins of such shell beds. Richard Norris (1986) concluded that they formed in several ways, using evidence such as the location and density of burrows, the orientation and preservation of shells, and the occurrence of borings, encrusting organisms, bones, and certain minerals. Some are storm deposits—material eroded from the sea floor by storm currents and redeposited as the storms subsided. This process produced some of the graded beds discussed earlier. Other beds formed as currents winnowed the shells from the sand. A few represent prolonged exposure of the bottom with a low sedimentation rate. Still others preserve intact communities of organisms with bivalves oriented as in life and few broken shells.

Though the Purisima Formation records an overall shallowing of the sea in this region during the late Miocene and Pliocene, this was only a trend and not a constant. Even the relatively small section of the Purisima preserved at Capitola

shows alternating shallower and deeper water conditions. In the *Clinocardium* and *Crepidula* facies, burrows are more common and mollusks less common than in the other two facies. These units formed where sedimentation was slower, giving time for burrowing organisms to colonize the sea floor and many of the mollusk shells to dissolve before being permanently buried. Both facies probably record deposition on the middle continental shelf at a depth greater than 130 feet, based on sedimentary features and comparison with modern offshore deposits (see Norris, 1986). In contrast, the shell beds formed mostly in shallower water closer to shore, where storm influence was greater, and currents stronger. Norris (1986) suggested that the upper shell bed facies formed at a depth of approximately 30 to 90 feet. These depth estimates agree well with those based on mollusks.

There are two explanations for the changes in the water depth. One is tectonic: vertical movement of the sea floor, perhaps related to movement along the San Andreas and San Gregorio fault zones. The other is changes in sea level, such as those that occurred during the Pleistocene ice ages. Most likely both played a role in the depositional history of the Purisima Formation (Friede, 1987).

Summary

The beds of the Purisima Formation exposed along the marine cliffs between Capitola and New Brighton beaches were laid down 3 to 5 million years ago during the Pliocene Epoch. Over 60 species of fossil invertebrates have been found here along with abundant trace fossils. The fossils and sediment were deposited in shallow water (at a depth of roughly 30 to 150 feet) on the continental shelf at a time when the sea extended much farther inland than today. Good exposure, accessibility, and excellent fossil preservation make this stretch of coastline a valuable resource for the study of Pliocene fossils and the geologic history of the northern Monterey Bay area.

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Checklist of Fossil Invertebrates

Abbreviations: A, abundant; C, common; O, occasional; R, rare; NCN, no common name. List based on specimens in the collection of the Dept. of Invertebrate Zoology and Geology, Calif. Academy of Sciences.

Common Name	Scientific Name	Lower Shell Bed Facies	*Clinocardium* Facies	Upper Shell Facies	*Crepidula* Facies
BIVALVES					
Cooper's Yoldia	*Yoldia cooperii* Gabb	C		O	
Ark Clam	*Anadara trilineata* (Conrad)	A	R	A	C
Bittersweet Clam	*Glycymeris grewingki* Dall		O		
NCN	*Megacrenella* cf. *M. columbiana* (Dall)	R			
Horse Mussel	*Modiolus rectus* (Conrad)	C		C	C
Pacific Spear Scallop	*Chlamys hastata* (Sowerby)				R
Scallop	*Swiftopecten parmeleei* (Dall)			R	R
Ringed Lucina Clam	*Lucinoma annulata* (Reeve)		O	R	R
Cockle	*Clinocardium meekianum* (Gabb)		A	R	
Surf Clam	*Spisula coosensis* Howe	A		A	
Surf Clam	*Spisula* sp.		R		
Gaper Clam	*Tresus pajaroanus* (Conrad)			O	C
Jackknife Clam	*Solen sicarius* Gould			C	O
Razor Clam	*Siliqua* sp.	O		O	
Tellin	*Tellina modesta* (Carpenter)			R	
Macoma Clam	*Macoma addicotti* Nikas			C	A
Bent-nosed Macoma	*Macoma nasuta* (Conrad)	C		O	
Indented Macoma	*Macoma indentata* Carpenter		O	R	
Milky Venus Clam	*Katherinella subdiaphana* (Carpenter)			O	
NCN	*"Transennella"* sp.		R		
Littleneck Clam	*Protothaca staleyi* (Gabb)	C		A	
Thin-shelled Littleneck	*Protothaca tenerrima* (Carpenter)			R	
California Soft-shell Clam	*Cryptomya californica* (Conrad)	C	O	A	A
Geoduck	*Panopea generosa* Gould		C	O	R
Pacific Piddock	*Barnea subtruncata* (Sowerby)	C	R		
Dotted Pandora	*Pandora punctata* Conrad		R	O	
Thracia	*Thracia kanakoffi* Hertlein and Grant			R	
Thracia	*Thracia* sp.		O		
SCAPHOPODS					
Tooth Shell	*Dentalium* sp.			O	
GASTROPODS					
Top Shell	*Calliostoma* sp.			R	R
NCN	*Vitrinella* sp.			O	
Wentletrap	*Epitonium sp.*			O	
NCN	*Calyptraea fastigiata* Gould	O		O	A
Slipper Shell	*Crepidula princeps* Conrad	O	O	O	A
Lewis Moon Snail	*Polinices lewisii* (Gould)		O		O
Recluz's Moon Snail	*Neverita reclusiana* (Desheyes)	C	R	C	C
NCN	*Sinum scopulosum* (Conrad)				R
Moon Snail	*Natica clausa* Broderip and Sowerby	O	O	C	O
Whelk	*Mediargo mediocris* (Dall)			R	
Leafy Hornmouth	*Ceratostoma foliatum* (Gmelin)			R	
Frilled Dogwinkle	*Nucella lamellosa* (Gmelin)				R
Dogwinkle	*Nucella trancosana* (Arnold)		R		
Whelk	*Searlesia portolaensis* (Arnold)			R	
Whelk	*Beringius stantoni* (Arnold)			R	O
Dove Shell	*Mitrella gausapata* (Gould)	O		A	
Nassa Snail	*Nassarius californianus* (Conrad)	A		R	
Nassa Snail	*Nassarius grammatus* (Dall)	C	O	A	
Olive Snail	*Olivella pedroana* (Conrad)		O	C	C
Nutmeg Snail	*Cancellaria arnoldi* Dall	R	R	O	
Nutmeg Snail	*Cancellaria tritonidea* Gabb		R		
Tower Shell	*Ophiodermella graciosana* (Arnold)	O		O	
Turrid Shell	*Megasurcula remondii* (Gabb)			O	
NCN	*Cylichna* cf. *C. attonsa* Carpenter			R	
NCN	*Odostomia* spp.			O	
NCN	*Turbonilla* spp.			O	
BRACHIOPODS					
Brachiopod	*Discinisca* sp.		R		
CRUSTACEANS					
Barnacle	*"Balanus" gregarius* (Conrad)				C
Cancer Crab	*Cancer productus* Randall			O	O
Cancer Crab	*Cancer magister* Dana			R	
Sheep Crab	*Loxorhynchus* sp.			O	
Ghost Shrimp	*Callianassa longimana* Stimpson			O	
Mantis Shrimp	Stomatopod			O	
ECHINODERMS					
Sand Dollar	*Dendraster gibbsii* (Rémond)		C	R	
Sea Star	Asteroid			R	

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