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Late Pleistocene Mytilid and Petricolid Bivalves from the Open Rocky Shores of Pacific Baja California (Mexico): Unusual Preservation of Macrofossils

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ABSTRACT

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Fossils representing species living on wave-swept, open rocky shores are seldom found preserved in the stratigraphic record. This report documents the separate occurrences of the bivalves *Mytilus californianus* and *Petricola carditoides* found associated with the Pleistocene-Cretaceous nonconformity at Punta Cabras on the Pacific coast of northern Baja California, Mexico. A pocket beach deeply incised in the steep andesite coast at Punta Cabras is the repository of both a modern beach coquina and a 3.36-meter thick, fossil shell bank consisting predominantly of transported *M. californianus.* Analysis of the modern beach across an onshore-offshore transect helps explain distinct stratigraphic cycles in the homologous fossil deposit. These cycles may be related to modest changes in sea level during the last interglacial period (oxygen isotope stage 5a), to extraordinary storm events, or to local uplift. At another nearby locality, fossils of *P. carditoides* are preserved in borings directly penetrating a gentle andesite ramp. The ramp is also partially encrusted with fossilized red coralline algae. The *Mytilus* deposit, with its associated gastropod and barnacle species, signifies a transported death assemblage but the *Petricola* population represents part of an *in situ* community.

ADDITIONAL INDEX WORDS: *Ancient rocky shores, neptunian dikes, epifaunal bysate bivalves, hard substrate boring bivalves.*

INTRODUCTION

Some of the most prolific rocky-shore, intertidal to shallow subtidal invertebrates are species of the bysally attached blue mussel, *Mytilus.* Not only are mussels a successful occupant of rocky shores on all continents, but their extensive beds provide refuge for a diverse community numbering upward of 300 taxa (SUCHANEK, 1986). *Mytilus californianus* living on exposed, open coasts also demonstrates high rates of productivity rivaling that of kelp beds or even tropical rain forests (LEIGH *et al.,* 1987). Given the success of this genus and its close relatives in the present rocky-intertidal setting, it is striking how few examples of macrofossils have found their way into the stratigraphic record. There is a growing literature on cold-water carbonates with a high concentration of material derived from *Mytilus,* other molluscs, and barnacles (RAYMOND and STETSON, 1932; LEONARD and CAMERON, 1979; SCOFFIN, 1988; SMITH, 1988), but this research is from a sedimentological viewpoint.

Not all *Mytilus* are restricted to rock cliffs and tide pools. *Mytilus edulis,* for example, often occurs in scattered clumps attached to bits of rock or shell on intertidal sand flats (see RAUP and STANLEY, 1978, p. 276). Most reports of *M. edulis* or *M. californianus* as macrofossils from the Upper Pleistocene of the North American west coast relate to a similar setting from rubbly terrace deposits (EMERSON and ADDICOTT, 1953, 1958; ADDICOTT and EMERSON 1959; VALENTINE, 1957, 1980; ZULLO, 1969). In all these examples, the fossil mytilid is but one species among a highly diverse molluscan macrofauna characteristic of protected outer shores or sheltered embayments. Few reports, such as that by RUSSELL (1991), explicitly demonstrate fossil mytilids from open-coast, high-energy environments. Based on the bibliography assembled by JOHNSON (1992), the oldest occurrence of mytilid macrofossils associated with an unprotected rocky shore is late Oligocene in age (MILLER and ORR, 1988).

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Petricolid bivalves are also intertidal to subtidal, but more characteristic of an infaunal habit. Species of *Petricola* are known to nestle in the empty holes made by boring bivalves or to burrow into clay or soft rock in protected bays (MORRIS *et al.*, 1980). Associated with fossil *Mytilus californianus* as cited above, *Petricola carditoides* is commonly reported from Upper Pleistocene strata deposited as terraces on protected outer shores or in sheltered embayments (EMERSON and ADDICOTT, 1953, 1958; ADDICOTT and EMERSON, 1959; VALENTINE, 1957, 1980). An unexpected habitat for this species, or any other boring bivalve, would be an igneous substrate on an open coast. So called "sand pipes", however, are reported by MASUDA (1968) as structures excavated by boring bivalves which penetrated coastal Miocene andesite in Japan.

The purpose of this contribution is to document the separate occurrences of fossil *Mytilus californianus* and *Petricola carditoides* in close association with the Pleistocene-Cretaceous nonconformity at Punta Cabras in Baja California, Mexico. With respect to wave shock, RICKETTS *et al.* (1968) draw the useful distinction between low-energy bays and high-energy outer coasts, with the latter consisting of open as opposed to more protected rocky shores. The andesite headlands in the Punta Cabras area are now, as they were in late Pleistocene and even late Cretaceous times, open rocky shores on the Pacific Ocean. The preservation of late Pleistocene faunas in this harsh setting sheds light on older, comparable faunas from ancient rocky shores.

LOCATION AND GEOLOGIC SETTING

Two study sites at Punta Cabras on the Pacific shores of northern Baja California, Mexico, are compared in this report. One site is situated on the tip of Punta Cabras and the other is found below Paseo Cueva, beyond Half Moon Bay to the southeast, but still on part of the Punta Cabras promontory (Fig. 1). This entire coastline is dominated by resistant headlands consisting of andesite belonging to the Middle Cretaceous Alisitos Formation (CLARK and JOHNSON, 1995). These headlands project perpendicular from the shoreline into the Pacific Ocean, separated by broad embayments underlain by Upper Cretaceous and Upper Pleistocene sedimentary rocks.

Coastal facies belonging to the Upper Cretaceous Rosario Formation in these embayments are described by LESCINSKY *et al.* (1991) and by JOHNSON and HAYES (1993). The geomorphology of the igneous rocks, against which the Cretaceous and Pleistocene sedimentary rocks abut in a nonconformable relationship, is treated in the companion study to this report by CLARK and JOHNSON (1995). The only previous local study on Pleistocene deposits is devoted to a terrace exposed in the Punta Cabras embayment immediately southeast of the Punta Cabras promontory (Fig. 1). ADDICOTT and EMERSON (1959, p. 1) found a diverse mollusc-dominated assemblage of 107 species in this embayment, which they interpreted to reflect "a significantly colder hydroclimate than exists at this latitude today." The nature of this late Pleistocene fauna together with its low position on the present shoreline suggest a correlation to oxygen isotope stage 5a of SHACKLETON and OPDYKE (1973), representing the final pulse of the last interglacial period before the onset of glaciation (George Kennedy, personal communication, 1993).

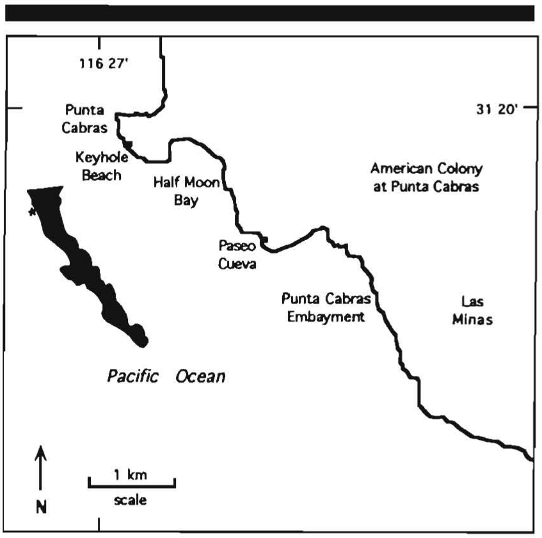


Figure 1. Map of the Punta Cabras area, with an inset showing the location in northern Baja California (star).

METHODS

Field methods used in studying the fossil deposits on the Punta Cabras promontory involved photography, mapping, stratigraphy, and comparative sedimentology. At Paseo Cueva, the thin drape of carbonate materials on the andesite ramp 1.5 m above sea level was surveyed using a square-meter quadrate. Distribution of algal encrustations and a census of the *Petricola* population was tallied from three randomly chosen spots on the ramp. At Keyhole Beach on the tip of Punta Cabras, a map of the narrow inlet, deeply recessed in coastal andesite, was made using a meter tape and brunton compass. Deposits bearing fossil *Mytilus* were examined on three sides of this feature, but the description of a stratigraphic column was possible only above the modern beach on the innermost wall. All possible dimensions of this deposit were recorded in order to gauge its overall size.

Due to the homologous nature of the modern pocket beach associated with the Pleistocene deposit in the same inlet, an experiment was undertaken using beach sedimentology as a key to understanding stratigraphic patterns preserved in the fossil accumulation. Both the Pleistocene deposit and the modern pocket beach consist overwhelmingly of materials derived from the disaggregation of *Mytilus* shells, but also include eroded andesite clasts. Representative fabrics range from coarse carbonate "sand" to coquinas composed of relatively whole, but disarticulated, bivalve shells.

Beach sediments were collected and analyzed according to the following parameters. Seven stations, A–G, were marked out with stakes at intervals of 1.5 m along an onshore-offshore transect running perpendicular to the back wall of the inlet. The first was set atop the beach berm, farthest from the water. The last was set at the lowest accessible level of the surf zone still visible when waves retreated from the inlet. Once the transect was established, a 1 liter sample of beach material was retrieved from each station. All seven samples were collected at the same time on the day following a full moon, so as to insure peak tides. Each sample was dried and sorted for its igneous component as opposed to its shell component.

In each sample, the andesite clasts were first separated from the shell debris. Then each andesite clast was sorted by scale into categories at 0.5 cm intervals, from <0.5 cm to 6.0+ cm. The number of clasts in each category was counted and recorded on bar graphs. The shell count was accomplished in a slightly different manner. In compiling this data, a shell was defined as a whole single valve of *Mytilus* and not the articulated shell. Using a valve from a fresh specimen as a template for gauging fragmentation, the shell was marked off into three equal sections. These entailed the thickened, posterior third of the shell including the hinge; the middle third of the shell; and the thinner, distal anterior third of the shell. With this template in hand, shell bits were sorted into one of six categories. Categories 1–3 correspond directly to the three divisions described above. A category 4 fragment, however, is the heavier ⅔s of the *Mytilus* shell (amalgamation of categories 1 plus 2). A category 5 fragment is the thinner ⅔s of the *Mytilus* shell (amalgamation of categories 2 plus 3). Category 6 is the designation reserved for the rare intact valve. For each sample, the shell debris was sorted according to these categories and their frequencies recorded on bar graphs.

RESULTS

Description of the Keyhole and its Fossil Deposits

Keyhole Beach is the small pocket beach on the western tip of Punta Cabras, and the Keyhole is the distinctive inlet enclosing the beach (Fig. 1). Several other narrow inlets are deeply incised in the coastal andesite of Punta Cabras. They appear to owe their origin to fractures enlarged from blow holes (CLARK and JOHNSON, 1995), spectacular examples of which are still active on the point. Dimensions of the Keyhole (Figs. 2A and 2B) are approximately 60 m in length and no more than 8–10 m wide. The feature's name is derived from the map outline (Fig. 2C), which resembles the shape of an old-fashioned keyhole with a long slot below a circular head for the insertion of the key stem. The mouth of the Keyhole faces the open Pacific Ocean, from which large swells are funneled directly into the narrow inlet and break as surf (Fig. 2A). Dense populations of *Mytilus californianus* thrive on the rocks outside the Keyhole and their dislodged shells are washed into the Keyhole in great quantity.

Deposits with fossil *Mytilus californianus* occur on benches 4.5 m above the floor of the Keyhole on the northwestern and southeastern walls and, most significantly, across the back northeastern wall of the Keyhole (Fig. 2C). None of the other similar inlets on Punta Cabras retain Pleistocene deposits. The Keyhole's southeastern deposit was probably the most extensive of the three, but it is not very informative. This is due to the fact that weathering has removed most of the deposit, except for a calcium-cement matrix draping the bench together with scattered andesite clasts, fossil mytilid shells, and barnacles. All are firmly

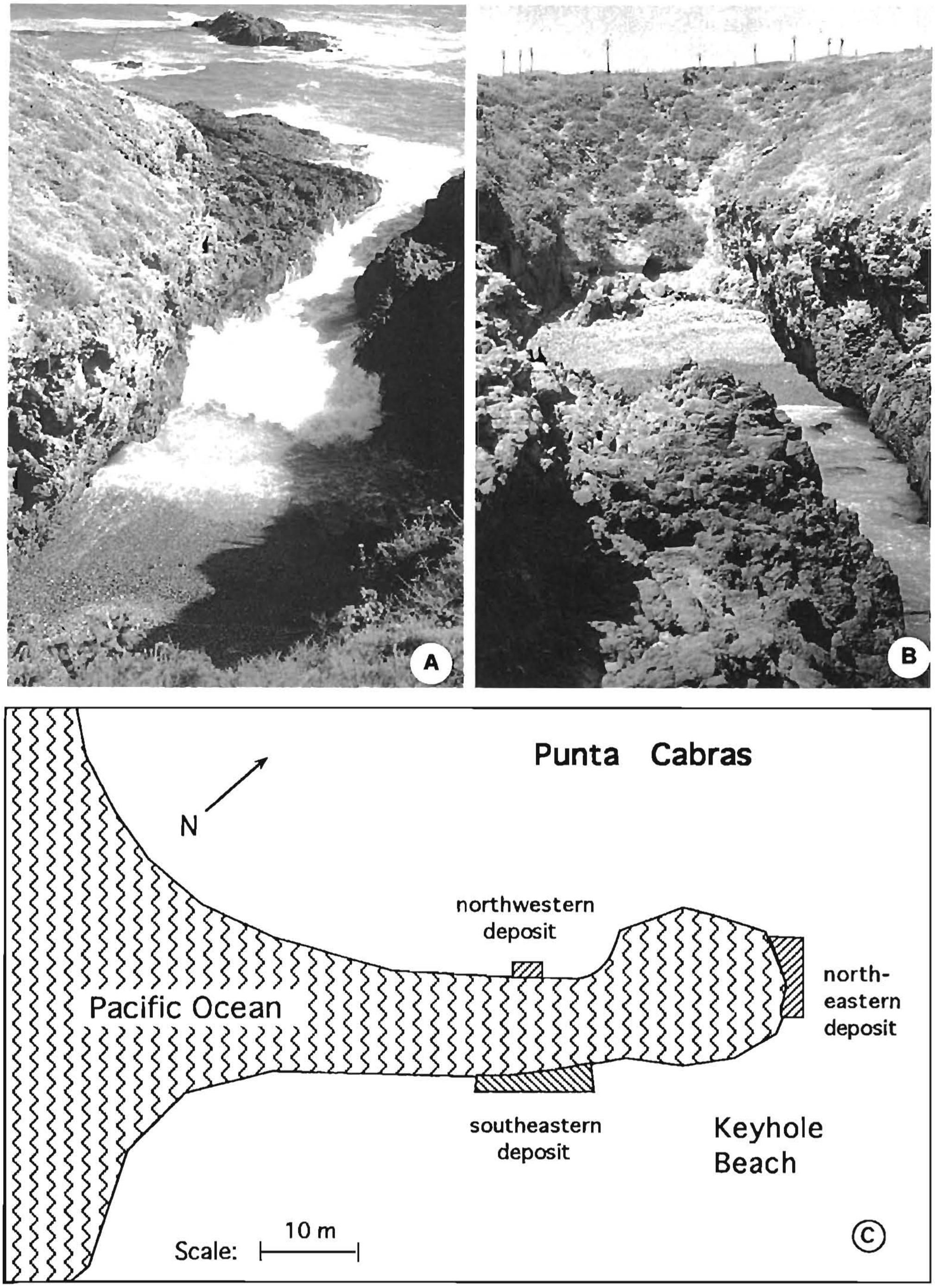


Figure 2. A. Seaward view of deep pocket beach (Keyhole Beach) incised in andesite on the tip of Punta Cabras, Baja California (Mexico). B. View of same beach looking landward. C. Map of the "keyhole" at Punta Cabras and its associated late Pleistocene deposits.

fixed in the matrix. Patches of the matrix may be traced over a width of 4 m across the bench and several meters up the side of the adjacent vertical wall. Little more than 1 m^2 of the same matrix with welded andesite clasts and mytilid shell fragments remains on a shallow bench on the opposite side of the inlet to the northwest.

From a stratigraphic point of view, the most intact Pleistocene outcrop is found abutting much of the back wall of the Keyhole (Figs. 2B and 3A). The base of the outcrop is covered by the modern beach, but a stratigraphic thickness of 3.36 m is well exposed. In fabric, the deposit is a shell bank dominated by fossil *Mytilus* debris with an admixture of rounded andesite cobbles and pebbles (Fig. 3B). The bank stretches laterally 7.5 m across the back wall. Due to a small cave eroded in the bank (behind figure in Fig. 3A), the other lateral dimension is known as not less than 1.8 m in depth.

At least five crudely stratified units are discernable, each with its own distinctive clast sizes of eroded andesite and variation in shell fragmentation (Fig. 4). Judging from the range in size of shell debris and andesite clasts, the depositional origin of each layer may be hypothesized. Intervals 1, 3, and 5 (Fig. 4) are similar in containing larger andesite pebbles and some cobbles floating in a coquina of relatively complete mytilid valves or large fragments thereof. Layers 1 and 5 also include some examples of the barnacle, *Megabalanus californicus,* with intact rim plates and basal plates showing attachment to mytilid shells. Rare whole specimens of the predatory gastropod, *Nucella emarginata* occur in layer 5. In contrast, layers 2 (Fig. 3B) and 4 include much smaller andesite clasts in the pebble to granule range mixed together with mytilid shells effectively reduced to coarse calcirudite.

From these relationships, it appears that water level was comparatively lower during the deposition of Units 1, 3, and 5. The environment of deposition probably corresponds to an upper foreshore and its berm, with the implication that larger shell fragments were better preserved and andesite clasts were less reduced in size. High tides swept whole valves onto the berm and large andesite clasts, which found their way there, had less time to be abraded into smaller particles.

Conversely, it seems likely that water level was comparatively higher during the deposition of units 2 and 4. The environment of deposition probably corresponds to the lower foreshore and surf zone. Shells and andesite clasts were subjected to longer periods of exposure in this environment within the zone of constantly breaking waves and, thus, were reduced to smaller sizes.

Analysis of Modern Sediments at Keyhole Beach

As a confirmation of the above hypotheses regarding formation of the homologous Pleistocene deposit depicted in Fig. 4, quantification of different rates of sedimentary processes across the upper surf zone and beach profile at the Keyhole is shown by the graphs in Figs. 5 and 6. The bar graphs presented in Fig. 5 relate to the disaggregation of *Mytilus* valves into different grades of coquina. The bar graphs given in Fig. 6 concern the erosion of andesite clasts into a range of size classes.

As explained above under methods but also noted pictorially by the insets in Fig. 5, the *Mytilus* data are arranged according to the size of shell fragments. Six separate sets of bar graphs are shown for each of the 6 size categories, with the 7 sample stations from the onshore-offshore transect differentiated by coded patterns. It is readily seen that the overwhelming majority of shell fragments are from the more anterior, thinner portion of the *Mytilus* valve (shell section #3). Within the bar graph for fragments originating from this part of the valve, station E reflects the highest concentration. The bar graphs for shell sections #1, #2, #4, #5, and #6 all show similar patterns to each other, with the largest number of fragments generally found at station B. These mostly larger and more robust fragments tend to show a depositional preference for the upper beach in zones of reduced contact with waves. Among these four, however, the least variability is demonstrated for the thickest part of the *Mytilus* valve with the hinge line (shell section #1). This fragment is able to persist through much of the shore face.

The graphs for shell section #6, however, tell even more about Keyhole Beach. This set of bar graphs represent the distribution of nearly complete *Mytilus* valves. Such valves were recovered only at three stations, A–C. While the overall numbers are low, it is clearly shown that the survival of entire valves is restricted to the three most onshore stations, where wave energy is the lowest.

Treatment of data for andesite clast size distribution across the upper surf zone and foreshore follows the same format as for the *Mytilus* shell fragments. Bar graphs are clustered into separate sets, spanning distributions for clast sizes at 0.5

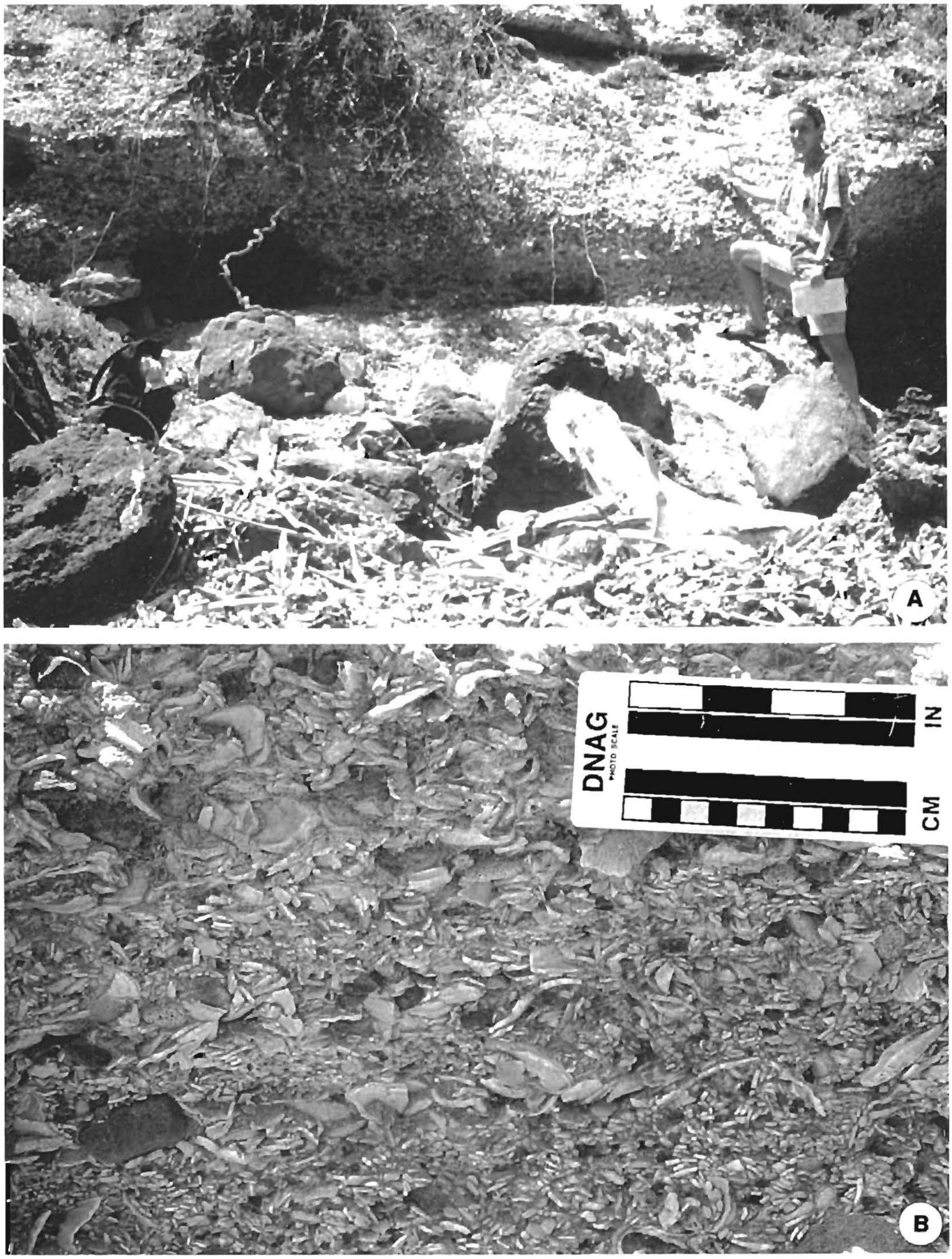
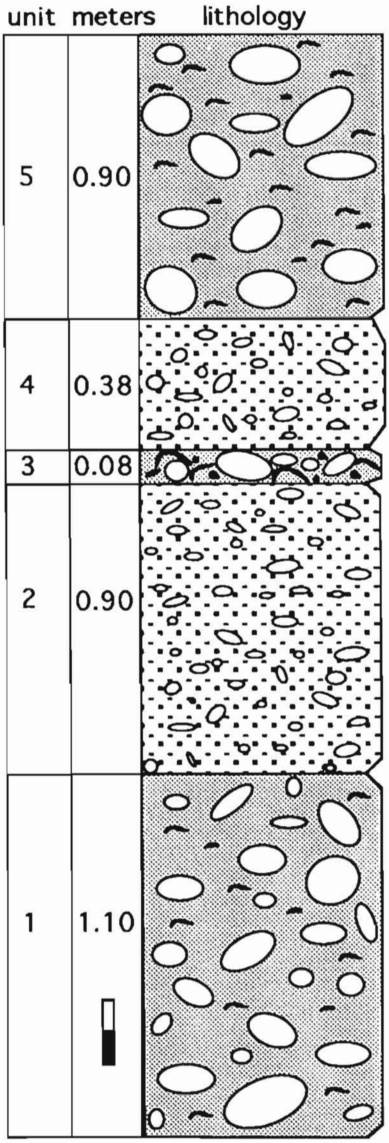


Figure 3. A. View of upper beach and deposit of late Pleistocene shell beds at the back of the "keyhole" on Punta Cabras. Fuller perspective of the same view is shown in Fig. 2B.
B. Close-up view of fossil *Mytilus* coquina intermixed with andesite clasts at Punta Cabras (unit 2).



unit	meters	description
5	0.90	Conglomeratic coquina, dark tan, calcarinite matrix, andesite cobbles ranging in diameter from 8 cm to 13 cm, *Mytilus californianus, Megabalanus californicus* and *Nucella emarginata.*
4	0.38	Calcirudite, tan, with very small shell fragments and scattered andesite pebbles ranging in diameter from 1 cm to 3 cm, *Mytilus* debris.
3	0.08	Conglomeratic coquina, dark tan, calcarenite matrix, andesite pebbles ranging in diameter from 3 cm to 10 cm, large fragments and whole valves of *Mytilus californianus.*
2	0.90	Calcirudite, tan, with abundant crushed *Mytilus* debris and abundant andesite pebbles ranging in diameter from 1 cm to 4 cm.
1	1.10	Basal conglomeratic coquina, tan, calcarenite matrix with andesite pebbles and cobbles ranging in diameter from 2 cm to 13 cm, large shell fragments of *Mytilus californianus* and *Megabalanus californicus.*

Figure 4. Stratigraphic profile of the Upper Pleistocene *Mytilus* beds from the "keyhole" at Punta Cabras. Vertical scale represents 20 cm.

cm intervals, from <0.5 cm to 6.0+ cm (Figs. 6A and 6B). It is readily apparent from these distributions that the overall frequency of clasts is markedly size dependent. Very fine pebbles (<0.5 cm in diameter) are exceedingly abundant, especially in stations E–G. Medium pebbles (1.5 cm to 3.0 cm in diameter) are much less common, but occur almost exclusively in stations A–D. A closer look reveals that sample stations D or E accumulate the most clasts in all the smaller size ranges. This result supports the observation that these stations experience maximum wave action, due to the fact that their central position on the beach insures constant energy input both when the tide rises and falls. The smallest pebbles, <0.5 cm in diameter, occur only in the three most offshore

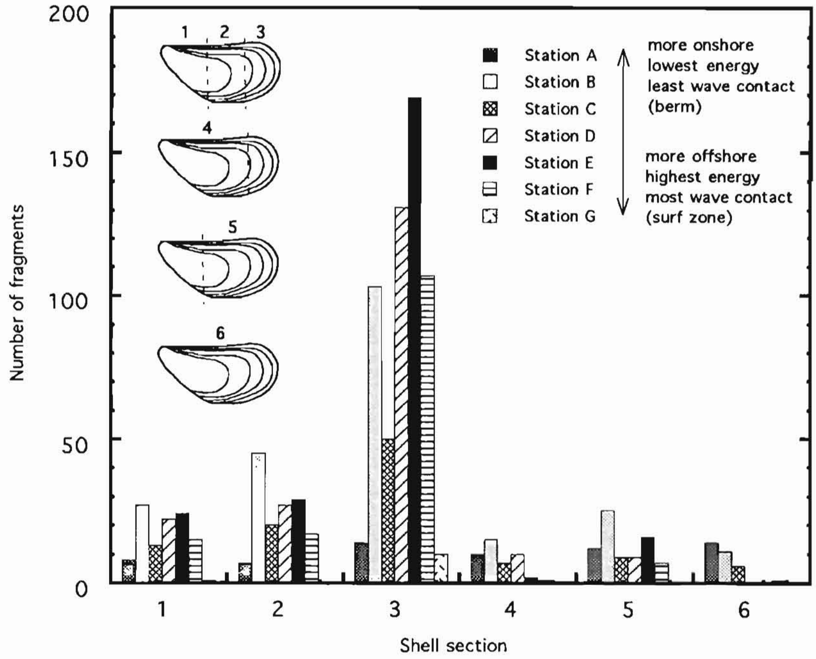


Figure 5. Set of histograms showing the distribution of *Mytilus* fragments at seven different sample stations from an onshore-offshore transect across the modern beach at the back of the "keyhole" on Punta Cabras.

stations (Fig. 6A), while the larger pebbles and few cobbles are found exclusively in the more onshore stations (Fig. 6B).

Quadrate Survey from Paseo Cueva

Paseo Cueva is so named for the coastal path below a local cave, which opens high on the face of the Punta Cabras promontory (Fig. 1). Dispersed over approximately 10 m^2 directly on a substrate of andesite below the path are Pleistocene fossils, including some encrusting red coralline algae and abundant *Petricola carditoides.* The andesite forms an uneven ramp, shown only in part by the photograph in Fig. 7A. Situated some 30 m back from the present line of wave attack during high tide, small tidal pools undergoing active salt precipitation are interspersed through the study site. Ocean water probably reaches this high onto the shoreline (+1.5 m) only during storms. The surface also exposes pockets of the same kind of calcium-carbonate cement matrix observed on the two benches flanking the northwestern and southeastern sides of the Keyhole (Fig. 2C). As at the Keyhole, scattered andesite clasts of various sizes are firmly welded in place by this cement.

Table 1 summarizes data collected from a survey of three sample quadrates of 1 m^2 each. Very distinct from the calcium-carbonate cement, an algal rind 2 mm or more in thickness covered 28% of one sample quadrate. The most unusual features are the bivalve borings, which penetrate vertically into the exposed andesite substrate. Only a few of the borings are empty. As many as 52 borings, occupied by single individuals of *Petricola carditoides,* were registered in a meter^2 quadrate. In some cases, the same boring was occupied by two or more generations of *P. carditoides,* as illustrated by the cross sections through two borings shown in Fig. 7B. Four or more generations utilized the same boring, using the wedging effect of the last occupant to push aside the valves of the immediate predecessors. This nestling behavior is noted in modern populations of *P. carditoides* (MORRIS *et al.,* 1980, p. 378). It cannot be proven that *P. carditoides* did anything other than occupy the borings. Following the claim of MASUDA (1968), however, some unknown pholad bivalve

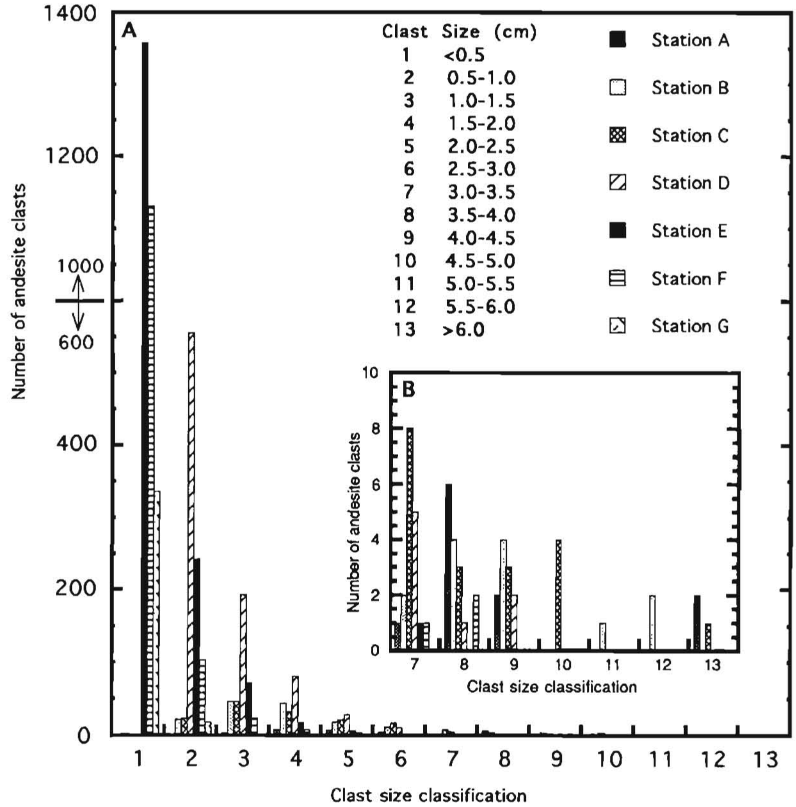


Figure 6. Set of histograms showing the distribution of eroded andesite clasts at seven different sample stations from an onshore-offshore transect across the modern beach at the back of the "keyhole" on Punta Cabras (A). Insert (B) shows range of larger clasts on an enlarged frequency scale.

must have excavated the original borings in the andesite substrate.

DISCUSSION

Ecological Coherence and Comparison with Other Examples

That the principle macrofossils discussed in this report are closely associated with geological nonconformities is well established by the photographic evidence (Figs. 2, 3, and 7). Comparisons with the ecology of extant species fully corroborate the argument that the nonconformities developed in rocky intertidal to shallow subtidal zones. Although the Keyhole deposit clearly signifies a transported death assemblage, its component species represent a coherent ecological story. According to MORRIS *et al.* (1980, pp. 282, 360 and 526), *Nucella emarginata* is strongly affiliated with mussel beds in the high and middle intertidal zones; *Mytilus californianus* occurs most abundantly in the uppermiddle intertidal zone on outer coasts, but may range to subtidal depths of 24 m, and *Megabalanus californicus* is uncommon in the low intertidal zone, but commonly ranges to a subtidal depth of 9 m. Although the mussel community is richly diverse (SUCHANEK, 1986), only these three species were recovered from the Pleistocene Keyhole deposit. They are among the same chief elements of the living community's matrix.

The setting of the Keyhole deposit may be likened to an over-sized neptunian dike (i.e. cross-cutting relationships in sedimentary rocks) filled with shell material transported from the nearby Pleistocene rocky intertidal and shallow subtidal zones, but deposited in a pocket beach. The only

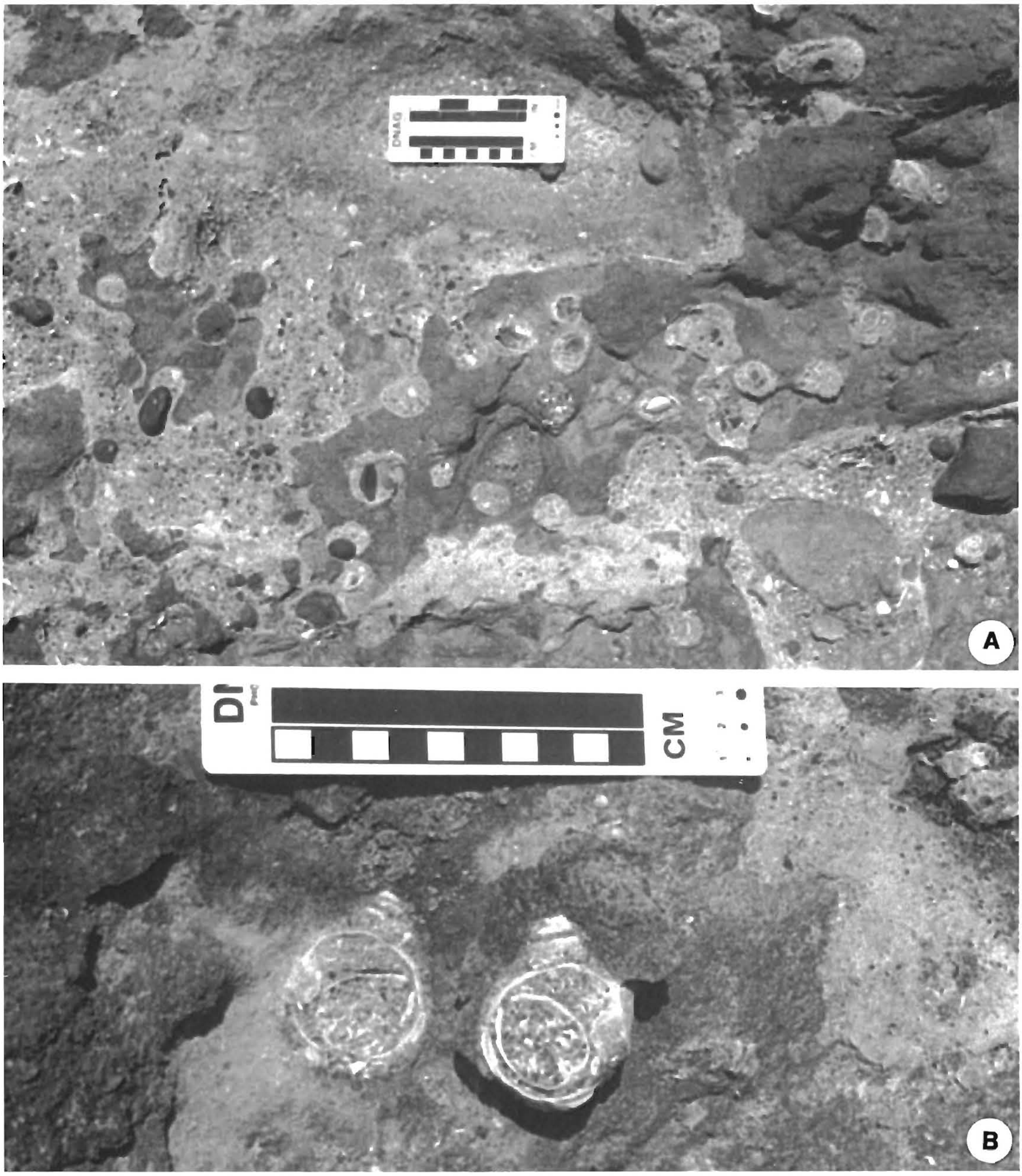


Figure 7. A. Andesite ramp at Paseo Cueva on the Punta Cabras promontory (see map, Fig.1), exposing abundant *in situ* borings filled with *Petricola carditoides* and encrusting rinds of red coralline algae. Scale is 10 cm long.
B. Close-up view of two vertical borings in andesite, occupied by multiple generations of the bivalve *Petricola carditoides*.

Table 1. *Pleistocene cover on andesite ramp at Paseo Cueva.*

Content	Meter^2 Quadrates Sample #1	Sample #2	Sample #3
Calcium matrix as a percent cover	37	28	72
Red coralline algae as a percent cover	0	0	28
Empty bivalve borings	3	9	0
Petricola carditoides (single generation)	52	41	6
Petricola carditoides (multiple generations)	9	11	0

other example of a fossil-rich, intertidal, neptunian dike is known from the Pleistocene of Western Australia, where fossil limpets comprise part of the organic fill (SCOTT and JOHNSON, 1993).

As a shell concentration, however, the Pleistocene Keyhole deposit is not quite like any other shell bank previously described. It comes closet to the "cross-stratified barnacle limestone facies" and associated conglomeratic sediments of Oligocene age in Oregon, as described by MILLER and ORR (1988). The *Mytilus* and barnacle remains in this facies account for a shell content of over 60%. The facies is in a nonconformable relationship with the Little Butte Volcanics. The Pleistocene Keyhole deposit at Punta Cabras is not cross bedded, and *Mytilus* remains probably account for not less than 95% of the shell content. Both examples generally fit the Type IV model of KIDWELL (1986, p. 10), in which shell beds "rest on a sharp erosion surface and grade upward with diminishing shell packing density into less fossiliferous sediments." This classification is not fully satisfactory, however, since the upward diminution of shell packing at Punta Cabras is due not to an influx of clastic sediments but rather to the more thorough disassociation of shell fragments into a calcirudite or calcarenite.

Living populations of *Petricola carditoides* typically dwell in the low intertidal and shallow subtidal zones of the Californias (MORRIS *et al.*, 1980, p. 378). Their co-occurrence at Paseo Cueva with algae encrusting a hard substrate is characteristic of a coastal abrasion platform. *In situ* communities well preserved in this kind of setting are rare in the stratigraphic record. Another good example of a coastal abrasion platform with encrusting red algae and associated bivalves is known from the Pleistocene of Western Australia (JOHNSON *et al.*, 1995). In this case, however, the bivalves are epifaunal oysters, and the platform exhibits oriented tidal rills or small channels. The Paseo Cueva ramp does exhibit an uneven surface but one without much suggestion of tidal rills (Fig. 7A).

Curiously, the absence of some faunal elements at Paseo Cueva may be more significant as an indicator of an open coast, high-energy setting. Immediately south of the Punta Cabras promontory, which Paseo Cueva is part of, fossil *Petricola carditoides* and the pholad bivalve *Penitella penita* are commonly associated with an abundant population of the gastropod *Olivella biplicata* in the shelter of the Punta Cabras embayment (ADDICOTT and EMERSON, 1959). According to VALENTINE (1980, p. 1314), "rocky-shore assemblages at sites where *O. biplicata* is relatively rare . . . presumably represent more exposed conditions" because large populations of that species tend to occur in "protected shores and lagoonal habitats as well as subtidally offshore."

Age of the Pleistocene Keyhole Deposit

Based on faunal indications of a colder hydroclimate than exists at the same latitude today (ADDICOTT and EMERSON, 1959), the age of the Pleistocene terrace near present sea level in the Punta Cabras embayment closely predates the oncoming of the last major glaciation. In terms of the chronology established by SHACKLETON and OPDYKE (1973), the timing suggests a correlation with oxygen isotope stage 5a. The neighboring Pleistocene deposits on the Punta Cabras promontory also occur close to present sea level and they must be virtually the same age.

The Keyhole deposit, however, is clearly cyclic in its stratigraphy (Fig. 4). Comparison to the homologous beach deposit presently accumulating within the Keyhole strongly implies lateral shifts in the surf zone and foreshore through time. The stratigraphic cycles could be due to the effect of major storms, but recurring storms on an extended time scale would tend to amalgamate the entire deposit. Another possibility is that the cycles are actually related to modest changes in sea level related to glacial flux. Under this scenario, Units 2 and 4 (Fig. 4) would represent small landward advances in the foreshore related to short warming trends. If so, the Keyhole sequence may involve a more complete record of transition near or during oxygen isotope Stage 5a.

SHERMAN *et al.* (1993) recently proposed evidence for two highstands in sea level during the last interglacial period, within oxygen isotope Stage 5e. Their work was based on laterally shifting beachrock and lagoonal deposits on the island of Oahu, in Hawaii. Comparable changes in sea level could be recorded by lateral shifts in the surf zone and foreshore on coastlines with moderate tides, as in the case of Baja California. Alternatively, such cycles could be related to small tectonic changes in the elevation of the shoreline.

Unfortunately, the prospects of dating fossils from the Keyhole deposit by the methods of uranium series ^{230}Th/^{234}U or electron spin resonance are not very promising. Aragonitic materials are very scarce.

CONCLUSIONS

Geological unconformities representing rocky shorelines are not necessarily rare in the rock record. The maximum highstand in sea level during the last interglacial period left unmistakable signs of coastal erosion on the granitic Seychelle Islands (MONTAGGIONI and HOANG, 1988) and cut a distinctive terrace around the perimeter of an exposed gabbroic pluton on the Gulf of California (ASHBY *et al.*, 1987). The same highstand was responsible for the development of abrasion platforms and the emplacement intertidal neptunian dikes in resistant coastal sandstones of Western Australia (SCOTT and JOHNSON, 1993; JOHNSON *et al.*, 1995). The fossil fabric which should be associated with these old rocky-shores is usually muted by erosion, especially where high-energy open coasts are concerned.

In this regard, the Upper Pleistocene record from the Punta Cabras promontory of Baja California stands out with superb examples of fossil preservation on an open rocky shore in marked contrast to more normal preservation on protected shores and embayments. The following conclusions may be reached:

(1) During late Pleistocene time, as today, the Keyhole formed a recess in the steep andesite coast and trapped a small pocket beach. Materials accruing to the deposit were eroded from the walls of the inlet and derived from the *Mytilus californianus* community living immediately outside the inlet on an open coast.

(2) The fossil deposit is completely dominated by *Mytilus* coquina, calcirudite, and calcarenite. It clearly represents a transported death assemblage. The presence of other fossil species, inducing a barnacle and a predatory gastropod, indicate that the signature of the *Mytilus* community is still ecologically coherent.

(3) Cycles recorded in the fossil Keyhole deposit relate to sedimentary processes ongoing in the accumulation of the modern Keyhole beach. Stratigraphic beds with larger andesite clasts and more intact *Mytilus* valves aggregated on the upper foreshore and berm of the beach. Intervals with smaller andesite clasts and reduced *Mytilus* debris were deposited in the lower foreshore and surf zone.

(4) Bay deposits adjacent to the Punta Cabras promontory have already been implicated as having formed during the waning years of the last interglacial period (ADDICOTT and EMERSON, 1959). Although precise dating of the fossil Keyhole materials is not feasible, correlation with oxygen isotope Stage 5a (SHACKLETON and OPDYKE, 1973) is likely. This conclusion awaits confirmation by better dating of appropriate materials from adjacent Half Moon Bay.

(5) In contrast to the fossil Keyhole deposit, fossils from nearby Paseo Cueva represent the remains of an *in situ* community, including red coralline algae and *Petricola carditoides.* A large population of the bivalve was preserved in borings penetrating an andesite ramp exposed to the open ocean. *P. carditoides* may not have excavated the borings, but their discovery indicates that the prior description of "sand pipes" in igneous rocks by MASUDA (1968) is not aberrant.

Mytilids and the more generic boring bivalves have a long history spanning much of the Mesozoic and Cenozoic eras. When did these invertebrates make the transition to a wave-swept habitat on rocky, intertidal shores? Preservation of late Pleistocene *Mytilus californianus* and *Petricola carditoides* macrofossils in an open rocky-shore setting begs the question for a more careful search of ancient rocky shores. Neptunian dikes, both in the more usual sense of the word and in the enlarged context of pocket-beach deposits, require greater attention from paleontologists. Unconformities of all kinds, including nonconformities on igneous rocks, are potential rocky shores with a fossil history.

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