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20. SHELL HORIZONS IN CENOZOIC UPWELLING-FACIES SEDIMENTS OFF PERU: DISTRIBUTION AND MOLLUSK FAUNA IN CORES FROM LEG 112[1]

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ABSTRACT

Shell layers in cores extracted from the continental margin off Peru during Leg 112 of the Ocean Drilling Program (ODP) show the spatial and temporal distribution of mollusks. In addition, the faunal composition of the mollusks in these layers was investigated. Individual shell layers have been combined to form shell horizons whose origin has been traced to periods of increased molluscan growth. It seems that the limiting factor for the growth of mollusks in upwelling regions near the coast of Peru is primarily the oxygen content of the bottom water. Optimal living conditions for mollusks are found at the upper boundary of the oxygen-minimum layer (OML). This OML in the modern sea ranges in depths from 100 to 500 m.

Fluctuations in the OML boundary control the spatial and temporal distribution of shell horizons on the outer shelf and upper continental slope. The distribution of mollusks depends further on tectonic events and bottom current effects in the study area. In the range of outer shelf and upper slope, these shell horizons were developed during times of lowered sea level, from the late Miocene through the Quaternary, especially during glacial episodes in the late Quaternary.

INTRODUCTION

Ten holes were drilled using the drill ship *JOIDES Resolution* during Leg 112, in November and December 1986, on the continental margin off Peru (Fig. 1). Various thicknesses of Cenozoic sediments were cored in water depths of 150 to 5000 m on the shelf and continental slope between 9° and 14°S. This cored material was used to establish the tectonic development of this convergent plate boundary and to identify paleoceanographic changes in the upwelling pattern during the Tertiary and Quaternary. Initial results from Leg 112 were summarized in von Huene et al. (1987), Emeis et al. (1988), and Suess, von Huene, et al. (1988).

Prominent shell layers containing calcareous gastropod and bivalve shells were found in certain horizons within relatively undisturbed sediment sections (Suess, von Huene, et al., 1988). The purpose of this study is to relate the distribution and generic composition of mollusks to the geologic and oceanographic development of the sedimentary environment during the Cenozoic. Special attention has been given to the following questions:

1. Under what oceanographic conditions do shell layers form?
2. At what times did these conditions exist?
3. What accounts for the different generic combinations found in the cores?

The distribution of mollusks on the shelf and continental slope off Peru is not well known. The few studies that have been published focus on either the present depth distribution of the entire macrobenthos (Frankenberg and Menzies, 1968; Kucheruk, 1982; Rosenberg et al., 1983) or the short-term effects of "El Niño" events on the overall ecosystem and on certain species of the present macrobenthos (Arntz et al., 1985). The studies of Keen (1971) and Olsson (1961) provided comprehensive reviews of the bivalve and gastropod taxonomy of the equatorial East Pacific faunal province, but contained little information about the ecology of the genera described.

SEDIMENTS AND OCEANOGRAPHIC REGIME IN THE STUDY AREA

Several sedimentary basins are located on the outer shelf and continental slope off Peru between 7° and 14°S. Extending along the shelf break is a crystalline rise that separates the shelf basins (Salaverry and East Pisco) from the slope basins (Trujillo, Lima, and West Pisco) (Thornburg and Kulm, 1981). These sedimentary basins are overlain by a zone of upwelling produced by strong southeasterly winds. The sedimentary facies in the basins are determined by upwelling intensity, influx of terrigenous sediment, and erosion. Figure 2 (adapted from Kulm et al., 1984) shows the various surficial sediments in the study area. An organic, carbon-rich, clay-ooze facies consisting of a hemipelagic, fine-grained, organic-carbon-rich diatomaceous mud is common in water depths of 100 to 500 m, between 11° and 15°S. A calcareous clay-ooze facies having a lower organic-carbon content and coarser sediment components dominates in the northern part of the study area, between 6° and 10°S at the same depth.

Cores from Leg 112 reveal variable thicknesses of Cenozoic deposits in the different sedimentary basins (Suess, von Huene, et al., 1988). The oldest sediments cored are middle Eocene. Following a hiatus during the Oligocene, the oldest sediments that display evidence of upwelling processes were deposited in the late Miocene. The early Miocene sequence is missing in cores from the northernmost transect at 9°S. The thickness of Quaternary sediments increases from north to south in the study area: at Site 684 (9°S), 14 m of Quaternary sediments were recovered, while at Site 686 (13°30′S), 300 m were retrieved. The sedimentary sequences are condensed into shorter sections toward the north, while higher sedimentation rates in the south have led to thicker sequences that provide a greater temporal resolution of the Quaternary. The combination of factors that determined the different stratigraphic and sedimentological sequences observed in the various basins is as follows: the tectonic development of the

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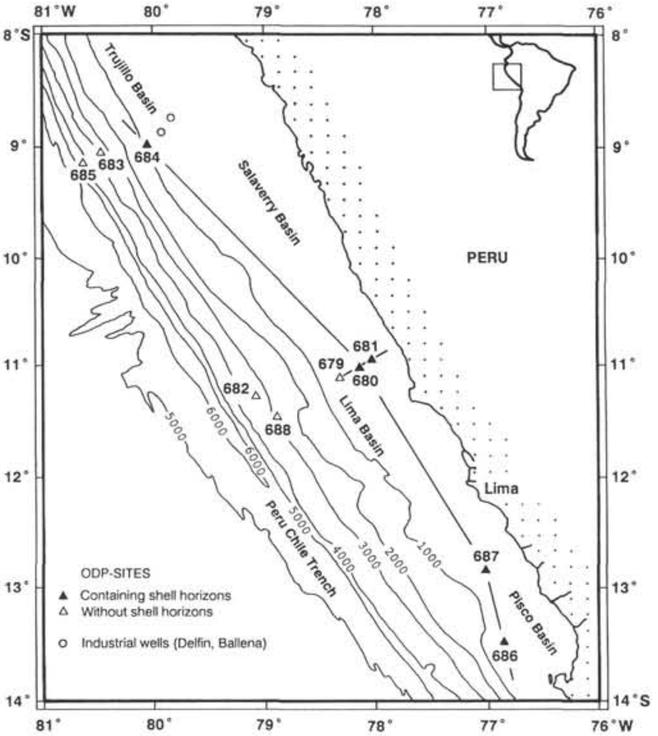

Figure 1. Positions of Leg 112 sites. The holes where mollusk shells were found and that were investigated in this study lie along a northwest-southeast profile (9° to 14°S), and along an east-west profile at 11°S.

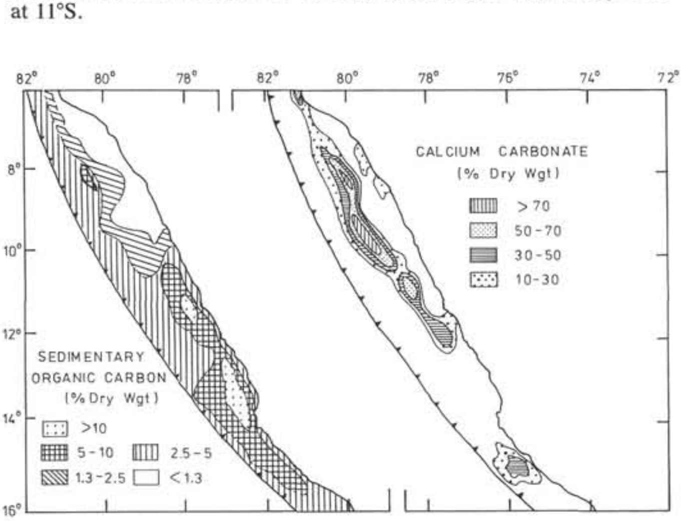

Figure 2. Distribution of the various sediment facies underlying the upwelling zone off Peru (from Kulm et al., 1984).

continental margin, the rate of bioproductivity (intensity of upwelling), and the polar-oriented bottom current (Suess et al., 1986).

CHANGES IN THE NEARSHORE UPWELLING SYSTEM

Fluctuations in the intensity of upwelling (bioproductivity) during the Quaternary are particularly well recorded in cores from the more southerly sites. Quaternary sediments consist primarily of organic-carbon-rich diatomaceous muds that display a cyclical sequence of alternately laminated and bioturbated horizons. Bioturbated sediments dominated in the early Pleistocene, while laminated deposits were more common in the late Pleistocene.

The decomposition of organic substances in the water column and on the bottom resulted in the production of an oxygen-minimum layer (OML) beneath today's main upwelling cell between 100 and 500 m (Zuta et al., 1978). The OML inhibits or even prevents the development of a benthos at these depths. Laminated and bioturbated sediments are interpreted as deposits within and outside the OML, respectively (von Huene et al., 1987). On this basis, temporal and spatial variations of the upwelling zone off Peru can be reconstructed from the sediment record, and in turn, changes in sea level and in the oceanographic regime during the Quaternary can be established.

BOTTOM CURRENTS

Poleward-flowing bottom currents have a pronounced influence on the broad, flat shelf in the northern part of the study area (Suess et al., 1986). As a result of current velocities in the range of 6 to 16 cm/s at a depth of 90 m, shelf sediments between 8° and 11°S are reworked, and the finer sediment fractions are washed out. In contrast to the northern region, the shelf between 12° and 14°S is relatively narrow (Thornburg and Kulm, 1981). In this southern area, current velocities in the direction of, and parallel to, the coast have very low values from 1 to 5 cm/s at the sediment surface (Suess et al., 1986).

METHODS

Initial Data from ODP Leg 112

Due to the available sample set, the distribution of the individual shell layers was extracted from core descriptions from Holes 680B, 681B, 684A, 684B, 686B, and 687B of Leg 112. These layers were combined into shell horizons and their positions are shown in core profiles (Figs. 3 through 7). These figures also summarize the information from core descriptions (Suess, von Huene, et al., 1988). The lithology was adapted in a simplified form, and the legend conforms to ODP's technical specifications (Rabinowitz et al., 1985). The stratigraphy is based on both magnetostratigraphic results (Brunhes/Matuyama boundary), and the diatom and coccolith biostratigraphy described in Suess, von Huene, et al. (1988). More detailed stratigraphic control is given by Heinze (unpubl. data) and Wefer et al., (this volume). Information about the depositional environment is derived from the data that were gathered aboard ship by processing core-catcher samples having a sample interval of 9 m (Suess, von Huene, et al., 1988). Supplementary data from Heinze (unpubl. data), Oberhänsli et al., Resig, Schrader, and Sorknes, (this volume), accomplish the data base about environmental changes. For comparison and to increase the mollusk data, the positions of the shell horizons in the cores from Holes 680A, 681A, 684A, 686A, and 687A were also noted in the core profiles.

Sample Processing

The sample material consists of 10 cm^3 syringe samples that were extracted on board the ship from the cores from Holes 679B, 680B, 681B, 684B, 686B, and 687B at about 50 cm intervals. A small number of samples were collected from shell layers in cores from Holes 680A, 681A, 682A, 683A, 684A, 684C, 685A, 686A, 687A, and 688E as well. Core samples from the B-holes were washed over a 63-μm sieve to perform analyses of the coarse sediment fractions, as well as isotopic analyses (Heinze, unpubl. data; Oberhänsli et al.; Wefer. et al., this volume). Subsequently, the available mollusk material >300 μm in size was hand-sieved and separated

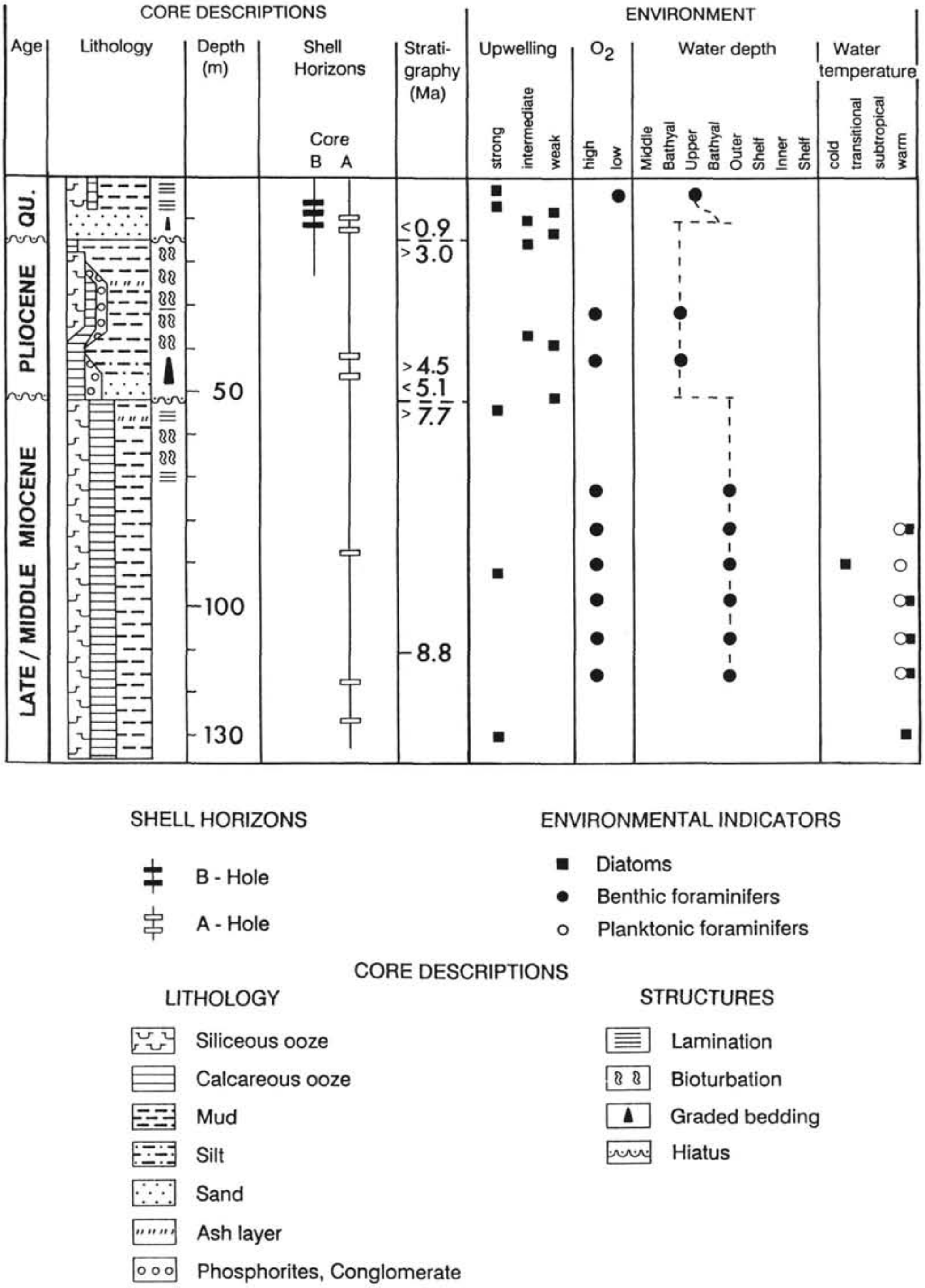

Figure 3. Profile from Site 684 (9°S) showing position of the shell horizons. Information about the environment is from the shipboard investigations (Suess, von Huene et al., 1988).

by sorting. Following calculation of the dry weight contribution of the >300-μm shell fraction to the total sample, well-preserved shell fragments, such as bivalve shells with intact hinges and whole gastropod shells, were identified and counted. Then, weight percentage contribution of each genus to the total shell fraction in each sample was calculated.

The standard literature for the East Pacific faunal province (Olsson, 1961; Keen, 1971) was used as a guide for taxonomic determinations. For every core sample from Holes 680B, 681B, 684B, 686B, and 687B containing mollusks, the weight proportion of mollusks to total sediment, as well as the frequency distribution of each genus, was determined. The weight proportion of the total molluscan material in samples from Holes 680A, 681A, 684A, 686A, and 687A was estimated on the basis of a 10-cm^3 sample volume. These values are only used to support conclusions based on the generic distributions in cores from Holes 680B, 681B, 684B, 686B, and 687B. The indicated depths of the samples from Holes 680A, 681A, 684A, 686A, and 687A reflect their positions in these cores. Finally, the mollusk genera were combined into faunal com-

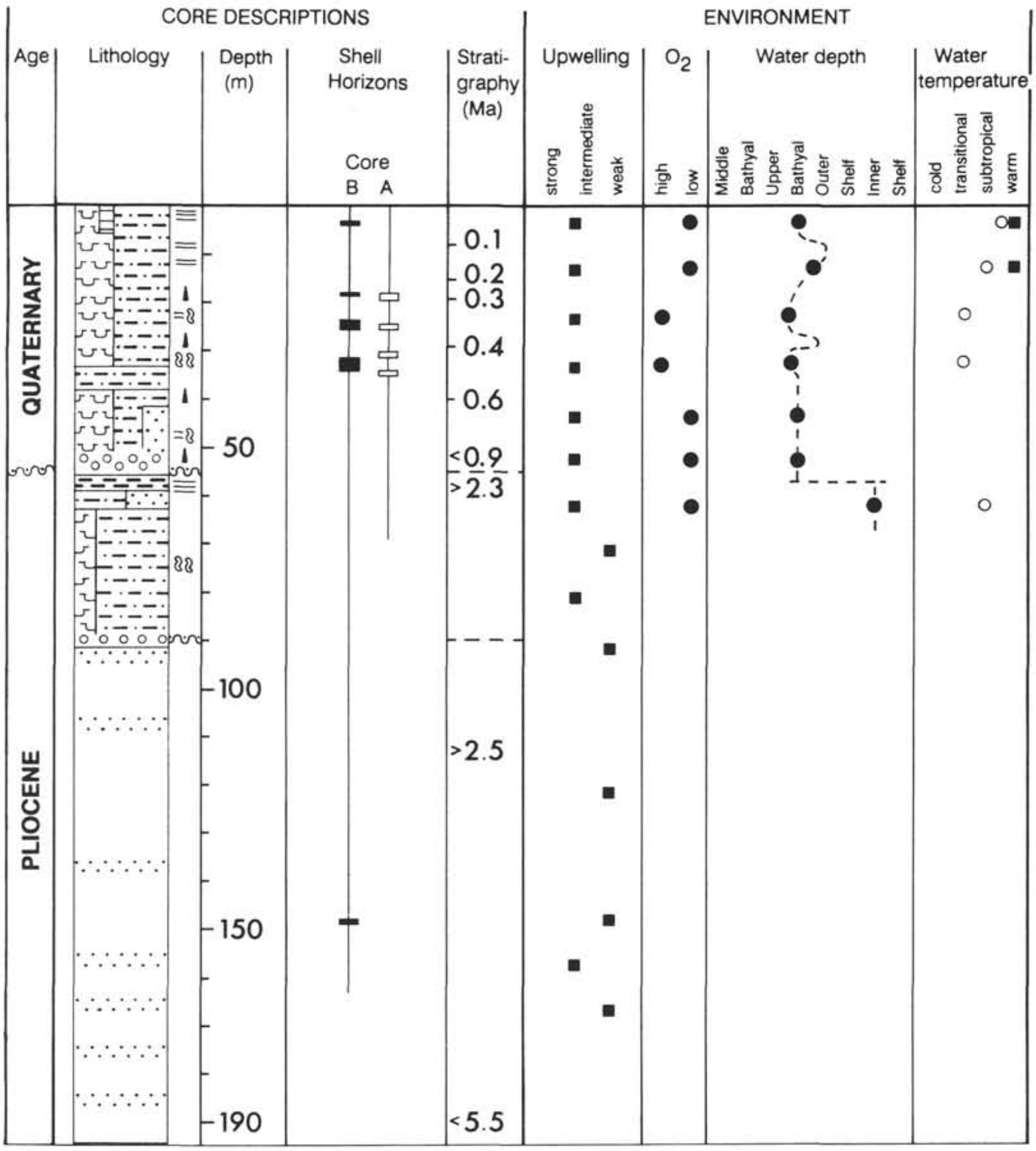

Figure 4. Profile from Site 680 (11°S) showing position of the shell horizons. The legend is the same as that shown in Figure 3.

munities, and their distribution in the cores from Holes 680B, 681B, 684A,B, 686B, and 687B was plotted.

RESULTS

Distribution of the Shell Horizons

No shell horizons were found in the cores of Sites 679 and 685. Sediment samples collected from core sections described as shell layers, from Sites 682, 683, and 688, contained no mollusk fauna. Therefore, presentation of results has been restricted to data from Sites 680, 681, 684, 686, and 687. For these sites, Table 1 provides an overview of the shell horizons described in Suess, von Huene, et al., (1988).

Sites 680, 681, 684, 686, and 687 sample the outer shelf and the upper continental slope (upper bathyal) along a northwest-southeast and an east-west transect (Fig. 1). Distribution of the shell horizons in the core profiles at 9°, 11°, and 13°S is shown in Figures 3 through 7 and described below.

Site 684 (9°S; 430 m Water Depth; Fig. 3)

Core recovery at Site 684 was 136 m. Because Hole 684B extended only to 33 m, data at greater depths originate from the cores from Hole 684A. Sediments consist mainly of calcareous and siliceous clay and silty oozes, whose succession is separated by two hiatuses. Immediately above these hiatuses, sections of graded bedding containing foraminiferal sands with glauconite and phosphorites are present. Proximal and below the hiatuses, increased phosphorite and bioturbation occur.

The hiatuses separate the middle Miocene from the middle Pliocene, and the middle Pliocene from late Quaternary. Each of the two time gaps encompasses a period of 2 to 3 m.y. Benthic foraminifers indicate a depositional environment having a water depth of around 150 m in the late Miocene, about 700 m in late Pliocene, and growing water depths from 300 m to 450 m in the late Quaternary (Resig, this volume). Bottom-water oxygen conditions are low in the late Miocene and latest Quaternary, and normal from late Pliocene to late Quaternary.

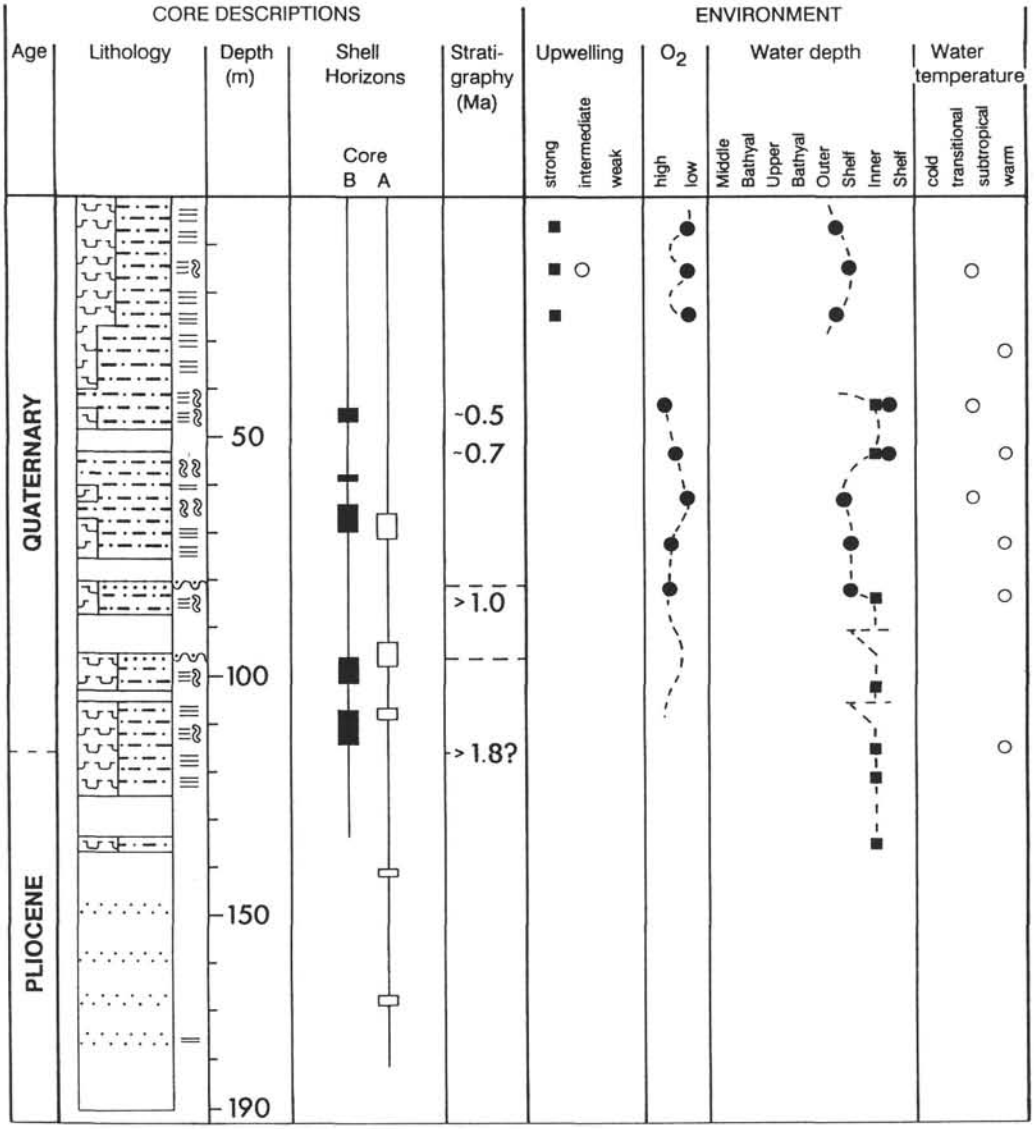

Figure 5. Profile from Site 681 (11°S) showing the positions of the shell horizons. The legend is the same as that shown in Figure 3.

Planktonic foraminifers and diatoms indicate warm surface water temperatures during the late Miocene.

Shell horizons are thin and concentrated in condensed sediment sections from late Pliocene and late Quaternary, containing diatomaceous, laminated to bioturbated mud, or glauconitic, sandy silt layers. These condensed sections indicate periods with stronger bottom currents reworking the sediments and increasing the bottom-water oxygenation (Heinze, unpubl. data; Oberhänsli et al., this volume). Individual shell layers, also within Miocene sediments, were observed in the deeper cores of Hole 684A. In this case, the sediments are described as typical "upwelling calcareous mud facies" (Suess, von Huene, et al., 1988), deposited on the outer shelf.

Sites 680 and 681 (11°S; 250 m and 150 m Water Depth, respectively; Figs. 4 and 5)

At both sites a borehole depth of 190 m was achieved. Since Hole 681B stopped at 135 m, its core profile is supplemented with data from Hole 681B. In the late Quaternary (up to 1 m.y. ago), both sites display the same cyclical sequence of dark-gray, laminated, diatom-rich clays and silts with a high organic carbon content. Gray, clastic silt layers having a higher terrigenous influx are interpolated within these sediments. At Site 680, the clastic layers contain thin sandy layers with phosphorites, while at Site 681, the same clastic sediments display evidence of greater bioturbation. This sequence is interpreted as representing typical Quaternary upwelling (Suess, von Huene et al., 1988).

The sedimentation rates amount from 7 to 15 cm/k.y. (Site 680, Wefer et al., this volume) and 8 cm/k.y. (Site 681) in the upper Pleistocene. The sequence is interupted by hiatuses in the early Quaternary. In the early Quaternary, the sediments at Site 680 display an increased terrigenous influx and the presence of phosphorite sands. Diatoms and benthic foraminifers indicate intense upwelling and oxygen-minimum conditions for the Quaternary at both sites, that are interrupted by short phases (0.3 to 0.6 Ma., Site 680 and 0.5 to 0.7 Ma, Site 681) having higher oxygen levels and weaker upwelling. Diatoms and benthic foraminifers indicate shallow shelf environment at Site 681 during this short period. Further fluctuations in water depth are noticeable only for the Quaternary at both sites.

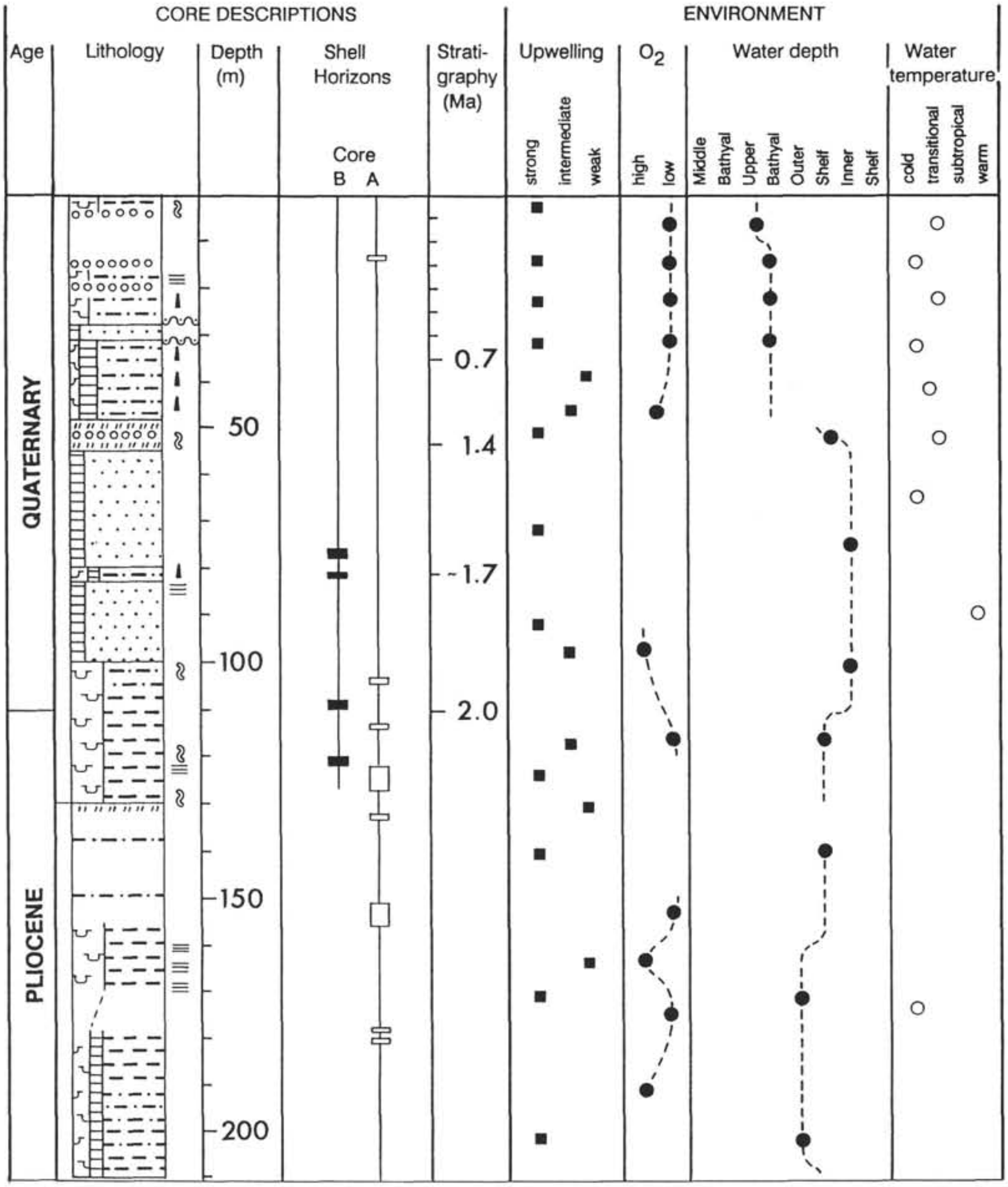

Figure 6. Profile from Site 687 (12°50'S) showing the positions of the shell horizons. The legend is the same as that shown in Figure 3.

Surface water temperatures during the Quaternary are governed by larger fluctuations than indicate at the other studied sites. While the sediments at Site 680 indicate only a warm-cold-warm cycle, three cycles in the Quaternary sediments can be resolved at Site 681, despite the large sampling interval.

The Pliocene begins at a depth of 55 m at Site 680, and a depth of 120 m at Site 681. These sediments consist of silty sands with interpolated diatomaceous muds, phosphorite layers, and authigenic carbonate. Core-catcher samples do not allow us to identify the Pliocene depositional environment reliably.

At Site 680, the shell horizons are present only in the late Quaternary, down to 0.7 Ma. One shell layer was found in the Pliocene section (112-680B-18X-CC). The shell horizons occur in condensed sediment sections, combined with diatomaceous to calcareous, thinly laminated muds, intercalated with feldspathic, phosphatic, sandy silt layers. A detailed study from Schrader and Sorknes (this volume) for the latest Quaternary shows that upwelling intensity was moderate at Site 680 when shell horizons were found. The shell horizons at Site 681 occur at 0.5, and between 0.7 and 1.8 Ma. Two shell layers were found in Pliocene sediments (Site 681A). The Quaternary shell horizons appear in sediment sections that consist of diatomaceous, laminated mud, intercalated with silty, bioturbated, diatomaceous to calcareous muds. Pliocene shell layers at Site 681 occur in phosphatic silt or sand with thin laminations. Benthic foraminifers from Hole 681A (Resig, this volume) indicate moderate to high bottom-water oxygenation for the Quaternary time periods when shell horizons occur. To summarize, the borehole profiles of Sites 680 and 681 reveal that the shell horizons appear more frequently at times of outer shelf (water depth 150 m, Site 681) to upper slope (water depth 250 m, Site 680) environment during the Quaternary. At

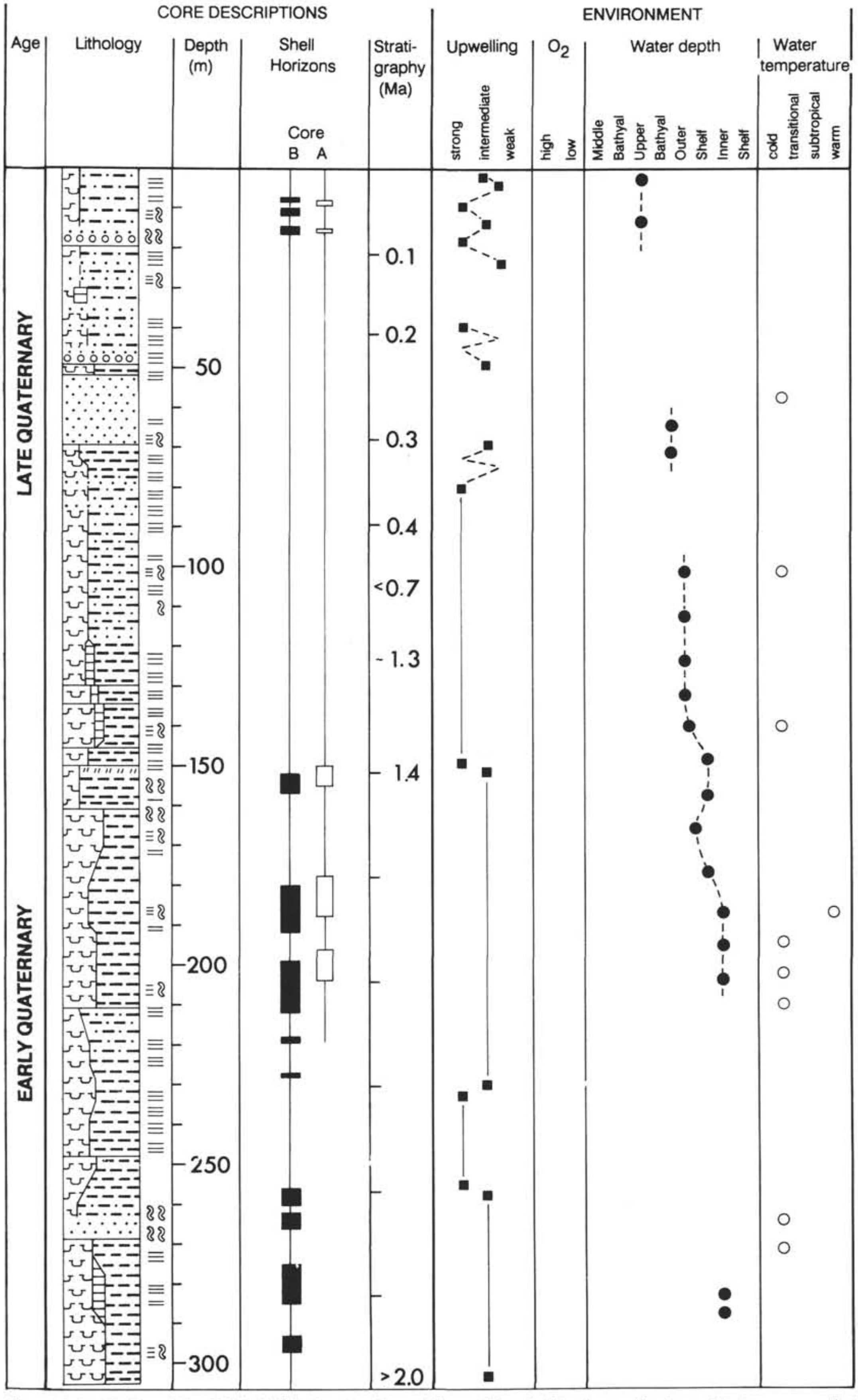

Figure 7. Profile from Site 686 (13°30′S) showing the positions of the shell horizons. The legend is the same as that shown in Figure 3.

Table 1. Distribution of shell horizons.

		Generic distribution				
Depth in core (m)	Age (Ma)	Total shell fraction (ϕ wt%)	*Nuculana*/ *Aequipecten* (ϕ wt%)	*Pitar*/ Veneridae (ϕ wt%)	Gastropods (ϕ wt%)	Sediment (Core descriptions Leg 112)
Site 680 (water depth, 250 m)						
3.1–3.3	[a]18 k.y.	<0.1	—	—	—	Diatomaceous mud, laminated, sand layers, calcareous, foraminifers
24.0–25.0	[a]0.35–0.36	10.8	90	—	0.5	Diatomaceous mud, graded silt- and sand layers
31.0–34.0	[a]0.43–0.52	0.4	82	—	—	Diatomaceous mud, sand layers, phosphorites
148.0	4.0	3.4	70	—	—	Mud, olive gray, sandstone and phosphorite fragments
Site 681 (water depth, 150 m)						
44.0–46.5	[b]0.43<?<0.7	0.8	—	—	—	Diatomaceous mud, intercalated in silty bioturbated mud
63.0–71.5	[b]0.78–0.84	0.1	—	16.5 (Max. 70%)	—	Dark gray silty mud, bioturbated, calcareous
96.0–100.0	1.0<?<2.0	0.1	—	13.0 (Max. 47%)	— (1 × 1.3%)	Laminated diatomaceous mud, gravel and phosphorite fragments
105.5–113.5	1.0<?<2.0	0.4	—	— (1 × 25%)	—	Olive gray diatomaceous mud
139.5–141.0	Pliocene	[c](1.5)	—	18	—	Black silt, sandy, thinly laminated
168.0	Pliocene	[c](0.8)	—	1	—	Dark gray sand, silty
Site 684 (water depth, 430 m)						
6.0–8.5	0.3<?<0.9	0.1	—	—	—	Olive gray diatomaceous mud, intercalated with graded sands
10.5–12.0	0.3<?<0.9	2.1	90	—	0.3	Olive gray sand, phosphorites, bioturbated mud layers
46.5	4.5<?<5.1	[c](40)	—	—	—	Diatomaceous mud, sand layers, silty, foraminifers, phosphorites
88.6	7.7<?<8.8	[c](0.5)	100	—	—	Siltstone, calcareous, phosphorite fragments
126.6	>8.8	[c](1.0)	65	—	—	Dark olive diatomaceous mud, mixed with sandstone fragments
Site 686 (water depth, 450 m)						
7.0–7.5	14–16 k.y.	0.9	67.5	—	—	Olive gray, bioturbated diatomaceous mud, foraminifers, silt layers, phosphorites
13.5–14.0	80–82 k.y.	<0.1	100	—	—	Laminated to bioturbated diatomaceous mud, sandy, phosphorites
16.0–16.5	91–93 k.y.	0.4	100	—	—	Laminated to bioturbated diatomaceous mud, sandy, phosphorites
179.5–186.0	1.45–1.48	2.5	—	18.5	—	Laminated to bioturbated diatomaceous mud, sandy, dolomitic
187.5–192.5	1.48–1.51	6.6 (Max. 30)	—	—	14 (Max. 56%)	Dark olive diatomaceous mud
198.5–207.5	1.55–1.59	3.4	—	—	1 (Max. 5.5%)	Dark olive diatomaceous mud, silty, sand layers, dolomitic
259.0–263.0	1.84–1.86	[d](30)	—	—	—	Diatomaceous mud, silty, bioturbated, sand layers, dolomitic
278.5–279.0	1.95	13	—	81	—	Laminated, olive gray diatomaceous mud, dolomitic
283.1	2.0	3	—	—	52	Laminated, olive gray diatomaceous mud, dolomitic
Site 687 (water depth, 310 m)						
76.5–78.0	1.7	0.3	—	3	—	Black diatomaceous mud, bioturbated, sand layers, silty, dolomitic
103.5–104.5	1.8 (687A)	[d](0.9)	—	—	98	Silt, gray, bioturbated, graded lithogenic sand layers
109.9	2.0 (687B)	0.3	—	—	—	Olive gray diatomaceous mud
113.5–114.0	1.9 (687A)	[d](6.7)	—	—	—	Olive gray mud, bioturbated, silt layers
120.0–121.0	2.1 (687B)	0.3	—	—	—	Diatomaceous mud, calcareous, bioturbated, sand and silt layers, dolomitic
153.7	Pliocene	[d](0.5)	—	—	—	Olive gray mud, silty, bioturbated, dolomitic

[a] Values from Wefer et al. (this volume).

[b] Values from Heinze (unpubl. data).

[c] Extrapolated weight percent from A core samples.

[d] Extrapolated weight percent of A and B core samples.

both sites, less intense upwelling is indicated for the core sections where shell horizons are present. Due to poor core recovery the few shell layers that were deposited in the Pliocene could not be assigned either to specific sedimentological, or environmental, characteristics. However, there are some hints for moderate upwelling (Suess, von Huene, et al., 1988) and shallow water depths (Resig, this volume).

Site 687 (12°50′S; 310 m Water Depth; Fig. 6)

In both Holes 687A and 687B, a depth of 200 m was reached. Sediments from these holes consist of a dark-gray, laminated diatomaceous mud that is interrupted by layers of calcareous sand/silt. Phosphorite pebbles are often present on single erosional surfaces. In Hole 687B, the Quaternary/Pliocene boundary is situated at a depth of 110 m, while in Hole 687A, it lies at 130 m. A further biostratigraphic division of the Pliocene, or dating of the Pleistocene, was not possible. The Brunhes/Matuyama magnetic boundary at 0.7 Ma lies beneath two hiatuses. The ash layer at 50 m was radiometrically dated at 1.4 Ma (Suess, von Huene et al., 1988). The biostratigraphy of Site 687 gives an age of less than 0.9 Ma for a core depth of 50 m. This age, together with the Quaternary/Pliocene boundary at a 110 m core depth, was used to calculate a sedimentation rate of about 6.5 cm/k.y.

Changes in the sedimentary environment, as reflected in the lithology, are supported by changes in the microfossil fauna. The most distinct trend is apparent in variations of the water depth. Benthic foraminifers (Resig, this volume) indicate a development from outer shelf environment (water depth 100–150 m) during the late Pliocene, to water depths characteristic of the inner shelf (80 m) during the middle Quaternary, to Holocene water depths of 310 m (upper bathyal). Poor oxygen conditions are particularly prevalent during the late Pleistocene. The lithology and abundance of diatoms suggest the occurrence of intense upwelling during the Pliocene and Quaternary. This was interrupted by periods of weaker upwelling between 0.7 and 1.0 Ma, and between 1.4 and 1.9 Ma, when shallow shelf conditions prevailed. The cold-water and transitional forms of planktonic foraminifers indicate cold surface water temperatures in the late Quaternary.

Suess, von Huene, et al. (1988) reported that the abundance of shell layers differs from Hole 687A to 687B descriptions. This probably results from the lower core recovery in Hole 687B. In the Pliocene and earliest and latest Quaternary, single-layer shell horizons occur. Shell horizons are absent in the middle Pleistocene, at which time shallower water depths prevailed and coarser, calcareous sediments were deposited. These shell horizons are found in diatom-rich upwelling sediments in core sections, having greater bioturbation and a higher proportion of sand/silt than laminated diatomaceous muds. In Figure 6 the positions of the shell horizons within cores from Holes 687A and 687B do not coincide with one another, due to a displacement of 20 m of the Pliocene/Quaternary boundary.

Site 686, (13°30′S; 450 m Water Depth; Fig. 7)

Cores of Site 686 document a complete Quaternary sedimentary sequence in the central upwelling region off Peru. Hole 686A reached a depth of 210 m, while Hole 686B stopped at 305 m. Wefer et al. (this volume) have calculated a sedimentation rate of 15 cm/k.y. for the late Quaternary above 120 mbsf and 100 cm/k.y. below.

The sediments consist of dark diatomaceous mud that, in bioturbated intervals, have been interpolated with sand or silt layers, or are subdivided into laminated sequences with phosphorite layers. These intervals are composed of small cyclical series of laminated and bioturbated sediments. The large intervals probably represent times of highest and lowest sea levels (von Huene et al., 1987), while the durations of smaller cycles suggest a correspondence to glacial/interglacial periods in the Quaternary.

The lithologic upwelling record is based on laminated vs. bioturbated sediment sections, where laminated intervals represent low oxygen conditions and strong upwelling and bioturbated intervals indicate higher bottom-water oxygenation and reduced upwelling intensity. Diatom abundances and benthic foraminifers provide more detailed information about upwelling intensity, bottom-water oxygenation, and changes in water depth (Schrader and Sorknes, Resig, this volume). The distribution of the benthic foraminifers suggests a continual increase in water depth during the Quaternary in the West Pisco Basin. The subsidence amounts to 400 m in the last 2 m.y. As was the case at Site 687, planktonic foraminifers indicate low surface-water temperatures. Fluctuations between cold-water and transitional forms of planktonic foraminifers are not particularly distinct.

Shell horizons are most predominant in the time intervals between 15 and 100 k.y., and between 1.4 and 2.0 Ma. A distinct correlation exists between the occurrence of shell horizons and that of silty, bioturbated diatomaceous mud sediments. These were not present in laminated diatomaceous oozes and at the time of greatest subsidence, between 0.1 and 1.4 Ma. The shell horizons from the latest Quaternary appear in sediment sections where moderate upwelling intensity is indicated by diatoms (Schrader and Sorknes, this volume). Note that these shell horizons occur at a water depth of 450 m (Resig, this volume). Thick shell horizons from early Quaternary, also occur at times of reduced upwelling intensity (see Fig. 7: 150 through 230 mbsf, and 255 through 300 mbsf), but benthic foraminifers indicate water depths of about 100 m (Resig, this volume).

Composition of Shell Horizons

Sample Sizes and Shell Proportions

The shell horizons described in the "Distribution of Shell Horizons" section (this chapter) were almost entirely sampled in cores from Holes 680B through 687B, with sampling intervals of 10 cm to 1 m. Shell horizons that were not sampled in these cores were usually supplemented by corresponding samples from Holes 680A through 687A, although no complete sample set was available. A listing of all core samples containing molluscan shell material from all holes of Sites 680, 681, 684, 686, and 687 is given in Schneider (1988).

The samples of approximately 10 cm^3 volume weigh between 2 and 15 g, while the weights of the shell proportions >300 μm vary from <0.1 mg to 10 g. The accuracy of the weight measurements is ± 0.1 mg. The resulting shell contributions to the total sediment in each sample range between <0.1 and 60 weight percentage. Well-preserved (identifiable) mollusk shells constituted <0.1 to 100 wt% of the total shell material >300 μm. These fluctuations result primarily from size differences in the shells of the various genera, which range between 0.3 and 30 mm.

Bivalves and Gastropods

The following bivalve genera and subgenera were identified on the basis of single valves with intact hinges:

1. *Nuculana (Saccella)* sp. (Pl. 2, Fig. 1): 0.5–2.0 cm size; in some cases both valves preserved; ecology: infaunal, sediment feeder, soft substrate.
2. *Aequipecten* sp. (Pl. 2, Fig. 2): 0.3–2.0 cm size; strongly corroded; ecology: epifaunal (free/byssate), suspension feeder, hard or soft substrate.
3. *Pitar* sp. (Pl. 2, Fig. 3): 0.5–3.0 cm size; often only the hinge and umbo were preserved intact; ecology: infaunal, suspension feeder, soft substrate.
4. Unidentified venerids.

The gastropod genera listed below were identified on the basis of well preserved gastropod shells:

1. *Calyptraea (Calyptraea)* sp. (Pl. 2, Fig. 4): 0.3–4.0 cm size; the large specimens were incomplete and only preserved with the shelf; ecology: epifaunal (free), algae feeder, hard substrate.
2. *Cosmioconcha* sp. (Pl. 2, Fig. 8): 0.3–1.0 cm size; shell structures poorly preserved; ecology: epifaunal (free), hard substrate.
3. *Epitonium* sp. (no figure): 3–6 mm size; well-preserved shell structure, aperture is missing; ecology: epifaunal (free), hard substrate.
4. *Nassarius* sp. (Pl. 2, Fig. 6): 0.8–1.2 cm size; excellent shell preservation; ecology: epifaunal (borer), soft substrate.
5. *Odostomia* sp. (Pl. 2, Fig. 5): 3–8 mm size; good preservation of the initial chambers, no surface structures were recognizable; ecology: epifaunal (free), parasitic or hard substrate.
6. *Polinices* sp. (Pl. 2, Fig. 7): 1 cm size; only one specimen with bore traces; ecology: infaunal (free), soft substrate.

Ecological data from McKerrow (1978) and Kidwell (1986).

Amount of Shell Material and Distribution of Mollusks

For each shell horizon the contribution of shell material to the total sediment, and the bivalve and gastropod distributions as weight percents of the total shell fraction >300 μm are described below.

Site 684 (9°S; 430 m Water Depth)

Six shell horizons between 6 and 12 m were sampled in cores from Hole 684B. The weight contributions of the shells to the sediment increase with the age of the samples. Only three individual samples from the Pliocene and Miocene were available from Hole 684A. The mollusks from the Miocene through the Quaternary sediments are restricted to the genera *Nuculana* sp., *Aquipecten* sp. (bivalves), and *Cosmioconcha* sp. (gastropod) in both Holes 684A and 684B. The identifiable proportion of the shell material ranges between 65 and 90 wt% in the individual samples.

Site 680 (11°S; 250 m Water Depth)

Samples containing mollusk shells from Site 680 are mostly from the late Quaternary. Pliocene mollusk shells only appeared in one core sample from Hole 680B. The shell contribution to the total sediment fluctuates between 0.1 and 11 wt% in the shell horizons. Only a minor shell proportion was found in core sections from latest Quaternary. Both Holes 680A and 680B contain the same faunal community as at Site 684: *Nuculana* sp., *Aquipecten* sp., and *Cosmioconcha* sp. The identifiable shell proportions were of equivalent size in both holes (60 to 90 wt%). The contributions of the various genera to the individual samples from Holes 680A and 680B were also in general agreement.

Site 681 (11°S; 150 m Water Depth)

The Quaternary shell horizons are recorded by core samples from Hole 681B. Three samples containing shell material were collected within Pliocene sediments from Hole 681A. The shell contributions vary between <0.1 and 3 wt%. Only bivalves of the family Veneridae, and abundant individuals belonging to the genus *Pitar* sp., could be identified in the shell material from Pliocene and Quaternary sediments. A single gastropod of the genus *Cosmioconcha* sp. occurred in a sample from a depth of 97 m (Section 112-681B-12X-1). The identifiable shell proportion in samples having well-preserved mollusks is between 1 and 70 wt%.

Site 687 (12°50′S; 310 m Water Depth)

In Holes 687A and 687B only a few samples having mollusk shells were found to represent different shell horizons. Shell contributions to the total sediment were small (<0.1 to 1 wt%), with the exception of one sample with 15 wt% at 113.5 m core depth. The identifiable proportions of the total shell material were also low, with <0.1 and 5 wt%. In four core samples from Sections 112-687A-12X-1 and -12X-2, well-preserved gastropods of the genera *Nassarius* sp. and *Polinices* sp. were found. Only a few poorly preserved bivalves of the family Veneridae occurred in the remaining samples.

Site 686 (13°30′S; 450 m Water Depth)

The proportions of mollusk shells in the individual samples from this site show distinct fluctuations within shell horizons. The samples at 260 and 279 m lacked a portion of the total sediment volume; therefore, the shell proportions of the two samples are based on a total volume of 10 cm^3. Shell proportions in the latest Quaternary shell layers are relatively small compared with those in early Quaternary shell layers. They are separated by a 160-m core interval that contains no shell material. Distribution of bivalves and gastropods shows two distinct changes. Samples from latest Quaternary contain only pectinids and a little heterogeneous shell material, while the bivalves in the early Quaternary (150 through 300 mbsf) are all venerids, while some are more accurately identified as the genus *Pitar* sp. The unidentifiable proportion of the shell fragments contributes 60 to 100 wt% in the deeper samples. The second important change is the large abundance of gastropods between 186 and 203 m in the core. The genus *Calyptra* sp., which also occurs in the deeper core samples, contributes the highest weight proportions. Other genera do not reach considerable proportions by weight because of their smaller sizes.

Faunal Communities

The distribution of the bivalve genera allows us to discriminate two communities. The *Nuculana-Aequipecten* community occurs at Sites 680 and 684 from the Miocene through the Quaternary and at Site 686 in the latest Quaternary. The second community, composed of genera from the family Veneridae and dominated by the genus *Pitar* sp., was found in cores from Sites 681, 686, and 687 in early Quaternary sediments. Late Quaternary sediments from Site 681 likewise contain a venerid community. Gastropod shell material only occurred in significant amounts at Sites 686 and 687, where it was concentrated in sediments from the early Quaternary.

Only a few specimens of the genus *Cosmioconcha* sp. were found in late quaternary sediments from Sites 680 and 684.

The macroscopic shell structure of the unidentifiable fragments of bivalve and gastropod shells indicate that no other genera occur and that a mixture of the two bivalve communities within individual samples is unlikely.

To summarize these data, the values from the individual shell layers were recalculated to average values for the depth intervals of the shell horizons, following identification of the mollusk communities (Table 1).

DISCUSSION

Sample Sizes

Sorted shell material was insufficient for a statistical analysis. Large fluctuations in the dry weight results primarily from the small, 10-cm^3 sample sizes. To determine the depositional environment from the generic composition and distribution of mollusks, 200 to 300 g of core sample material is required (Petersen, 1986). Arntz et al. (1976) used about 0.5 to 15 kg of sediment per sample in their comparison of the shell proportions of living mollusks with dead mollusks in Kiel Bight.

The numbers of individuals that were counted in the 10-cm^3 samples (Schneider, 1988) also were too low for a statistical analysis. To identify the depositional environment more accurately, faunal communities of at least five or six genera and 50 to 100 individuals per sample are required. These numbers occurred in only five core samples from Holes 680B and 686B. Nevertheless, this sample material provides important data regarding the oceanographic development of the sedimentary environment during the Cenozoic.

Origin of Shell Horizons

In the section, "Distribution of Shell Horizons" (this chapter) we show that shell horizons occur only in sediment sections characteristic of a moderate upwelling facies: diatomaceous calcareous muds at Sites 680 and 684 or diatomaceous organic-carbon-rich muds at Sites 681, 686, and 687. These sections also display strong bioturbation and coarser sediment fractions. Sediments containing mollusk shells were deposited at water depths from 100 to 300 m (Site 686: also 450 m). Shell layers are absent from sediments showing intense upwelling (massive laminated diatomaceous muds, von Huene et al., 1987, Site 686B), and in terrigenous, coarse-clastic sediment horizons with no, or a small, upwelling component. They were not found in sediments from water depths <100 m and >450 m. From core descriptions (Suess, von Huene, et al., 1988) it is apparent that the shell layers are concentrated in condensed sediment sections, influenced by bottom currents (Oberhänsli et al., this volume) at Sites 680 and 684. Shell layers were found in transition zones between laminated and bioturbated sediments at Sites 681, 686, and 687. Table 2 lists the core sections where these lithologic features are described in detail by Suess, von Huene, et al. (1988). These sections are also characterized by changes in the proportions of diatoms (Schrader and Sorknes, this volume) and benthic foraminifers (Resig, this volume).

The change between laminated (little or no benthic colonization) and bioturbated (larger benthic colony) sediment, bottom current influenced sediments, and decrease in abundance of the benthic foraminifer *Bolivina* sp., indicative of low oxygen levels (Resig, 1981; Mullins et al., 1985), can be accounted for by changes in the oxygen content of the bottom water and surface sediment layer. So we assume that sediments containing shell horizons indicate an outer shelf to upper slope environment with reduced upwelling intensity and moderate oxygenation of bottom water.

Table 2. List of condensed or laminated to bioturbated sediment sections containing shell layers.[1]

Cores	Depth (mbsf)	Sediment structure
122-680A-3H	18.0–25.0	Condensed sections, above and below laminated.
680A-4H	31.0–36.5	
112-680B-3H	16.5–24.5	Condensed section.
680B-4H	33.5–34.0	Condensed section.
112-681A-8H	65.0–72.0	Laminated to bioturbated section.
681A-11H	93.0–98.5	Laminated to bioturbated sections, below laminated.
681A-12H	107.2–110.5	
681A-16X	140.0–141.0	Condensed section, below laminated.
112-681B-7H	57.0–59.5	Laminated to bioturbated section.
681B-8H	63.8–72.5	Bioturbated section, below laminated.
681B-12X	97.0–100.0	Bioturbated to laminated section, below laminated.
112-684A-2H	12.1–14.8	Condensed section, above laminated, below bioturbated.
112-684B-2H	7.5–15.5	Condensed section, above laminated, below bioturbated.
112-686A-2H	9.5–14.6	Bioturbated to laminated section.
686A-3H	14.6–20.0	Bioturbated to laminated section.
686A-18X	152.5–157.0	Bioturbated, faintly laminated section.
686A-21X	177.5–185.7	Bioturbated, faintly laminated sections, more laminated above and below.
686A-23X	197.0–205.7	
112-686B-1H	7.0–8.5	Bioturbated to laminated section.
686B-2H	8.5–16.0	Bioturbated to laminated section.
686B-17X	152.0–159.0	Bioturbated section, above laminated.
686B-20X	179.5–189.0	Faintly laminated section.
686B-21X	189.0–192.5	Massive, faintly laminated section.
686B-22X	198.5–208.0	Massive section, below bioturbated.
686B-23X	209.5–213.0	Bioturbated to laminated section.
686B-24X	218.0–220.0	Massive, faintly laminated section.
686B-28X	255.0–265.0	Massive to bioturbated section.
686B-29X	265.0–266.5	Massive to bioturbated section.
686B-30X	274.5–284.0	Massive faintly laminated section.
686B-32X	293.5–297.0	Massive to laminated section, slightly bioturbated.
112-687A-2H	13.5–14.0	Condensed sections, above and below laminated to bioturbated.
687A-3H	20.4–21.0	
687A-13X	113.4–114.0	Bioturbated section, below bioturbated, faintly laminated.
687A-14X	121.5–127.0	Bioturbated, faintly laminated section.
687A-15X	132.0–133.5	Bioturbated, faintly laminated section.
687A-17X	150.5–156.0	Bioturbated section, more laminated below.
687A-20X	178.5–179.0	Massive section, bioturbated to laminated below.
112-687B-10H	82.5–83.2	Condensed section.
687B-15X	120.0–122.3	Bioturbated to laminated section.

[1] From core descriptions (Suess, von Huene, et al., 1988).

Today's upwelling cell produces an oxygen-minimum layer (OML) between a water depth of 100 to 500 m that has oxygen values of less than 0.5 mL/L (Zuta et al., 1978; Rosenberg et al., 1983). Rosenberg et al. (1983) also showed that the benthic biomass in the OML is sharply reduced and that the faunal composition changes.

In addition to sufficient oxygen levels, the availability of food plays an important role in determining the extent of benthic colonization with macrobenthos (Thiel, 1978). The food level is most abundant in the area of upwelling. However, high sedimentation rates of organic material can lead to the complete depletion of oxygen.

In the study area off Peru, one can assume that the limiting factor for colonization of the bottom is the oxygen content of the bottom water. Further, the extent to which colonization takes place depends upon the availability of food. With the exception of a few species that have adapted to oxygen-poor conditions, the most favorable living conditions for macroben-

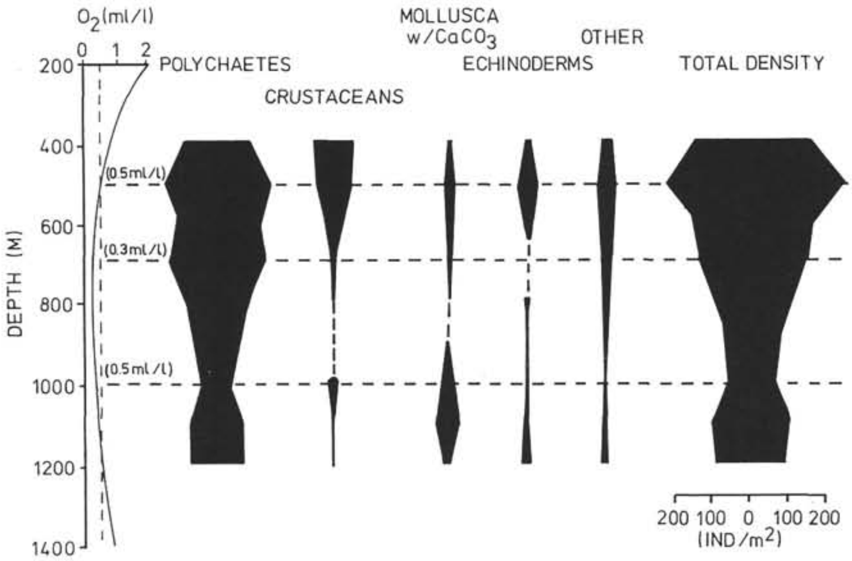

Figure 8. Population density as a function of water depth and oxygen concentration beneath the upwelling zone off California. The highest colonization densities of mollusks were found at the boundaries of the OML (from Mullins et al., 1985).

thos in the outer shelf to upper slope region appear to exist at the upper boundary of the OML. In this area, there is still adequate oxygen in the bottom water and sediment, as well as a sufficient food supply. This is particularly applicable to the mollusks that represent one of the dominant macroorganisms in the region of the outer shelf and continental slope off Peru (Frankenberg and Menzies, 1968; Rosenberg et al., 1983). Thus, mollusk productivity will be highest in areas where the upper boundary of the OML intersects the shelf or continental upper slope. This hypothesis is supported by the mollusk colonization pattern in a similar upwelling area off California (Fig. 8). According to Mullins et al. (1985), the most dense populations of mollusks were found at the upper and lower boundary of the OML within oxygen concentrations of 0.5 mL/L. A similar distribution pattern of mollusk abundance was also observed in the Baltic Sea in a completely different environment. The mollusk distribution in the channels of Kiel Bight shows a maximum colonization density and species diversity in the region where the pycnocline intersects the bottom (Arntz et al., 1976).

Based on oxygen profiles of the shelf and continental slope off Peru from Zuta et al. (1983) and Rosenberg et al. (1983), the upper and lower boundaries of the OML intersect the sediment surface at a water depth of 100 and 500 m. All sites studied here are located within the present OML. That appears to account for the lack of shell horizons in the uppermost sediment layers, which have missed the boundaries of the OML. Off Peru, shell horizons are present in times of lowered sea level (see Figs. 3 through 7, and "Stratigraphic Distribution" section, this chapter), when the OML is displaced seaward and down the shelf (Oberhänsli et al., this volume). Sites 679 and 684, today at a water depth of 450 m. contain no shell horizons in Miocene to Quaternary sediments from water depths of 400 to 500 m. No shell horizons were found in sediments deposited at water depths of 300 m or below. Only at Site 686 were three thin shell horizons from latest Quaternary deposited at a water depth of 450 m. Nevertheless, we assume that off Peru, increased growth of mollusks existed, especially at the upper boundary of the OML.

Displacements of the upwelling cell, fluctuations of its intensity, and changes in sea level shift the upper boundary of the OML, along with the region of greater mollusk colonization on the shelf and upper slope (Fig. 9, Stages 1 through 3). If shell horizons, relicts of periods of greater mollusk growth, appear in sediments indicating reduced upwelling intensity and moderate bottom-water oxygenation, then these correspond to periods in which the upper boundary of the OML lay in proximity to the respective site (Fig. 9, Stage 1). From the data it cannot be established whether Stage 1 in each case represented a longer time period with a stable OML, or whether short-term fluctuations were prevalent. However, the shell horizons can be used to reconstruct the migration of the OML with time.

The number of individual shell layers within the shell horizons (Schneider, 1988) and their thickness depends on the relationship between sedimentation and erosion in addition to the proximity of the OML (Fig. 9, condensed and normal sequence). North of the study area, where lower sedimentation rates prevailed during the Quaternary (Suess, von Huene, et al., 1988), and stronger erosion took place due to the bottom current regime (Suess et al., 1986), the shell horizons are thin and contain fewer shell layers than in the south. In the southern region, thicker shell horizons and higher sedimentation rates were observed. These regional differences can be seen by comparing the distribution profiles of Sites 684 and 686 (Figs. 3 and 7). Coarser graded sediments with phosphorite pebbles or with total shell proportions of more than 10 wt% at Site 684 are indicative of condensed shell horizons. In the sediments of Site 686 where high sedimentation rates prevailed, the total shell proportions between a core depth of 180 and 300 m are higher overall.

Biostratigraphic and lithologic descriptions, reported by Suess, von Huene, et al. (1988), indicate no large-scale sedimentary redeposition of sediment sections containing mollusk shells. According to Kidwell et al. (1986), shell layers within open-shelf sediments beneath the zone of wave action are biogenically deposited concentrations of mollusk shells. Thus, we presume that a sedimentary concentration of allochthonous shell material did not take place in the case of the observed shell horizons.

Distribution of the Bivalve Communities and Gastropods

Despite the small number of identifiable genera, the distribution of the mollusk communities in the study area (Fig. 10)

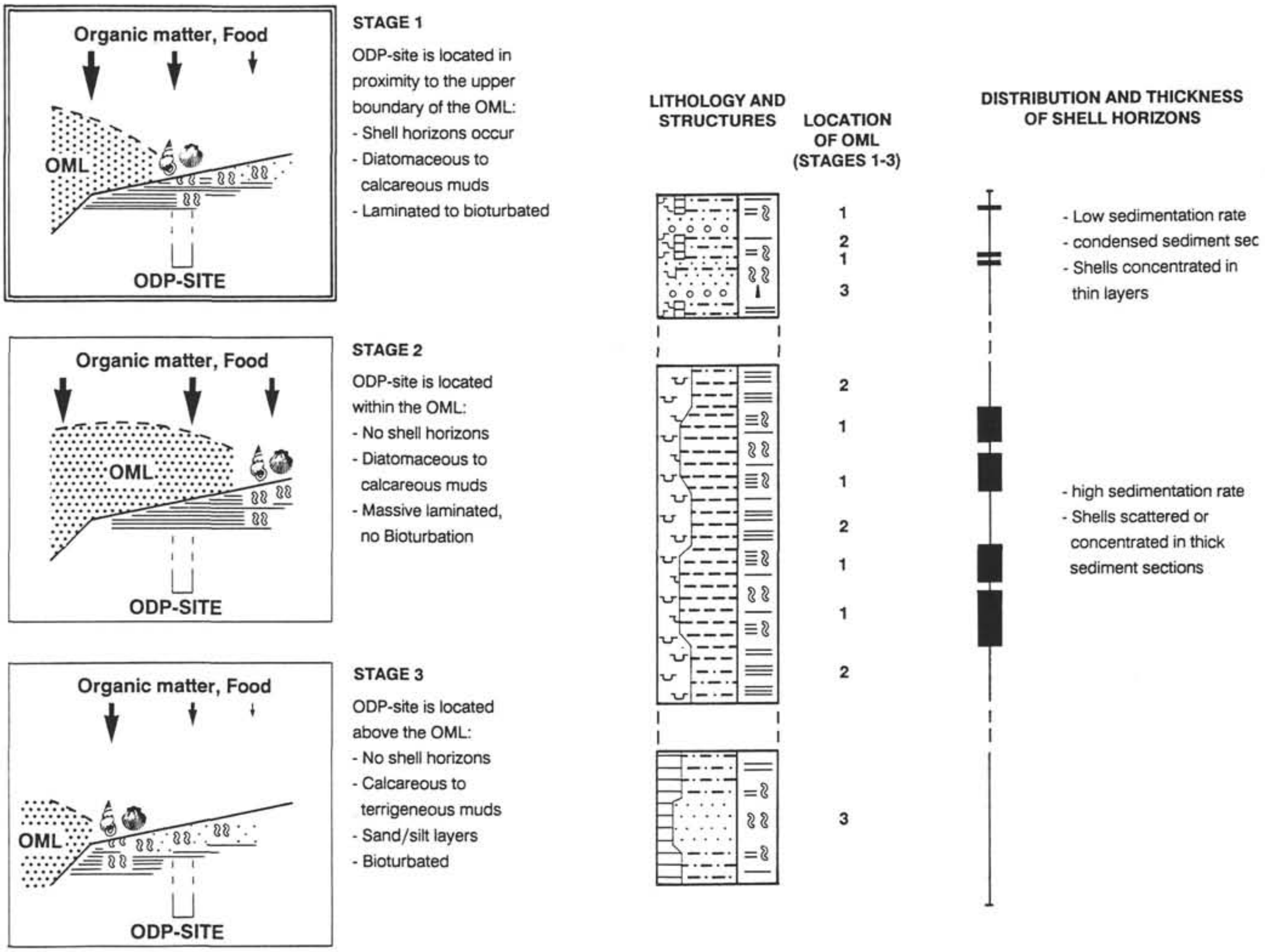

Figure 9. Formation and distribution of shell horizons as a function of the position of the oxygen-minimum layer and sedimentation rate.

shows a distinct zonation. A deeper-water *Nuculana Aequipecten* community appeared at Site 684 from late Miocene to late Quaternary, at Site 680 from late Pliocene to late Quaternary, and at Site 686 in the latest Quaternary. At Site 681 a venerid community, dominated by the genus *Pitar* sp., occurred from early to middle Quaternary. This venerid community, together with gastropods, prevailed at Sites 686 and 687 in the early Quaternary. A depth dependence of the discriminated communities is particularly visible in the sequence of shell horizons at Site 686. Here, subsidence of the continental margin during the Quaternary resulted in a progression from water depths characteristic of the inner shelf, to today's upper continental slope environment (Fig. 7).

Presuming that distributions of mollusks reflect substrate, food availability, and oxygen concentrations, the distinct community zonation may be related to differences in the upwelling regime between the northern (9° to 11°S) and southern (13°S) area. Holocene differences are shown by the surficial sediments (Fig. 2). A coarse, calcareous ooze facies with lower organic carbon content, influenced by bottom currents, dominates in the north. A fine-grained, carbon-rich, diatomaceous mud facies with high sedimentation rates occurs in the south (Kulm et al., 1984). The Holocene Peruvian mollusk fauna is restricted in diversity, and little is known to date about species living on the deeper shelf (Olsson, 1961). Therefore, we have no idea, whether a mollusk distribution related to today's specific environmental conditions and comparable to the community zonation found in the ODP sites exists.

Stratigraphic Distribution of the Shell Horizons

The stratigraphic distribution of the shell horizons sampled at the individual sites does not present a uniform picture (Fig. 10 and Table 1). The development of shell layers is dependent, among other factors, on the sedimentation rate, the tectonic development, and reworking of the sediment in the depositional environment. The most important factor, however, is the movement of the OML and fluctuations in its intensity over time. This is coupled primarily with changes in sea level and in the upwelling system. The available temporal resolution of the sediment sequences (Wefer et al., this volume; Suess, von Huene, et al., 1988) does not allow us to compare shell horizons directly with all sites studied. The ages of differentiated shell horizons at Sites 680 and 681 (681, from Heinze, unpubl. data) from the late Quaternary (Table 1) either agree with single glacial stages, based on $\delta^{18}O$ curves from marine deep-sea sediments (Imbrie et al., 1984), or the shell horizons occur in condensed sections that make up more than one glacial/interglacial cycle. For the latter, we assume that the shell horizons are relicts from glacial times. We make the same assumption for the late Quaternary condensed sediment sections containing mollusk shells at Site 684. At

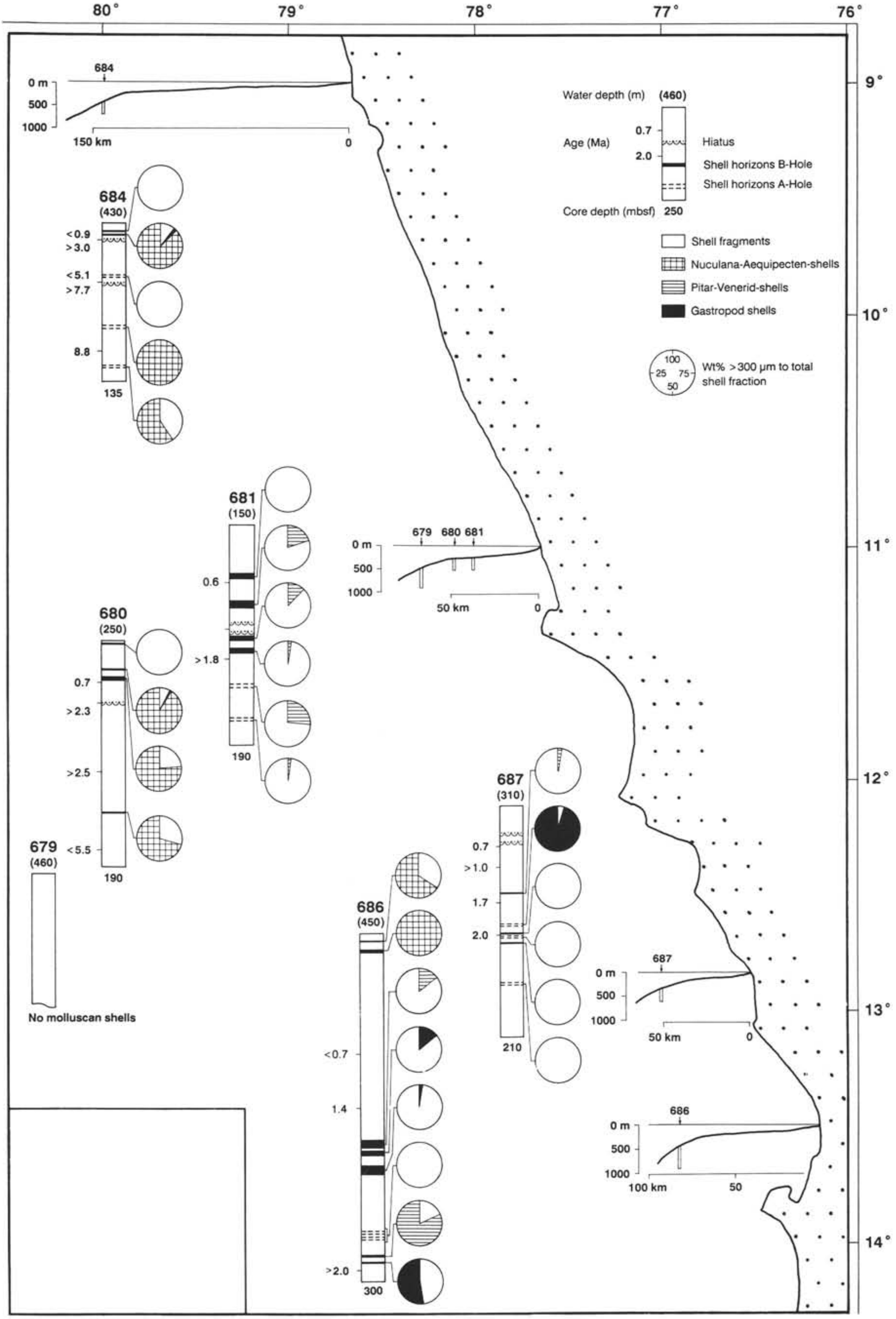

Figure 10. Regional and stratigraphic distribution of shell horizons and the mollusk communities.

Site 686 no $\delta^{18}O$ curve exists for the latest Quaternary. All shell layers from this period occur in sediments having a low organic carbon content (Wefer et al., this volume).

Shell horizons from the early Quaternary at Sites 686 and 687 appear to be concentrated between 1.4 and 1.6 Ma, and between 1.8 and 2.1 Ma (Table 1, Figs. 6 and 7). Two shell horizons from the early Quaternary, whose positions may correlate with the temporal distributions of Sites 686 and 687, also occur at Site 681. On the global eustatic sea-level curve (Haq et al., 1988), these intervals coincide with a regressive phase between 1.8 and 2.1 Ma, and a transgressive phase between 1.6 and 1.3 Ma.

This stratigraphic sequence represents only a first attempt using a minimal number of age indications and must be further developed following more detailed stratigraphic studies. Assuming that the suggested stratigraphy is roughly accurate, the shell horizons on the shelf and upper continental slope may be considered to have been deposited during times of lower sea level in the early Quaternary, and during glacial episodes in the late Quaternary. This contradicts results from von Huene et al. (1987); they suggest that the bioturbated sediments with shell horizons from Site 686 indicate periods of weakened upwelling and high sea level. This disagreement arises from an age shift of 0.4 m.y. between the biostratigraphic and radiometric age of an ash layer in cores from Site 686. For the Miocene and Pliocene shell horizons from Sites 684 and 681, benthic foraminifers also indicate shallow water depths: 150 m for Site 684 and 50 m for Site 681.

The decreases in sea level shown in Figures 3 through 7 do not correlate unequivocally with the shell horizons. This may be a result of the low temporal resolution of fluctuations in sea level, established from diatoms and benthic foraminifers, or of stratigraphic displacements between A-holes and B-holes.

CONCLUSIONS

Small sample sizes, as well as a minimal number of specimens in the individual samples, result in a large scatter in values of the distribution and generic composition of the mollusk faunas. Thus, statistical distribution methods could not be applied. Nevertheless, the 10-cm^3 samples from the cores of Leg 112 allow us to predict several aspects regarding the genesis of the shell horizons and the molluscan distribution in the shell layers. Optimal living conditions for mollusks at the outer shelf and upper slope setting off Peru lie at the upper boundary of the OML. The shell horizons can be used as indicators of paleopositions of the OML on the shelf and upper continental slope.

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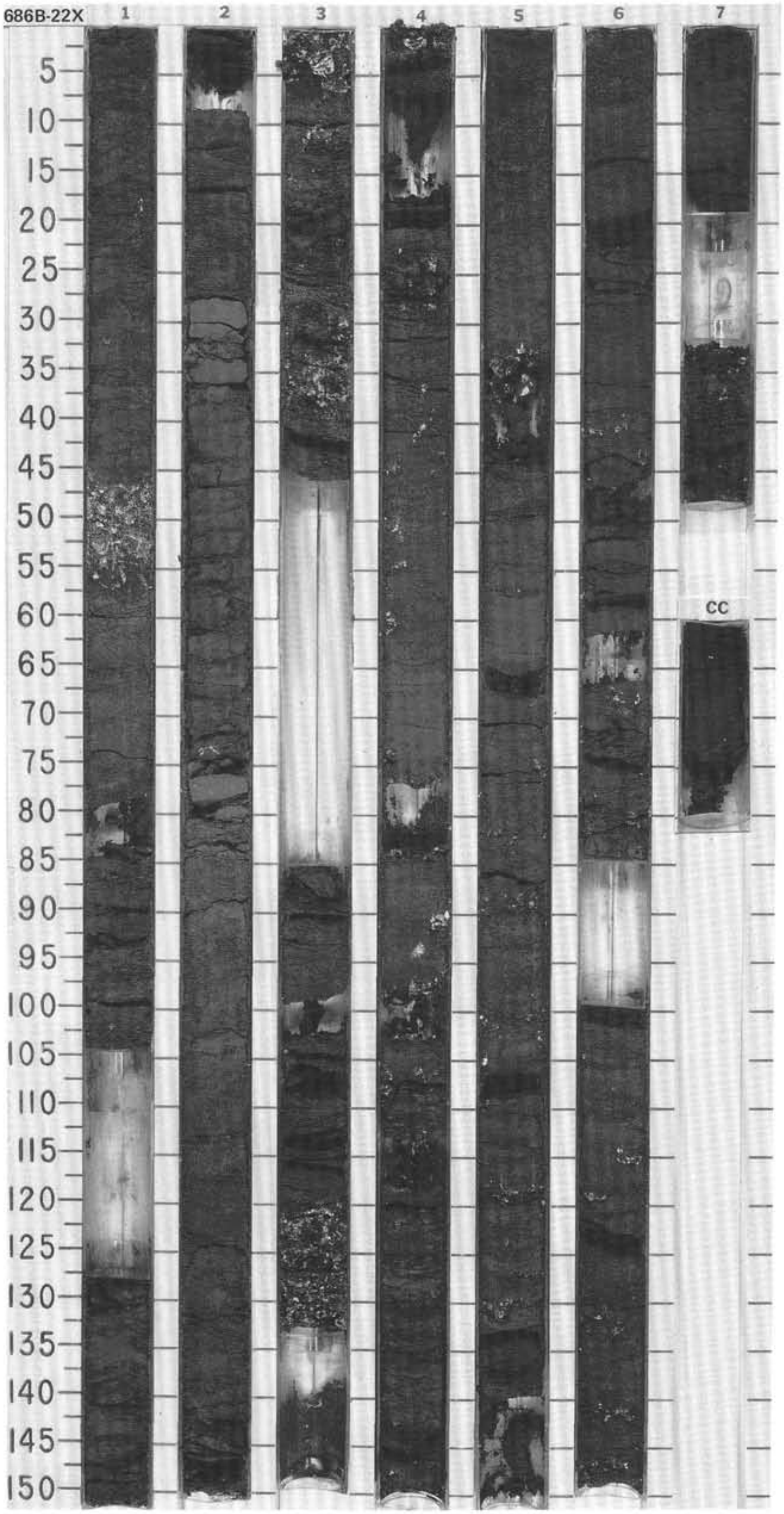
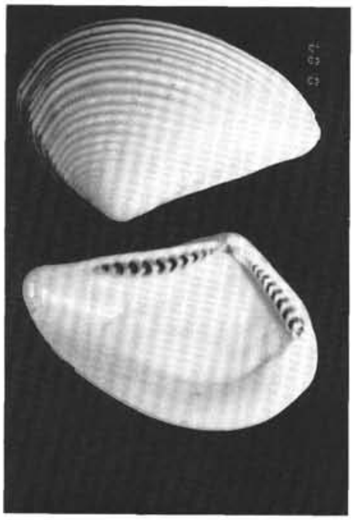


Plate 1. Shell horizons in Core 112-686B-22X, core depth is 198.5 to 208 m. Shell horizons in following core sections:
112-686B-22X-01: 44–55 cm
112-686B-22X-03: 0–10 cm, 30–40 cm, 120–135 cm
112-686B-22X-04: 0–5 cm, 90–115 cm
112-686B-22X-05: 35–40 cm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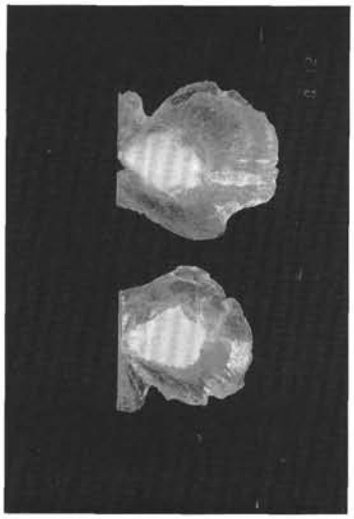
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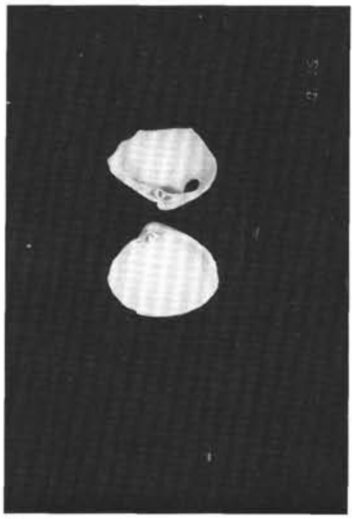
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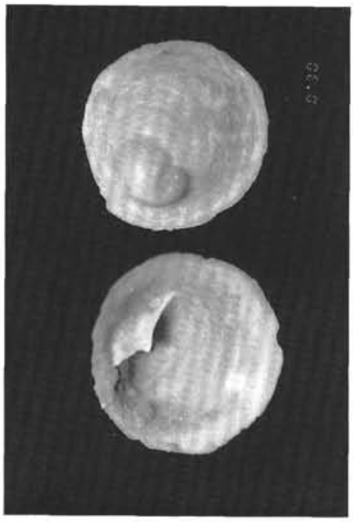
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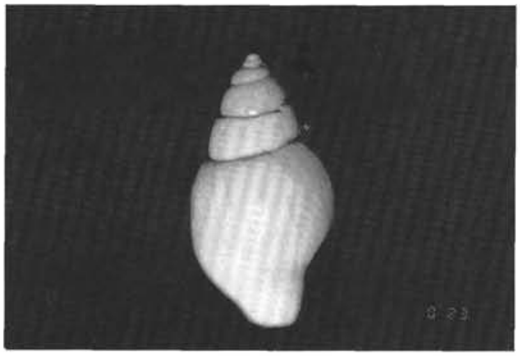
8

Plate 2. Mollusk species. Bivalves: **1**. *Nuculana* sp. (Size: 15 mm). **2**. *Aequipecten* sp. (Size: 10 mm). **3**. *Pitar* sp. (Size: 7 mm). Gastropods: **4**. *Calyptraea* sp. (Size: 6 mm). **5**. *Odostomia* sp. (Size: 8 mm). **6**. *Nassarius* sp. (Size: 17 mm). **7**. *Polinices* sp. (Size: 12 mm). **8**. *Cosmioconcha* sp. (Size: 8 mm).