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Abstract approved:

William G. Pearcy

Partly laminated sediments on the upper continental slope (200-600 m) off central Peru contain a diverse assemblage of fish debris, diatoms, and the remains of a variety of other nektonic, planktic, and benthic organisms. Approximately 97 percent of the fish scales recovered from the best preserved cores come from the anchoveta (79 percent), Peruvian hake (16 percent), and sardine (2 percent). Most of the diatoms belong to the genera *Chaetoceros*, *Skeletonema*, *Thalassionema*, *Thalassiosira*, *Coscinodiscus*, and *Rhizosolenia*. A discontinuous sedimentary record at 11°S. and 13°S. shows that the species composition of diatom and fish debris assemblages has changed very little in the past 15,000 years. However, the relative abundance of diatom species and genera, and to a lesser extent, fish species and genera, has fluctuated throughout the Holocene. These

fluctuations may be attributed to changes of primary and secondary productivity in the overlying water column and to subsequent chemical and physical alteration of the depositional environment.

An explanation of Holocene upwelling and productivity was developed based on the distribution of fish debris, diatoms, and silicoflagellates in sediments deposited during the Second Neoglacial Period (about 2700-1800 yr. B.P.) from core 7706-40 at 11°15'S. Floral and faunal assemblages, variously enriched in sardine and saury scales, diatoms of the species *Rhizosolenia shrubsolei*, *R. bergonii*, and *Skeletonema costatum*, and the silicoflagellate genera *Dictyocha* and *Distephanus*, suggest that periods of global atmospheric cooling were accompanied by both enhanced productivity and warmer surface water off the coast of Peru. Abundant sardine scales in sediments deposited during the close of the last ice age (11,700-11,400 yr. B.P.) and a tropical oceanic assemblage of diatoms (*Coscinodiscus nodulifer*, *Asteromphalus* spp., *Rhizosolenia bergonii*) deposited together with large numbers of *Skeletonema costatum* and *Rhizosolenia shrubsolei* at 11°15'S. during the 'Little Ice Age' (200-500 yr. B.P.) are further evidence supporting the proposed explanation of Holocene upwelling and productivity patterns.

Latitudinal compression of atmospheric and oceanic circulation in the South Pacific Ocean and a southward shifting Intertropical Convergence Zone are phenomena frequently attributed to climatic cooling. Intensified oceanic circulation and weakened southeast trade winds directly off Peru that may have resulted from the compressed and shifted circulation belts could have interacted to produce the paradoxical simultaneity of warm surface water and high productivity signals preserved in Peruvian marine sediments during some episodes of global atmospheric cooling. Further testing of this and competing hypotheses depends upon the availability of cores from the northern and southern reaches of the Peruvian continental margin that exhibit greater temporal continuity.

Nekton Remains, Diatoms, and Holocene Upwelling off Peru

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF FIGURES (cont)

LIST OF TABLES

LIST OF PLATES

Nekton Remains, Diatoms, and Holocene Upwelling off Peru

INTRODUCTION

Coastal upwelling off Peru until recently supported the largest single-species fishery in the world (Longhurst, 1971). The tremendous primary and secondary productivity of the region (Mikheyev, 1971; Sorokin, 1978) once enabled local fishing fleets and seabird populations to harvest more than ten million metric tons (Schaefer, 1971) of anchoveta (Engraulis ringens) annually.

Upwelling off Peru has traditionally been attributed to Ekman divergence driven by the prevalent southeast trade winds that flow more or less parallel to the coastline (Zuta et al., 1978). The source of the upwelled water, which arises from less than 100 m below the sea surface, is believed to be the Cromwell Current between 4-6°S., the Peru Undercurrent between 6-14°S., and Subantarctic water south of 14°S. (Zuta and Guillen, 1970). During the winter and early spring upwelling extends to 60 km offshore, but during the summer it is restricted to 10-20 km (Maeda and Kishimoto, 1970). The range of the anchoveta expands and contracts with seasonal changes in upwelling as the fish seek the cooler upwelled water (Sanchez, 1966).

A very narrow continental shelf underlies most of the upwelling area except at 6-10°S., where it widens to 100 km. The continental slope plunges steeply to the abyssal depths of the Peru-Chile Trench. Parts of the slope are only covered by a thin sedimentary veneer (Kulm, unpublished data), but on the upper slope between 10-14°S. lies a thick mud lens composed of fine-grained sediment (Scheidegger et al., 1978). High values of organic carbon (Suess, unpublished data), laminated and diatomaceous sediments, and fish debris are characteristic of the upper slope mud lens.

Laminated marine sediments are known to occur elsewhere, particularly in the intraslope basins of southern California (Hülsemann and Emery, 1961). Diatoms and fish debris are frequently associated with laminated marine sediments (Brongersma-Sanders, 1949; Soutar, 1970; Diester-Haass, 1978). A well-preserved floral and faunal record in relatively undisturbed laminated sediments could be used to reconstruct the history of biological productivity and oceanic circulation above such sediments and, indirectly, the paleoclimate of the region.

Although diatoms have frequently been used in biostratigraphic studies, fish debris has generally been ignored as a paleontological tool (Casteel, 1976). Lagler and Vallentyne (1956) suggested that fish debris be used in Quaternary studies after finding early Holocene scales in freshwater ponds in eastern North America. David (1947) speculated on the occurrence of fish debris in Tertiary deposits of California after finding scales, vertebrae, and otoliths of several species of fish in surface sediments off southern California. However, the first systematic study of fish debris was undertaken by Soutar (1967) and Soutar and Isaacs (1969, 1974). They enumerated the scales of anchovy, sardines, sauries, and hake in laminated sediments of the Santa Barbara Basin off southern California, going back to 2000 yr. B.P. More recently, Casteel et al. (1977) reported on a similar study in Clear Lake, California.

The present study endeavors to use a multitaxic approach employing nekton remains, siliceous microfossils, and other biogenous debris preserved in laminated marine sediments to infer the history of biological productivity in the upwelling zone off Peru during the past 15,000 years. The species composition and abundance of floral and faunal assemblages have been evaluated with special emphasis placed on the areal distribution of fish debris, onshore-offshore changes in the preservation of fish debris, and downcore patterns of fish debris and diatom diversity and abundance. A model has been developed to explain observed correlations between major variations in the character of the assemblages and late Quaternary climate changes. Implications of the explanation for upwelling behavior and circulation in the southeast Pacific Ocean are also discussed.

METHODS AND MATERIALS

A total of 59 Kasten cores (15 cm square) and Reineck box cores (22 cm square) were taken during the cruise of R/V WECOMA in May and June, 1977, to study patterns and processes of continental margin sedimentation off Peru. The physical properties, interstitial and bulk chemistry, mineralogy, and biogenous constituents of hemipelagic sediments sampled beneath coastal upwelling, non-upwelling, and oceanic waters were examined to determine the distribution and dispersal processes of sediments in relation to upwelling.

The cores were refrigerated onboard and later transferred to a walk-in cooler (6°C.) at Oregon State University. Although some of the cores had been processed onboard the R/V WECOMA, most were described ashore according to standard procedures by students and staff of the marine geology group at Oregon State University. After setting aside archival samples and material for X-radiography, the cores were cut into vertical intervals of 1 cm, 3 cm (Reineck box cores), or 5 cm (Kasten cores). All samples were then sealed in plastic bags for permanent storage in the cooler. Later, a number of these samples were used for a variety of purposes in this study (Figure 1).

Sedimentary structures in 23 cores from the vicinity of the Peru-Chile Trench and the continental margin of Peru

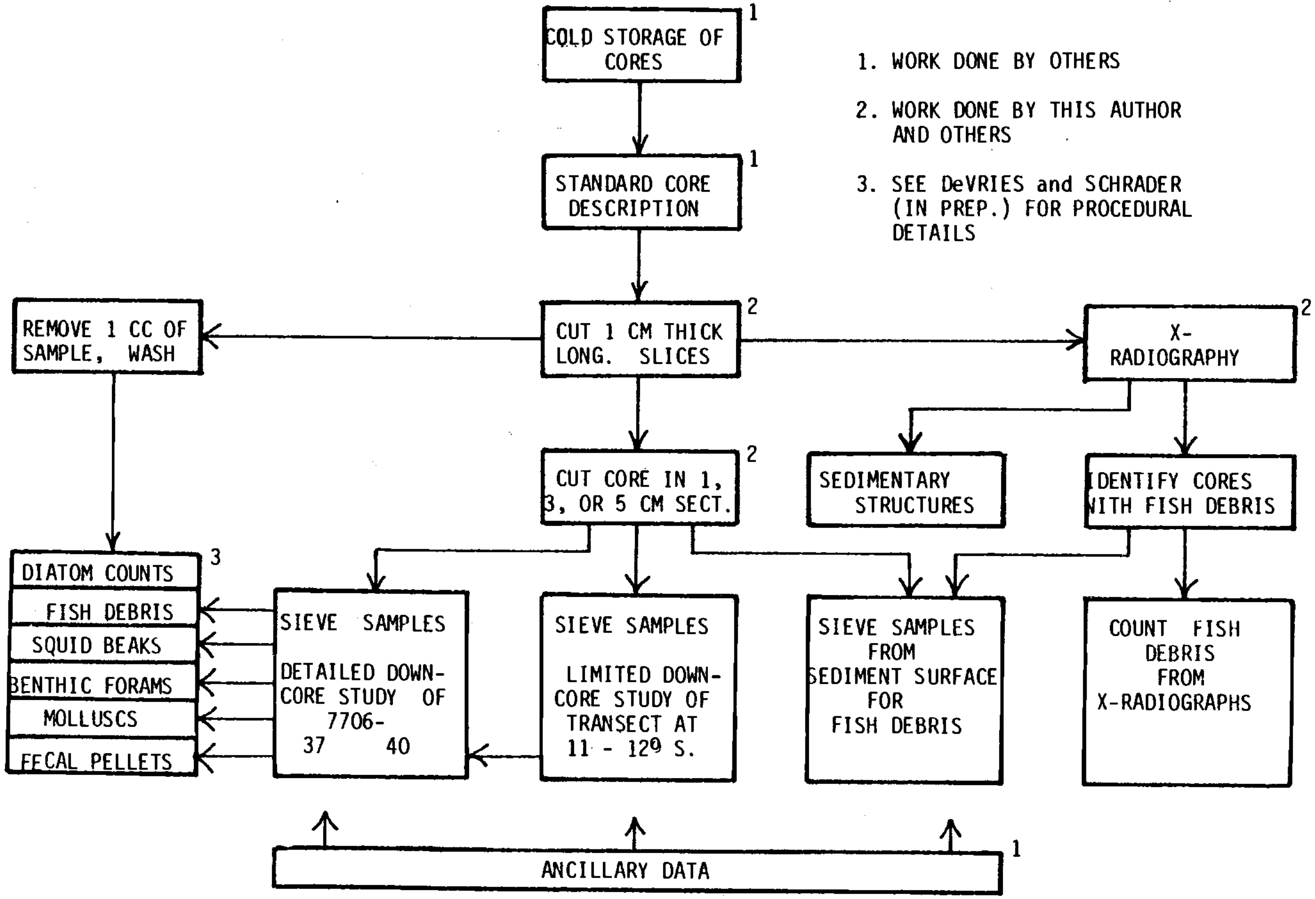


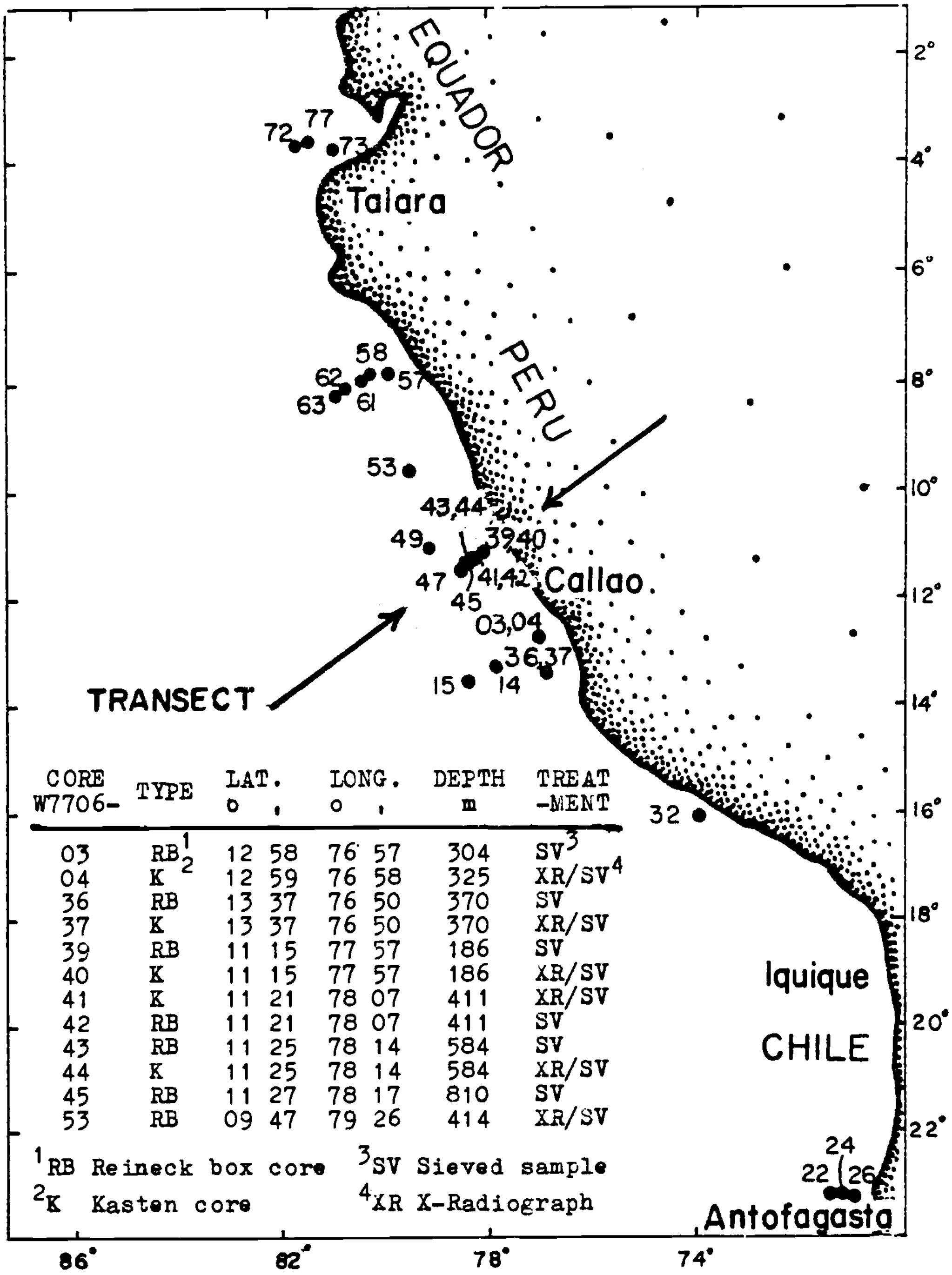
Figure 1. Flow chart of methods.

were examined by means of X-radiography (Figure 2). In some cores, fish debris was clearly seen on X-radiographs of 1 cm thick slices of sediment cut parallel to the vertical axis of the core. Numbers per cm^3 sediment of bones and vertebrae (no scales were visible) were estimated.

Surface samples from most of the 23 cores were sieved to recover fish scales and vertebrae. These scales and vertebrae were then counted to determine the areal distribution of recently deposited fish debris.

Twelve cores known to contain appreciable amounts of fish debris from X-radiographs (Figure 2, inset) were sampled downcore from the 5 cm sections of Kasten cores and 1 or 3 cm sections of Reineck box cores for fish scales and vertebrae. 200 g of untreated wet sediment taken evenly from each whole section were washed through 500, 1000, and 3000 μ screens. All scales, vertebrae, and other biogenous debris retained by the three screens were sorted with the aid of a 7X stereo microscope. After being sorted, the fish debris and other biogenous remains were soaked in fresh water for several days to remove excess sea salt and then air-dried or oven-dried at 60°C before being permanently stored in plastic vials. Ethanol was not used as a preservative so as to avoid altering the composition of the organic matrix of the fish debris.

A transect of cores between 11-12°S. were among the twelve cores studied in greatest detail. Special attention was paid to onshore-offshore variations of biogenous



CORE W7706-	TYPE	LAT. °	'	LONG. °	'	DEPTH m	TREAT -MENT
03	RB[1]	12	58	76	57	304	SV[3]
04	K[2]	12	59	76	58	325	XR/SV[4]
36	RB	13	37	76	50	370	SV
37	K	13	37	76	50	370	XR/SV
39	RB	11	15	77	57	186	SV
40	K	11	15	77	57	186	XR/SV
41	K	11	21	78	07	411	XR/SV
42	RB	11	21	78	07	411	SV
43	RB	11	25	78	14	584	SV
44	K	11	25	78	14	584	XR/SV
45	RB	11	27	78	17	810	SV
53	RB	09	47	79	26	414	XR/SV

[1] RB Reineck box core

[2] K Kasten core

[3] SV Sieved sample

[4] XR X-Radiograph

Figure 2. Location of selected cores from R/V WECOMA cruise 77 Leg 6. Inset lists pertinent locality data for cores most frequently used in this study. Note arrows marking transect of cores between 11-12°S.

constituents in these cores. One of the transect cores, 7706-40, contains an especially well preserved record of fish debris and diatoms. Therefore, nearly the entire length of the core (222 cm) was processed for biogenous remains.

Another core, 7706-37, also contained a well preserved sediment and fossil record. The downcore distribution of nekton and plankton species in this more southerly core (13°37'S.) was compared with that of core 7706-40.

Fish scales were identified using a reference collection of southern Californian Peruvian fish compiled by A. Soutar. Fish vertebrae were compared with freshly dissected specimens of similar genera from the coast of Oregon and with material provided by J. Sepulveda of the Universidad Catolica de Valparaiso, Chile. The vertebrae were generally more difficult to identify than scales because most of the relevant literature only dealt with caudal configurations (Regan, 1910, Whitehouse, 1910, Gosline, 1960), although Ford (1937) has presented a succinct summary of clupeoid vertebral characteristics for the entire backbone. Clothier's (1950) key relies too heavily upon vertebral counts and silhouettes to be of much practical use in a study of disarticulated fish debris. Illustrations of vertebral columns in Sanchez and Lam (1970) were more useful. Osteological studies of species and genera (viz., Chapman, 1944a, 1944b; Phillips, 1942; Tesch, 1973;

Collette and Chao, 1975) were most useful.

The counting of vertebrae and scales was straightforward. Anterior ends of vertebrae were scored as one vertebra. Scales with concentric circuli were scored as a single scale only if the focus of the scale was present. Many scales have transverse ridges (circuli) and indistinct, concentric, growth lines. Scales of this type were scored as one scale if the focal area, defined by contrasting anterior and posterior transverse circuli laterally bending towards the transverse median of the scale, was present. This procedure may have biased counts in favor of small scales if larger scales were excessively fragmented.

Fish debris abundance has been expressed both in terms of numbers per gram of dry sediment and as an accumulation rate (numbers of scales buried $\cdot$ cm^{-2} $\cdot$ yr^{-1}). Surface and downcore wet and dry bulk densities were measured by Keller and Busch (1978).

Accumulation rate calculations require a knowledge of sedimentation rates (Müller and Suess, 1979) which in turn are based on accurate dating of a core. Relative and absolute age data utilizing Pb-210 and C-14 were provided by DeMaster (1979) and Radiocarbon, Ltd., of Lampasas, Texas. In addition to facilitating the determination of accumulation rates, the radiometric data also provided an overall chronology for two of the cores, 7706-37 and -40, and frequently confirmed the existence of major sedimentary unconformities previously suspected from X-radiography.

The general preservation of the fish debris was noted. The severity of dissolution, as evidenced by pitted bones and weakly skeletized scales, varied from sample to sample. Some bones were blackened with iron sulfide. Others were partially covered with phosphatic or biogenic calcerous encrustations. From these observations it was hoped that qualitative properties of the depositional environment (e.g., rapidity of burial, extent of anaerobicity, solubility of apatite) might be inferred.

Other constituents of the sediment fraction coarser than 500 μ that were recorded included phosphorite nodules, squid beaks, fecal pellets, benthic foraminifera, and molluscs. In addition, the species composition and abundance of diatom assemblages were determined for two of the cores (7706-37, -40); the procedural details of the diatom study have been reported elsewhere (DeVries and Schrader, in prep.).

Ancillary data from the R/V WECOMA cruise 7706 were furnished by marine geologists at Oregon State University. These data included seismic profiles, textural, and mineralogical analyses (Scheidegger, Krissek, and Kulm, 1978), geotechnical data (Keller and Busch, 1978 and unpublished data), geochemical analyses of sediment and interstitial waters (Suess, 1978), and diatom and foraminiferal data for surface sediments (Schuette and Schrader, 1979a, b; Hutson, unpublished data). The results of these related studies were often used to substantiate conclusions drawn from the fish debris and diatom data alone.

RESULTS

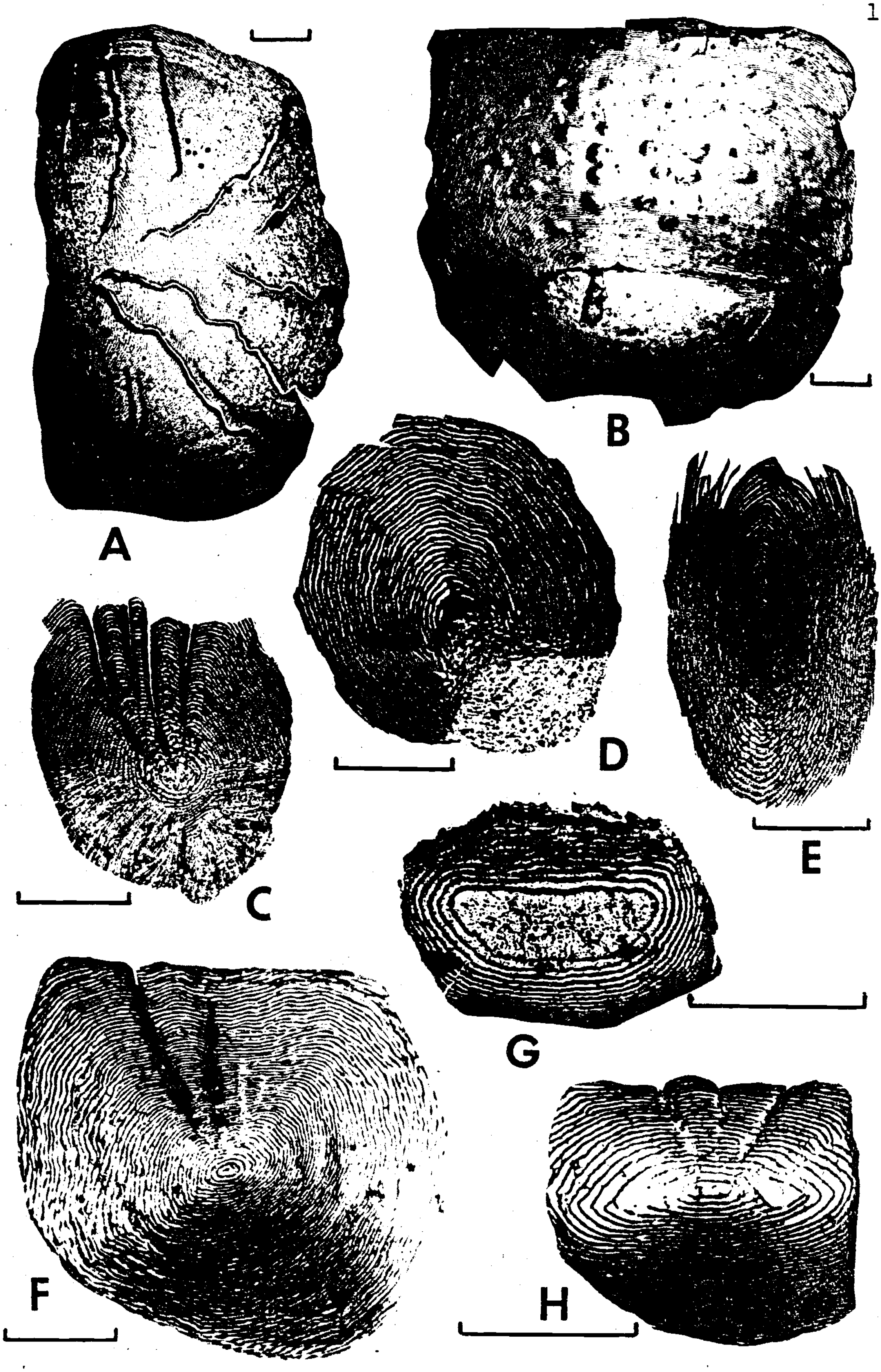
Fish debris comprises the bulk of nekton remains preserved in continental margin sediments off Peru. Table 1 lists the percent composition of fish species based on the combined data from cores 7706-37 and -40, the two cores having the best preserved record of fish debris. Not surprisingly, scales of the anchoveta (*Engraulis ringens* (Jenyns)) predominate. Peruvian hake (*Merluccius gayi peruanus* (Guichenot)) were next in numerical abundance. The remains of sardines (*Sardinops sagax sagax* (Jenyns)), sauries (*Coloabis adocetus* (Brevoort)), scombrids, carangids, myctophids, apodeans, and several unidentified species occurred less frequently.

Examples of some fish scales are shown in Plate 1. Scales usually have a distinctive appearance at the familial level and become increasingly characteristic at the generic level for those scales having a complex morphology. Carangids (*Decapterus*, *Trachurus*, and others) and scombrids (*Scomber*) have simple cycloid scales with sometimes poorly defined fields and undistinguished circuli (Plate 1G, 1H). Scales of the clupeoid fishes (*Anchoa*, *Cetengraulis*, *Engraulis*, *Harengula*, *Opisthonema*, and *Sardinops*) are typically sculptured with transverse circuli on the posterior field (Plate 1A, 1B). Genera can often be identified on the

Table 1. Relative abundance of fish species in marine sediments off Peru. Percentage composition represents composite downcore and surface scale counts from sieved samples of cores 7706-37 and 7706-40.

Species	Common Name	Percent Composition of scales
Engraulis ringens	Anchoveta	79.4
Meluccius gayi peruanus	Hake	15.9
Sardinops sagax sagax	Sardine	1.5
Myctophiformes	Lanternfish	0.9
Carangidae	Jacks	0.7
Cololabis adocetus	Saury	0.3
Physiculus sp.	Morid Cod	0.3
Scomber sp.	Mackerel	0.2
Scorpaenidae	Rockfish	0.1
Miscellaneous	--	0.7
	TOTAL	100.0

Plate 1. Fish scales in marine sediments off Peru. *Engraulis ringens* (A), *Sardinops sagax sagax* (B), *Myctophum* sp. (C), *Cololabis adocetus* (D), *Merluccius gayi peruanus* (E), *Lampanyctus* sp. (F), *Scomber* (?) sp. (G), *Decapterus* sp. (H). Scale is 1 mm for each fish scale.


A
B
C
D
E
F
G
H

basis of radii patterns in the posterior field and features of the anterior field myctophid scales differ from each other in radii pattern, density of the lateral circuli, and structural details of the anterior field (Plate 1C, 1F).

Otoliths, the calcium carbonate earbones of fish (Casteel, 1974), have been used previously in archaeological and geological studies involving fish remains (Fitch, 1969). Otoliths were rare in the laminated sediments off Peru, being restricted to horizons and cores which also contained other calcareous remains. Fish teeth were present in many samples but have not been used in this study.

Squid beaks were commonly found in core 7704-45 (804 m). However, only the rostrums were preserved. The loss of the lateral walls and wings precluded identification using Clarke's (1962) manual. However, Nesis (1973) has observed rostrums of *Gonatus antarcticus* in surface sediments at depths of 660-2100 m off the coast of Peru and Chile. He contended that *Gonatus* and other southern species were living "in a narrow strip along the continental slope...in a zone influenced by subantarctic subsurface waters (in the southern part of the region) and by cold deep waters of Peru and northern Chile which rise to the surface near the coast..." (p. 428).

Surface Sediment Results

Fish debris was scarce in surface sediments at water depths greater than 600 m, agreeing with the observations of Saidova (1971). The greatest abundance of fish debris occurred at depths of 200-400 m between 11-14°S., coincident with the center of the oxygen minimum zone (Zuta and Guillen, 1970) and the depositional center of the mud lens on the upper continental slope (Scheidegger et al., 1978). Cores from shallower depths were not available for study, but sediments rich in fish bones and cycloid scales were reported at 126 m at 6°S. by Frankenberg and Menzies (1968) and 30 m at 22°S. by Saidova (1971).

A marked change in the preservation of fish debris is apparent with increasing water depth. Fish debris is coarser at deeper stations (7706-44, -45) and is often encrusted with phosphatic overgrowths. Scales are virtually absent below depths of 600 m.

Scale:vertebrae ratios can be useful indicators of post-depositional degradative processes. The ratio of scales: vertebrae for a live adult anchoveta is about 13:1 (Chirichigno, 1974). The highest ratio for Peruvian sediments occurred in the laminated muds of core 7706-40 at a water depth of 186 m, where the average downcore ratio was about 4:1 (Table 3). This initial loss of scales may be largely due to differential digestion of scales by predatory fish, squid and mammals. Ratios less than 2.5:1 are characteristic of sediments at water depths greater than 400 m and strata in shallower cores that show signs of biological or physical reworking. Consequently, the quantity of scales from low scale:vertebrae ratios do not accurately represent fish scale production, but reflect the influence of post-depositional transport, dissolution, and biological degradation on the primary input signal.

Data on the distribution of anchoveta and hake vertebrae in surface sediments show that the occurrence of the two species in the sediment roughly parallels their occurrence in the overlying water column (Figures 3 and 4).

The present range of three species of pelagic fishes are shown in Figure 3. The anchoveta (*E. ringens*) occurs as three major stocks between 5°50'S. and 37°04'S. in cool, epipelagic waters of the Peru-Chile coastal current (Sanchez, 1966; Brandhorst and Canon, 1967; Brandhorst and Rojas, 1967; Jordan, 1971; Longhurst, 1971). Populations of the sardine (*S. sagax sagax*) are found off northern and central Peru (Borgo et al., 1967; Vasquez et al., 1970; Santander and Castillo, 1977) and off northern Chile (DeBuen, 1960; Brandhorst and Canon, 1967; Brandhorst and Rojas, 1967) in warmer epipelagic waters further offshore than the anchoveta, and around the Galapagos Islands (Alverson and Shimada, 1957). Peruivan hake (*M. gayi peruanus*) are most abundant over the wider continental shelf north of 9°S. at depths of 130-180 m (del Sola et al., 1965; Santander and Castillo, 1969). Chilean hake (*M. gayi gayi*) congregate at similar depths between 32-37°S. (Brandhorst, 1959).

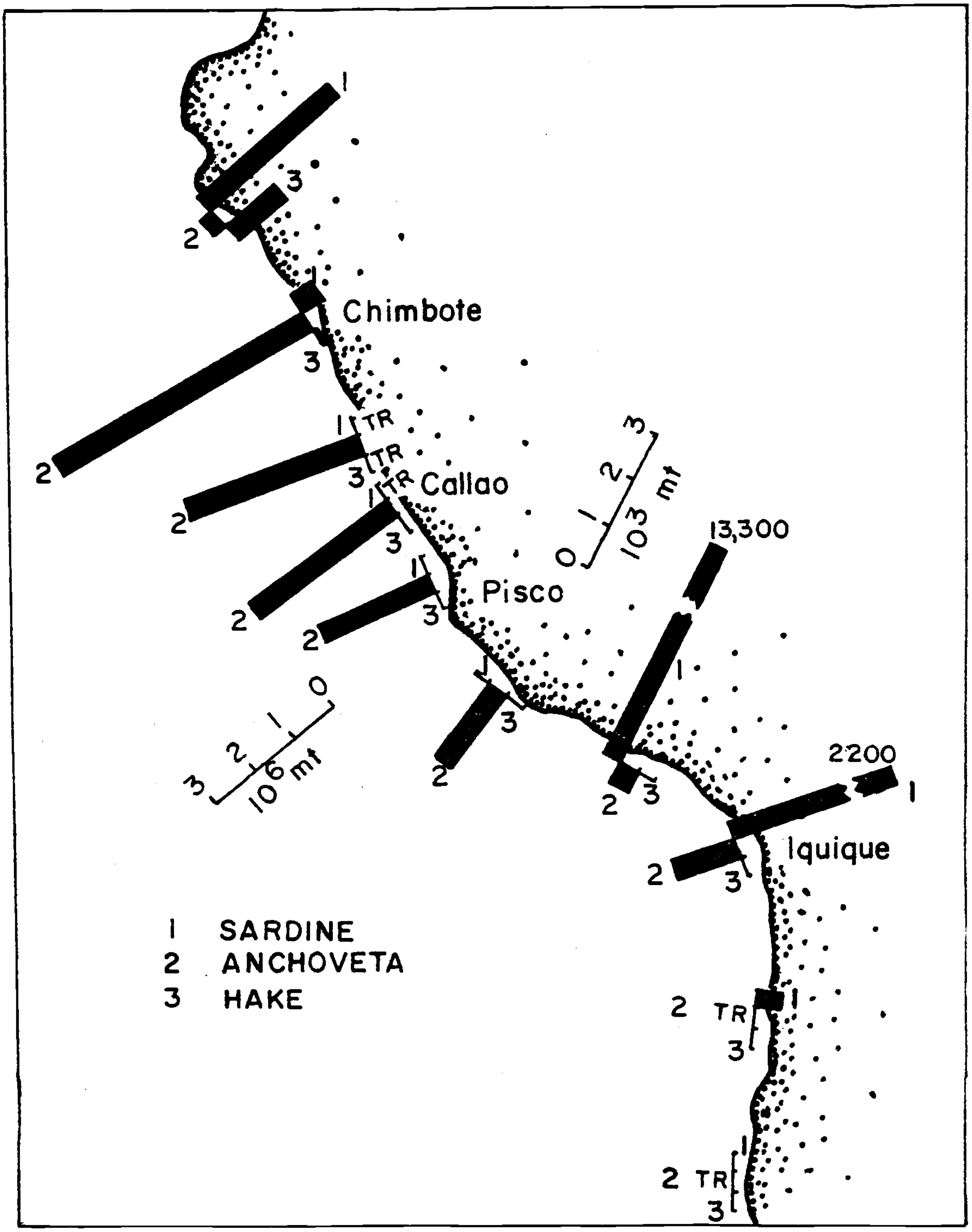


Figure 3. Landings of anchoveta, hake, and sardines showing stocks along Peru and northern Chile. Data from Instituto del Mar del Peru (1966) and Instituto de Fomento Pesquero (Chile, 1967).

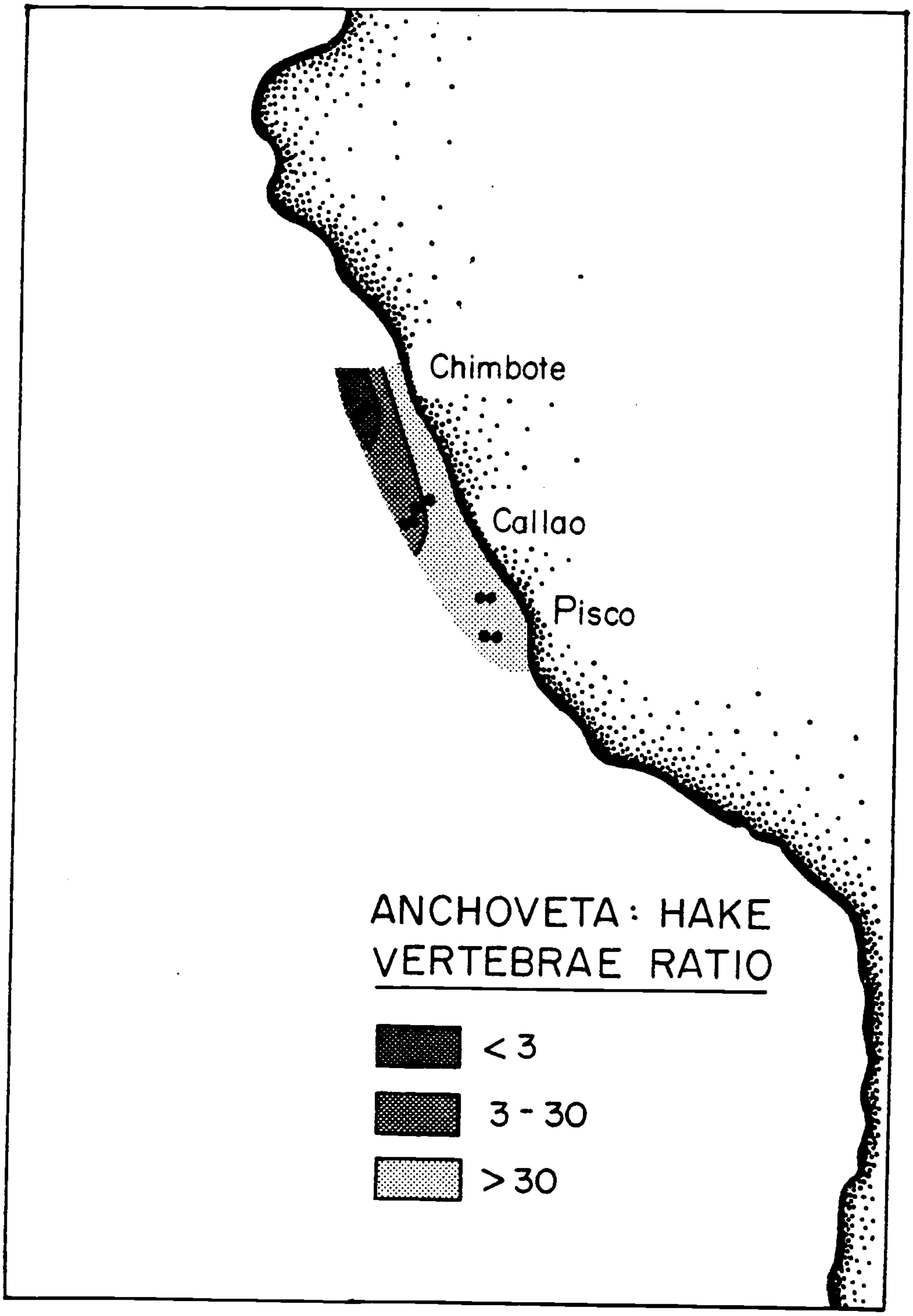


Figure 4. The distribution of hake and anchoveta vertebrae in surface sediments off Peru.

Limited sampling of radically different sedimentary facies and the vagaries of vertebrae and scale preservation do not permit any greater resolution of species distribution patterns in surface sediments at present.

Downcore Results

X-Radiograph data

X-radiographs of sediment cores expose both sedimentary structures and the presence of fish bones. A knowledge of the sedimentary record in the Peruvian cores is essential to an understanding of the downcore record of biogenous remains. Thus, the following section begins with a brief review of sedimentological data (texture, structure, sedimentation rates) and concludes with a presentation of the results from X-radiography in a context of the sedimentary record.

Lithologic columns for three Kasten cores situated along the transect of cores between 11-12°S. are shown in Figure 5. Also shown is a lithologic column for core 7706-37, located to the south of the transect. Varved sediments like those of the Santa Barbara Basin (Hülsemann and Emery, 1961; Soutar and Isaacs, 1974) were not recovered off Peru. However, coarsely laminated and thinly banded sediments were frequently encountered at depths of 200-600 m intercalated with discontinuously laminated, homogeneously bioturbated, and turbidite-like facies like those previously described from southern California by Hülsemann and Emery (1961). Whereas

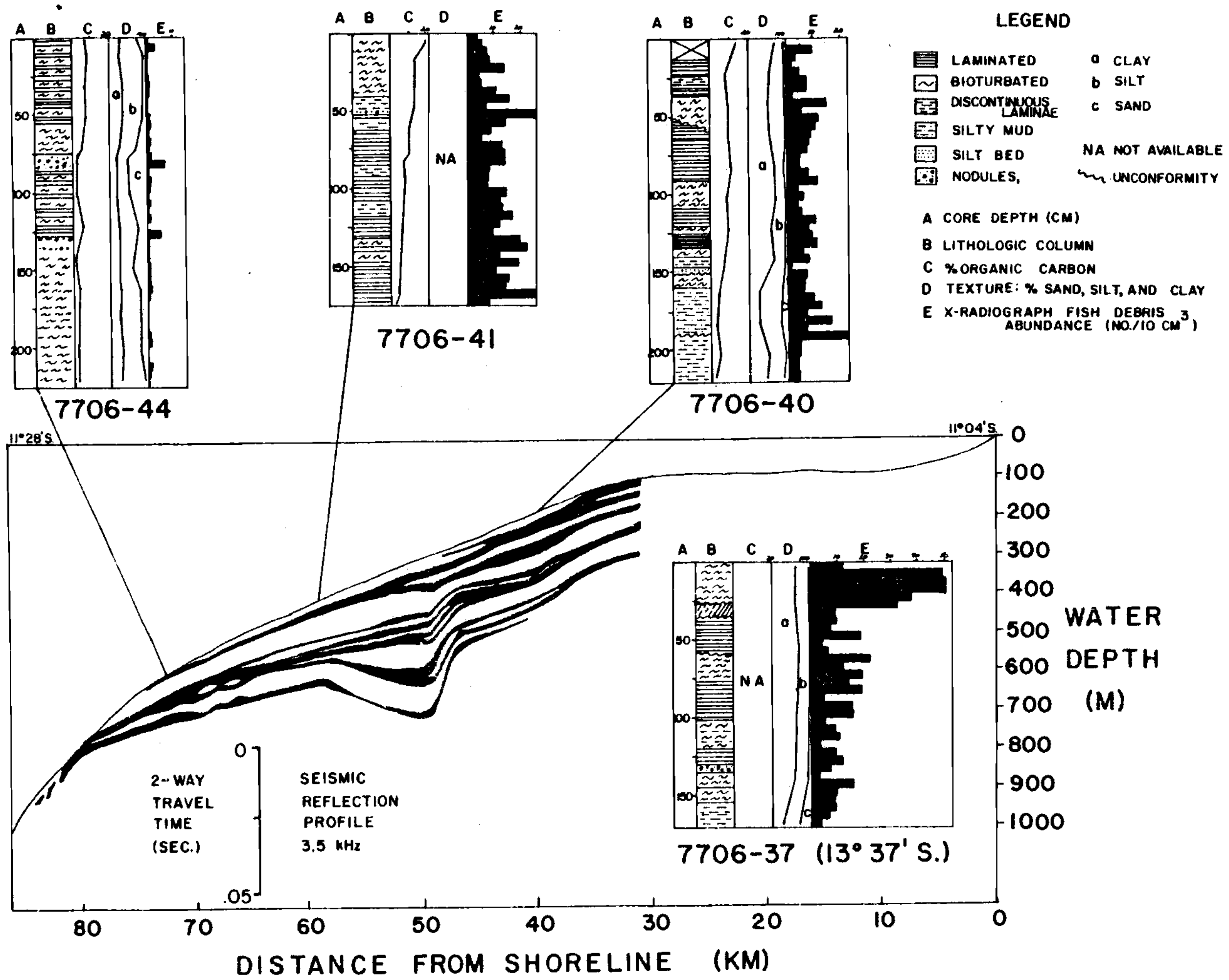


Figure 5. Lithologic columns, organic carbon (E. Suess, unpub.), textural analysis (Scheidegger and Krissek, unpub.), and X-radiograph fish debris abundance in the upper part of three cores along a transect at 11-12°S. Also shown are the same data for core 7706-37 (13°37'S.). Seismic reflection profile of upper slope mud lens along transect at 11-12°S. after Kulm (unpub.).

the least disturbed sediments from California occur in intraslope basins, the partially laminated sediments off Peru are restricted to an upper slope mud lens (Scheidegger et al., 1978) composed of at least 50 m of layered sediments (Figure 5) that are truncated at depths of 500-700 m.

Major unconformities occur in several cores, most notably in cores 7706-40 and 7706-37 (Figure 5). Angular erosive contacts, contorted bedding, and displaced, rotated, yet intact wedges of sediment suggest widespread slumping. Pb-210 and C-14 dating of core 7706-37 indicate that one unconformity at 26-35 cm represents a temporal hiatus of more than 11,000 years. Unpublished compactional tests conducted by W. Busch at Oregon State University indicate a former sedimentary overburden of 7-14 m. Less spectacular breaks in the sedimentary record are sometimes marked by parallel unconformities and residual accumulations (lag deposits) of coarse fish debris and pebbly or granular phosphorites (7706-40, 190 cm; 7706-44, 128 cm).

Little obvious correlation exists between fish debris and sedimentary organic carbon or lithology. Textural data (Scheidegger and Krissek, unpublished data) and the organic carbon content of the sediment (Müller and Suess, 1979) presented in Figure 4 can be compared with fish debris abundance in the same figure. Along the transect at 11-12°S. organic carbon peaks at the surface of core 7706-41 (411 m) and generally decreases with sediment depth in all cores. The coarsest sediments tend to have lower values of organic carbon (7706-40, 160-190 cm; 7706-44, 75-105 cm). The coarseness of these intervals can often be attributed to greater concentrations of fish debris.

There is a poor correlation of fish debris with sediment structure. The upper 30-40 cm of both 7706-41 (411 m) and 7706-37 (370 m) are bioturbated, yet the latter interval has nearly ten times as much fish debris as the former. Bioturbated intervals are also associated with both fish debris maxima and minima in the same cores (7706-40, 37-50 cm, 92-110 cm; 7706-37, 49-75 cm, 102-125 cm).

A detailed consideration of downcore patterns of fish debris abundance is best left to the following discussion section, but two points can be made now with respect to the X-radiograph data. First, a trend in the surface distribution of fish debris in Figure 4 is reiterated in Figure 5. Fish remains are rarely present below water depths of 600 m unless they have been locally introduced by slumps or concentrated as lag deposits by bottom currents.

Secondly, fish debris abundance is fairly uniform within cores (Figure 5) and between cores from similar water depths (Table 2). Standard deviations of scales and vertebrae within a core are typically only one-half of the mean. An exception to this rule is core 7706-37, in which the upper 30 cm contained anomalously high numbers of fish bones. Excluding the upper interval, however, the rest of the core

Table 2. X-radiograph abundance of fish debris in several cores on the upper continental slope off Peru showing relative uniformity of fish debris within cores and differences between cores.

Core W7706-	Number of Samples	X-radiograph Average	Fish Debris (No./14 cm) Standard Deviation
04	37	15.3	7.5
37	34	22.4	21.5
w/o 0-30 cm	28	14.5	7.4
40	43	10.8	5.8
41	36	16.8	8.0
44	43	1.1	1.8

had relatively uniform concentrations of fish debris comparable with other cores from similar water depths. The constancy of downcore abundance and the relatively uniform preservational state of the fish debris within cores suggests that the fish debris does not rapidly dissolve once it is buried, but remains intact for at least a period of several thousand years.

Downcore Sieving Results

Vertebrae and scale counts from the upper part of six cores collected along the transect between 11-12°S. are shown in Figure 6. Of these cores, a Reineck and Kasten core each were taken at two different stations. In the case of cores 7706-39 and -40 (Figure 2, see inset for locations), the fish debris stratigraphy is almost identical in the two cores to a depth of about 40 cm, at which point sedimentation in core 7706-39 is interrupted by an unconformity. Maxima of anchoveta scales and vertebrae at 0-15 cm and hake scales at 30 cm are common to both cores.

Another pair of cores, 7706-41 and -42, are as different from each other as any two cores from the entire upper slope off Peru (Figure 6). Whereas core 7706-41 has abundant fish debris and virtually no benthic foraminifera below a depth of 10 cm ($CaCO_3$ = 1-2%; E. Suess, unpublished data), core 7706-42, which was recovered at the same station and depth as core 7706-41, has only one-fourth as much fish debris and

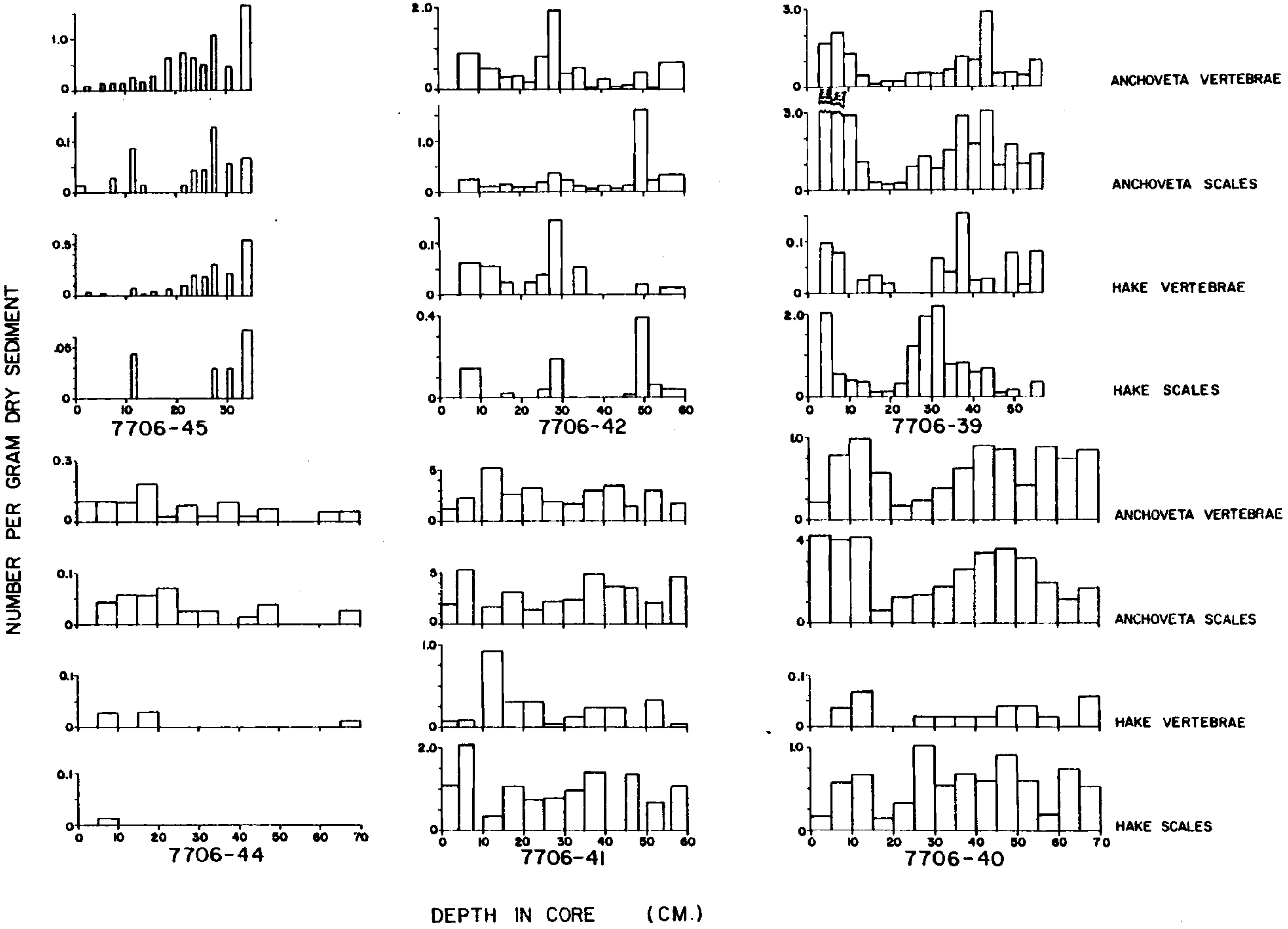


Figure 6. Abundance of anchoveta and hake vertebrae and scales in the upper part of six cores from the upper slope off Peru between 11-12°S.

many times the numbers of benthic foraminifera ($CaCO_3$ = 4.2%; E. Suess, unpublished data). Although the foraminifera-rich surface of core 7706-41 might be correlated with the base of core 7706-42 (the latter being known to have overpenetrated the sediment by several centimeters), neither the cruise log nor the high organic carbon values in the upper 10 cm of core 7706-41 that are typical of surface sediments elsewhere on the upper slope off Peru indicate that core 7706-41 overpenetrated the half-meter required to make such a correlation. Rather, the differences between the two cores are likely to be a real manifestation of sedimentary patchiness on the sea floor. The extreme variability of continental margin sedimentation off Peru has been remarked upon previously (Doe, 1978).

The average abundance (number $\cdot$ (g dry sediment)$^{-1}$) of anchoveta and the hake scales and vertebrae in cores along the transect at 11-12°S. is summarized in Table 3.

Anchoveta and hake vertebrae are 4.4 and 9.5 times as abundant, respectively, in core 7706-41 as they are in 7706-40, whereas the scales of the same two species are only 1.1 and 2.0 times as abundant in core 7706-40 (Table 3a). The relative loss of scales in core 7706-41 compared to 7706-40 is about the same for both species (Table 3b). There is also an equal relative loss of scales for both species in Kasten core 7706-41 compared to Reineck box core 7706-42, taken at the same station (Table 3b). Too little debris was

Table 3. a) Average abundance of anchoveta and hake scales and vertebrae (numbers per gram of dry sediment) and average scale:vertebrae ratios in the upper part of five cores between 11-12°S.

Core W7706-	39	40	41	42	44
Anchoveta scales	1.892	2.681	3.062	0.258	0.034
Anchoveta vertebrae	0.897	0.590	2.579	0.456	0.081
Ratio	-2.1-	-4.5-	-1.2-	-0.6-	-0.4-
Hake scales	0.743	0.536	1.081	0.058	0.001
Hake vertebrae	0.041	0.024	0.229	0.028	0.006
Ratio	-18.1-	-22.0-	-4.7-	-2.1-	-0.2-

b) Ratios of scale:vertebrae ratios in cores 7706-40, -41, and -42. Ratios > 1.0 indicate that the loss of scales relative to vertebrae in the core of the denominator is greater than that of the core in the numerator.

	Anchoveta	Hake
$\dfrac{\frac{\text{Scales}}{\text{Vertebrae}}\ 7706\text{-}40}{\frac{\text{Scales}}{\text{Vertebrae}}\ 7706\text{-}41}$	3.8	4.7
$\dfrac{\frac{\text{Scales}}{\text{Vertebrae}}\ 7706\text{-}41}{\frac{\text{Scales}}{\text{Vertebrae}}\ 7706\text{-}42}$	2.0	2.2

found in core 7706-44 to make analogous comparisons. These results suggest that some process has indiscriminately reduced the number of scales or concentrated vertebrae in cores 7706-41 and -42.

Further support of this idea is presented in Figure 6. It can be seen that scales of the hake and anchoveta have similar trends downcore in cores 7706-41 and -42, as do the vertebrae of the two species. In contrast, scales and vertebrae of the same species (anchoveta, hake) covary downcore in cores 7706-39 and -40. Selective winnowing, dissolution, or abrasion of scales has obviously greatly altered the fish debris record in the two former cores. The general homogeneity of the sediment in core 7706-41 indicates a more or less uniform depositional regime through time, probably continually subjected to some reworking by benthic organisms. Biogenic encrustations resembling the calcareous tubes of spirobid worms and lag deposits of fish debris distributed throughout the core support the winnowing hypothesis. In contrast, the covariance pattern of cores 7706-39 and -40 are believed to demonstrate a relatively unaltered signal of biological productivity.

The size distribution of hake and anchoveta vertebrae from several cores is shown in Table 4. The three size categories correspond to the three mesh sizes used in the sieving. Vertebrae of the two species of fishes were counted and summed to a depth of 60 cm in each of the cores and then

Table 4. The size distribution of anchoveta and hake vertebrae in cores above and below 500 m, between 11-12°S. Cores above 500 m include 7706-39, -40, -41, and -42. Cores below 500 m include 7706-43, -44, and -45.

	Anchoveta			Hake		
Depth (m)	500-1000[1]	1000-3000[1]	3000+[1]	500-1000[1]	1000-3000[1]	3000+[1]
Less than 500	62	28	8	29	51	20
Greater then 500	15	73	12	41	52	7

[1] Size fraction (μ)

summed again for cores above 500 m and cores below 500 m, the depth at which the upper slope mud lens begins to pinch out (Figure 5) and the anchoveta scale:vertebrae ratio decreases rapidly (Table 3). Anchoveta vertebrae are generally smaller in cores from shallower water. Hake vertebrae are coarser than anchoveta in cores from shallower water, which may be attributed to the original in vivo size distribution of vertebrae in populations of the two species. Of particular interest is the greater abundance of small hake vertebrae in cores from deeper water, a trend that is contrary to that of the anchoveta. The inverse trend in size distribution implicates a biological rather than physical explanation for the change.

Poulsen (1958) has observed that Chilean hake mature on the shelf, then return to deeper water to spawn. As a result, younger and smaller fish may tend to congregate on the upper slope. The greater relative abundance of smaller hake vertebrae in cores from deeper water may be a consequence of the hake's life history as well as the physical processes responsible for the actual deposition of the vertebrae. The relative decrease of small anchoveta vertebrae in deeper water may be due to greater disintegration of the bones at depth or may indicate a real scarcity of small anchoveta at distances greater than 70 km offshore, although no evidence for such a decrease in the numbers of small anchoveta has been reported (Sanchez, 1966; Jordan, 1971).

Core 7706-40: Downcore Study

Nekton remains, benthic invertebrates, diatoms, and other biogenic debris was collected from the entire length (222 cm) of core 7706-40 in an effort to learn more about the response of the Peruvian upwelling system to Holocene climatic and oceanographic events. The oldest sediments recovered from core 7706-40 are about 12,000 years (DeMaster, 1979). Time assignations for the core (Figure 7) are based upon radiocarbon analyses at 5-10, 40-45, 90-95, and 208-215 cm (DeMaster, 1979) and at 140-145 and 160-165 cm (Radiocarbon, Ltd., Lampasas, Texas). All ages are C-14 model ages. Inasmuch as surface age anomalies off Peru may vary according to the intensity of upwelling, which brings C-14 depleted water to the surface along the coast (Taylor and Berger, 1967; Killingley and Berger, 1979), the model ages should be accepted with caution.

Interpolation between radiocarbon dates was greatly complicated by the presence of sedimentary unconformities of vastly unequal time duration. Major unconformities inferred from lithological and radiometric data were identified at 55-60 cm, 147-151 cm, and 190 cm (Figure 7). Deposition appears to have proceeded more or less uniformly between 0-55 cm and 60-147 cm. A pair of C-14 dates above and below the first unconformity yield sedimentation rates of 100 and 135 cm per thousand years, respectively. Thus,

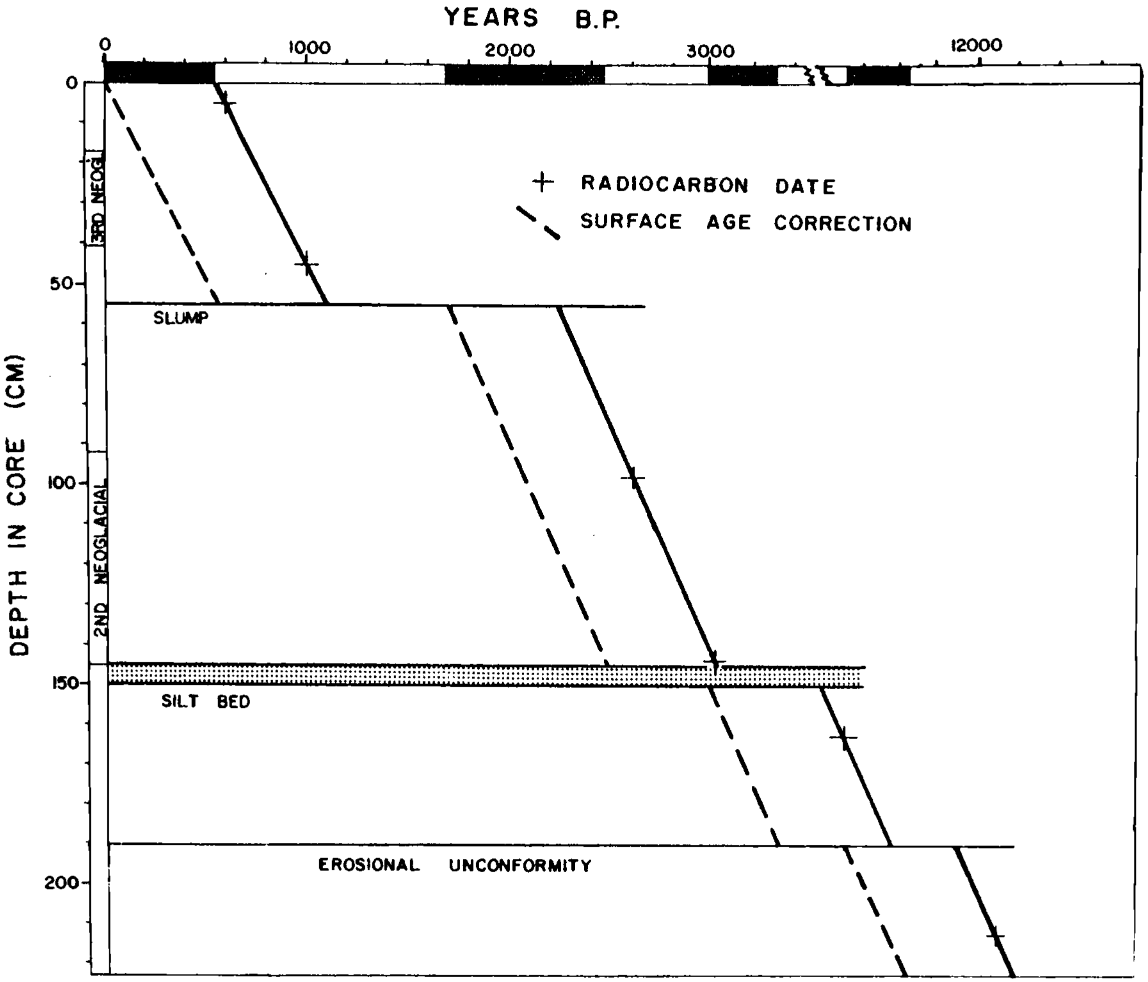


Figure 7. Radiocarbon dates and extrapolated C-14 model ages, core 7706-40. Note interrupted time scale. Shaded areas are time intervals preserved in core. Duration of second and third neoglacial periods are shown along depth axis. All ages discussed in text are C-14 model ages, which include surface age anomaly correction (dashed line).

the first unconformity is bounded by model C-14 ages of 550 and 1700 yr. B.P. Offset laminae and banded sediment layers along an inclined plane indicate the unconformity may be the result of slumping.

The second inferred unconformity (147-151 cm) is marked by a 4 cm bed of well-sorted silt and sand nearly devoid of organic remains. The basal interval (1 cm) of parallel lamination rests unconformably upon discontinuously laminated silty mud. The upper interval is somewhat gradational with the overlying mud and shows signs of minor bioturbation to a depth of 1 cm. The minimum age of the second unconformity is 2450 yr. B.P. The maximum age is problematical since there is only one C-14 age determination between the silt bed and the third unconformity (190 cm). If an average sedimentation rate of 115 cm per thousand years is assumed (an assumption not entirely warranted because of textural and structural differences between the intervals 0-147 cm and 151-190 cm), the maximum age of the second unconformity is 3000 yr. B.P. and the minimum age of the third unconformity is 3300 yr. B.P.

Deep (2-5 cm) burrows filled with coarse bioclastic and lithoclastic debris that contrasts sharply with the underlying clayey matrix define the third unconformity at 190 cm. Again, assuming a sedimentation rate of 115 per thousand years, the maximum age of the third unconformity is about 11,400 yr. B.P. The third unconformity would therefore represent a hiatus of 8,000 years. The single burrowed horizon at 190 cm suggests that some part of this time was a period of non-deposition. Consequently, the actual timing of the event responsible for the third unconformity may be the older age, in which case the non-deposition may be related to a lowered eustatic sea level 11,000 yr. B.P. (Donn et al., 1962). The two shallower unconformities were probably caused by instantaneous events coincident with the youngest age associated with them.

Accumulation rates of anchoveta, hake, and sardine scales in core 7706-40 are shown in Figure 8. Table 5 lists actual scale counts of all the rarer species present in the 41 sieved samples from core 7706-40. The dominance of the anchoveta and hake are evident from even a causal inspection of Figure 8 and Tables 2 and 5.

Details of the scale record are most easily presented in the context of unconformity-bounded sections of sediment representing discrete intervals of time.

Anchoveta scales are notably scarce in the oldest sediments of core 7706-40 (222-190 cm, 11,700-11,400 yr. B.P.), as are hake scales and the scales of most species of fish. Lest it be thought that all scales are less numerous in older and possibly diagenetically altered sediment, it should be noted that the highest accumulation rates of sardine scales occur in this interval.

The section 190-147 cm (3300-3000 yr. B.P.) contains

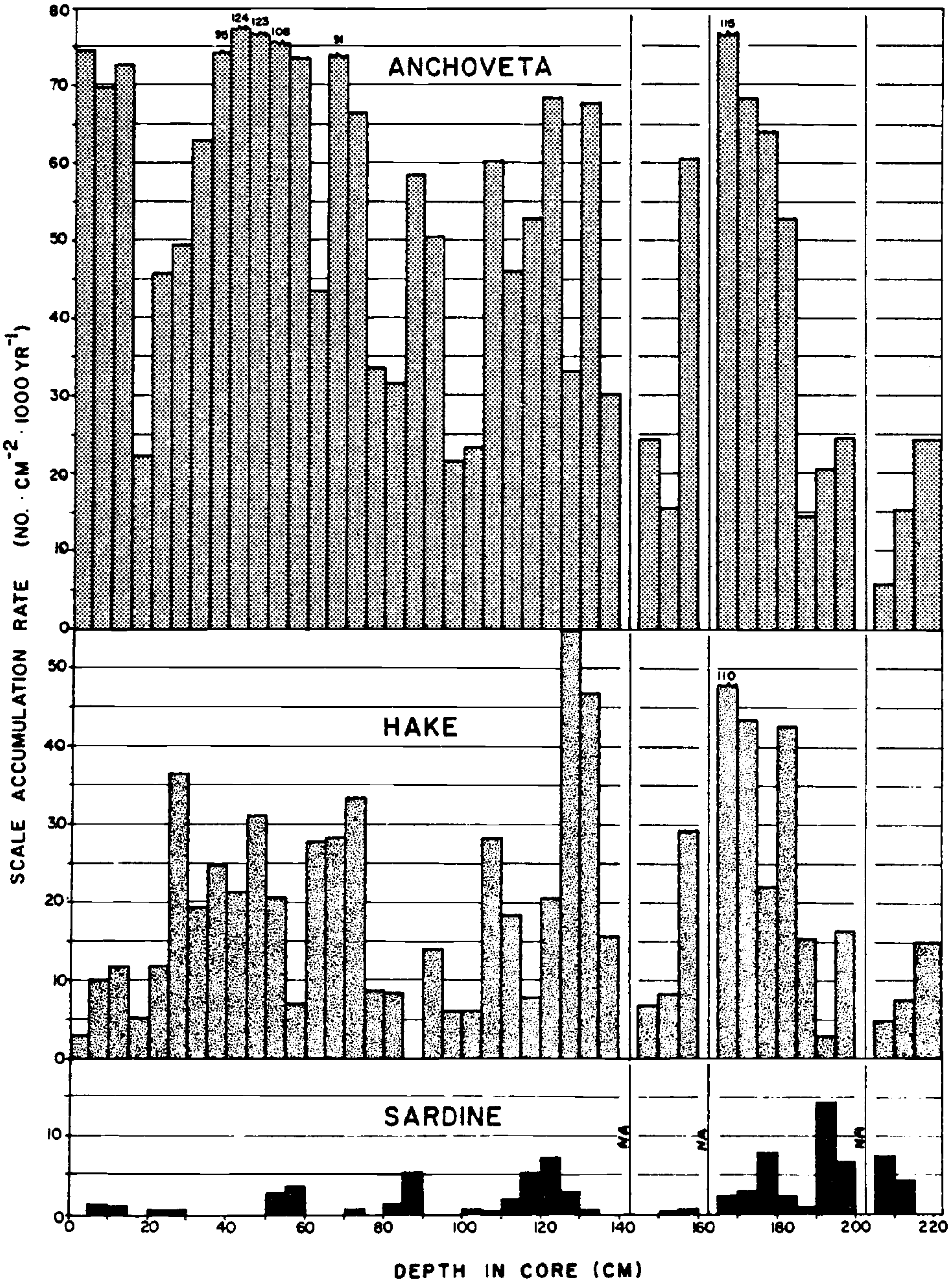


Figure 8. Accumulation rates of anchoveta, hake, and sardine scales in core 7706-40. NA=samples not available for study.

Table 5. Actual counts of scales belonging to rarer species of fish found in core 7706-40.

DEPTH IN CORE (cm)	Sardinops	Cololabis	Physiculus	Decapterus	Trachurus	Other Carangids	Scomber	Lampanyctus	Myctophum	Other Lanternfish	Scorpaenids	Unidentified Scales
0-5		1		3								7
5-10	2						1			1		2
10-15	2	2	1					1		1	1	
15-20												
20-25	1	2										
25-30	1	1	3			2					1	
30-35			1	1								
35-40		1	1					2				2
40-45								1				1
45-50			1					1			3	2
50-55	4	1					3					
55-60	5	1		2			1	4				1
60-65		1				1		3				
65-70				1		1	1	6				3
70-75	2							2		2		
75-80			1				1				1	
80-85	2					1						
85-90	8	1										1
90-95												3
95-100								1				
100-105	1					1						
105-110	1	1				2						
110-115	3	1				3		1				
115-120	5	1						2				
120-125	11				1		1			4		2
125-130	4		3			1	1				2	4
130-135	1		3			1						
135-140												
140-145	NOT AVAILABLE				....							
145-150								1				1
150-155	1						1			1		2
155-160			1		1	3		5		1		5
160-165	NOT AVAILABLE				....							
165-170	3	1	1	1	1	2		4	2	2		1
170-175	4		1		1		1	1		4		1
175-180	10		1			3				2		3
180-185	3	2	3	6	3	1	2			1	2	1
185-190	1	2				1		1				2
190-195	13	1		1		1	2	4				1
195-200	9						1	1				2
200-205	NOT AVAILABLE				....							
205-210	9					2	1			1		1
210-215	5					1						2
215-222		2		1							1	2

a diverse fish fauna and the first of several intervals characterized by an inverse correlation of sardine and hake scales. The interval begins with a synchronous increase in the number of hake and anchoveta scales at the unconformity at 190 cm, but is interrupted at 180-175 cm by a sudden decrease in the number of hake scales and a simultaneous increase towards a maximum of sardine scales. Following the sardine scale maximum there is a decrease in the number of sardine scales and an increase in the number of hake scales to the previous level of abundance. Finally, at the end of the interval there is a decrease in both the number of hake and anchoveta scales. A variety of other fish scales are found associated with the first interval, including those of sauries, carangids, morid cods, and lanternfish (Table 5).

The second interval commences at 147 cm, the base of the third section (147-60 cm, 2450-1750 yr. B.P.). Hake scales attain their two maxima at 125-130 cm and 110-105 cm and then decline in concert with anchoveta scales to a minimum at 100 cm. The sardine maximum occurs at 125-115 cm (2300-2200 yr. B.P.); it represents the greatest post-early Holocene accumulation of sardine scales present in core 7706-40. The diversity and abundance of rarer fish in the second interval is reduced from that of the first interval. Sauries and carangids are fairly well represented but scales of species belonging to the order Myctophiformes are rare.

A third interval, weaker than the previous two, extends from 100-60 cm. The sardine scale maximum and hake scale minimum at 90-85 cm (2050-2000 yr. B.P.) follow a poorly developed hake scale maximum between 95-90 cm and precede a very strong hake scale maximum at 75-60 cm. Fish scale diversity in the third interval is remarkably low. Only a single scale apiece was found of the saury, morids, carangids, lanternfish, and rockfish in 1000 g of sieved wet sediment.

The fourth interval (60-40 (?) cm), apparently attenuated by the unconformity at 55-60 cm, occurs at the base of the youngest interval (60-0 cm, 600-0 yr. B.P.). Lanternfish scales are especially abundant in the fourth interval and, in general, the diversity of this interval approaches a level previously reached in the first interval.

A fifth interval of dubious identity may occur between 40-0 cm (400-0 yr. B.P.). The interval is more clearly defined by the presence of saury and morid scales than it is by an inverse correlation of sardine and hake scales.

The fish debris record represents a mixed signal of biological production, deposition, and diagenesis. The character and relative importance of individual signals may be better understood by also looking at the sedimentary record of biogenous constituents other than fish debris. Among these other constituents are diatoms, benthic foraminifera, molluscs, and fecal pellets.

At depths of 0-60 cm in core 7706-40 (and 0-40 cm in core 7706-39) up to 100 percent of the sediment retained by the 500 μ mesh screen consisted of rod-shaped fecal pellets, 0.75 mm in diameter and 1-2 mm long (Figure 9). Each pellet was flattened dorso-ventrally and incised with a single, shallow, longitudinal groove on each side. Poorly preserved, longitudinal, internal canals were barely visible in transverse section. The canals were located at a common radius from the center of the pellet, forming a cylindrical zone of weakness about which the pellet broke when agitated. In many of the pellets there was a noticeable segregation of fine-grained material along the ventral margin. Moore (1932) observed all three characteristics (simply grooved exterior, canalized interior, size fractionation of fecal matter) in the fecal pellets of galatheid crabs. Pellets of other crustaceans, molluscs, annelids, and echinoderms described by Moore (1931, 1932, 1933) and Edge (1934) failed to resemble the rod-shaped pellets from Peru in all of the above respects.

A second kind of pellet, composed of loosely aggregated fibrous masses of diatoms (Thalassionema nitzschoides, Thalassoithrix frauenfeldii, and spines of Chaetoceros), yellow-brown organic matter, and a small quantity of silt, is bound together in roughly cylindrical form, 0.5-1 mm in diameter and 1-3 mm long. The pellets commonly occur in great numbers matted together in laminations between 70-147

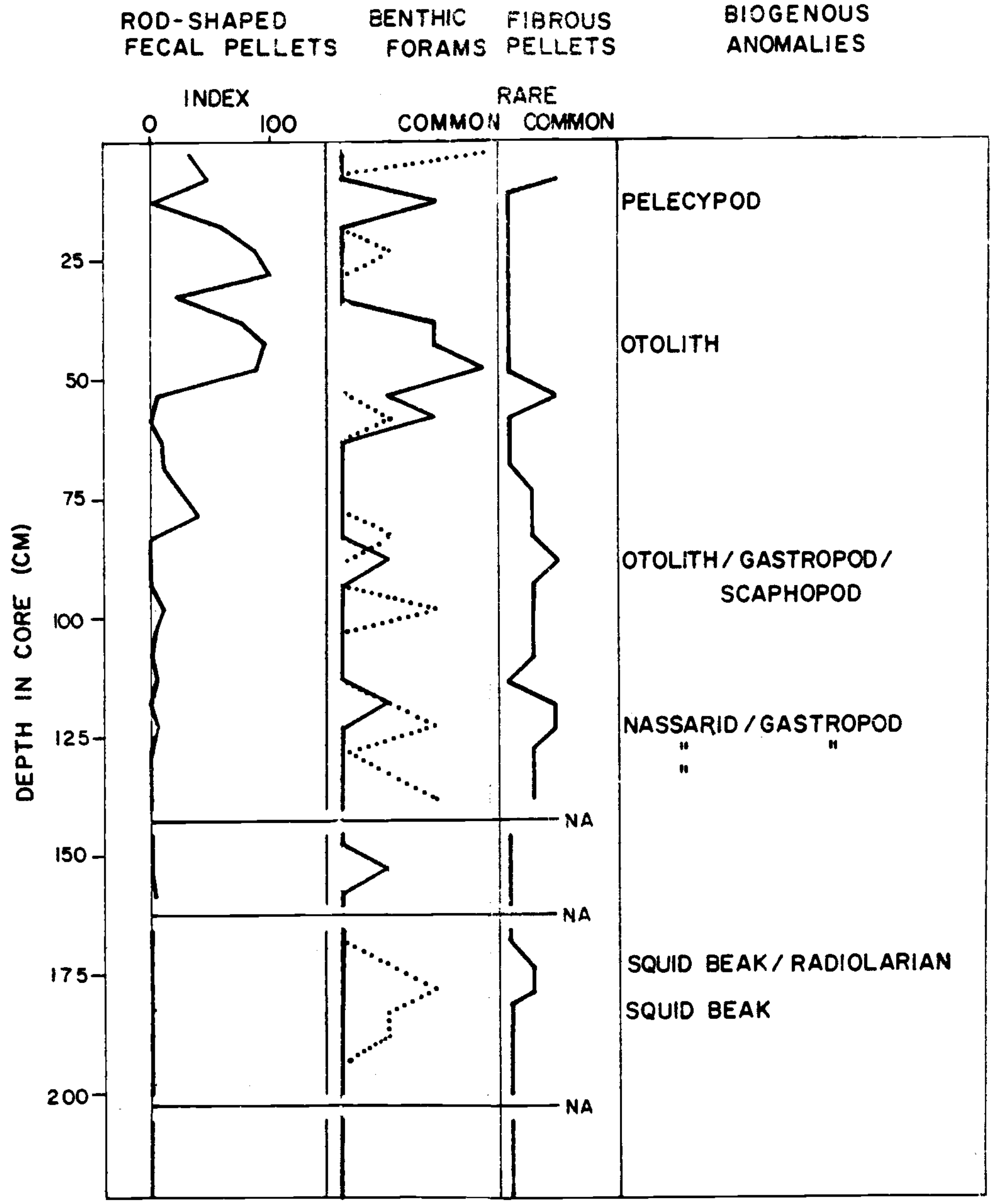


Figure 9. Biogenous debris in core 7706-40. Solid line in second column represents the benthic foraminifera *Cancris inflatus*; dotted line indicates abundance of all other species of foraminifera.

cm (Figure 9). They are found less frequently in laminae outside that interval and rarely as individual pellets dispersed freely throughout the sediment.

Most of the fibrous fecal pellets contain the full spectrum of diatom species that were present in the surrounding matrix. Some pellets, however, are selectively enriched with such diatoms as Actinocyclus octonarius and Roperia tesselata or the silicoflagellates, Dictyocha, Distephanus, and Octactis spp. The former pellet type might be the excretion of benthic organisms that feed indiscriminately on detritus, including diatom taphocoenoses, preserved at the sediment surface. In fact, several of the fibrous fecal pellets do resemble the irregular pellets of echinoderms or the segmented, cylindrical pellets of some molluscs illustrated by Edge (1934). Pellets containing a preponderance of one or a few planktonic species may have been excreted by epipelagic organisms (fishes, crustaceans) feeding upon low diversity phytoplankton blooms that are known to flourish in the coastal upwelling area off Peru (Sukhanova et al., 1978). N. Staresinic (written communication, 1979) has observed rod-shaped anchoveta fecal matter in the waters off Peru and found that anchoveta fecal matter was a major component of material collected in sediment traps from the same area.

The algal clumps identified as fecal pellets are not to be confused with the abundant organic remains preserved in near-surface sediments. Elongate, diaphanous tubes of algal and annelid origin and fibrous, woody fragments are not uncommon in the upper 10-15 cm of sediment on the upper continental slope off Peru.

The calcerous remains of molluscs are rarely encountered in core 7706-40 (Figure 9), but within the intervals in which they do occur (15-10 cm, 90-85 cm, 135-120 cm) they are not uncommon. Pelecypod fragments were only found in the shallowest interval. Two different gastropod assemblages were recognized. Between 135-120 cm (2400-2200 yr. B.P.) several well-preserved nassarids were discovered. Fragments of unidentified smooth-shelled gastropods were also present. Between 90-85 cm (about 1900 yr. B.P.) several fragile shells of tectibranchs were found intact, as was a single specimen of an unidentified scaphopod.

Planktonic foraminifera are poorly preserved and rare in the sediment samples. Benthic foraminifera are better preserved but still relatively uncommon in all size fractions of core 7706-40, compared with the numbers found in cores from deeper water. Cancris inflatus, an inhabitant of upper bathyal depths (Bandy and Rudolpho, 1964), was most abundant at core depths of 35-60 cm (Figure 9). Maximum numbers of Cancris were also found at the same core depth in the Reineck box core (7706-39), taken at the same station as 7706-40. Below a core depth of 60 cm, benthic foraminifera maxima generally coincide with intervals in which other calcareous remains were also well-preserved.

Between 190 and 170 cm the nature of the coarse fraction of sediment (> 500 μ), including the biogenous constituents, is unlike that of any other section of core 7706-40. Granular nodules and pebbles of phosphorite are scattered throughout the interval, which directly overlies the major sedimentary unconformity at 190 cm. Benthic foraminiferal species of _Globobulimina_ (?) and _Dentalina_ were found in low numbers. Also present were squid beaks (_Gonatus antarcticus_ (?)) and large spumellarian radiolarians. Since the association of phosphorites, radiolarians, squid beaks, _Globobulimina_, and _Dentalina_ is only well developed in core 7706-44 (same transect as 7706-40, 584 m) and to a lesser extent in core 7706-45 (804 m), its appearance in core 7706-40 has been termed "allochthonous".

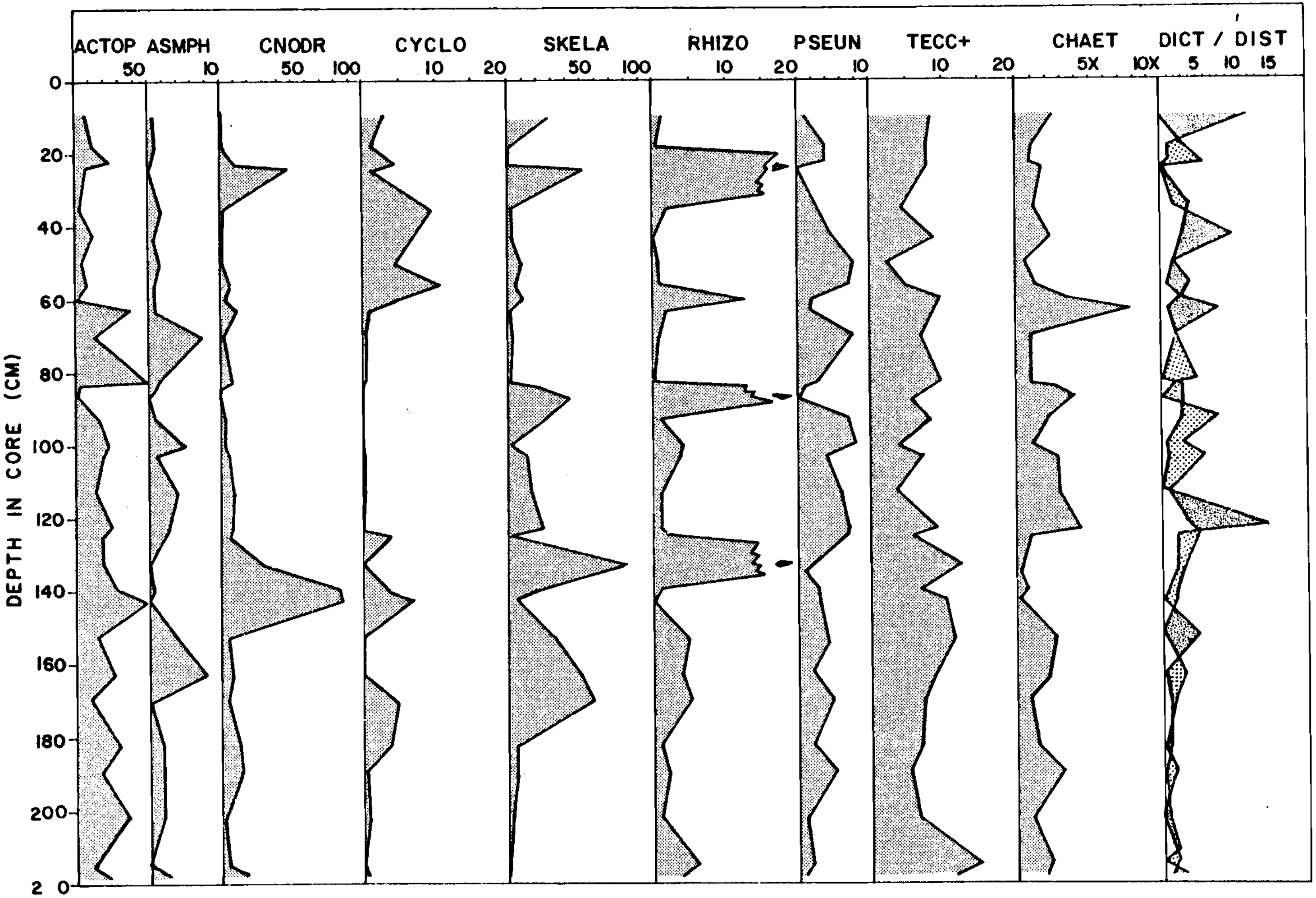
Diatoms are the dominant group of phytoplankton in surface waters off Peru (Sukhanova et al., 1978) and in surface sediments on much of the continental margin (Zhuse, 1972; Schuette and Schrader, 1979). The downcore distribution of selected diatom taxa in core 7706-40 is shown in Figure 10.

Vegetative cells and resting spores of _Chaetoceros_ comprise at least 50 percent of all diatoms in most downcore samples and more than 80 percent in a sample from 65-60 cm. Between 151-125 cm, however, _Chaetoceros_ cells and spores constitute only 33-50 percent of all diatoms.

Figure 10. Downcore distribution of selected diatom species groups in core 7706-40. Column heading abbreviations are:

ACTOP - *Actinoptychus* spp.
CYCLO - *Cyclotella striata*/*stylorum*
ASMPH - *Asteromphalus* spp.
SKELA - *Skeletonema costatum*
RHIZO - *Rhizosolenia* spp.
PSEUN - *Pseudoeunotia doliolus*
TECC+ - *Thallassiosira eccentrica* 'group'
CHAET - *Chaetoceros* spp.
DICT/DIST - *Dictyocha*/*Distephanus* (silicoflaggelates

All diatoms except *Skeletonema*, *Rhizosolenia*, and *Chaetoceros* are expressed as percentage composition of a *Skeletonema*-*Rhizosolenia*-*Chaetoceros* free diatom assemblage. *Skeletonema* and *Rhizosolenia* are expressed as percentage composition of a *Chaetoceros* free diatom assemblage. *Chaetoceros* spp. are expressed as multiple of all other diatoms. Diatom abundances are expressed differently to minimize the effect of abundant species on the percentage composition of less numerous species. Silicoflagellates are reported as actual counts. Shaded areas represent the excess of *Distephanus* tests over *Dictyocha* tests. Stippled areas represent an excess of *Dictyocha* tests over *Distephanus* tests.


ACTOP
50
ASMPH
10
CNODR
50
100
CYCLO
10
20
SKELA
50
100
RHIZO
10
20
PSEUN
10
TECC+
10
20
CHAET
5X
10X
DICT / DIST
5
10
15
DEPTH IN CORE (CM)
0
20
40
60
80
100
120
140
160
180
200
2 0

Skeletonema, a genus extremely sensitive to dissolution (Schuette and Schrader, 1979a), is found in large numbers between 175-84 cm. At depths of 175-125 cm *Skeletonema* valves generally comprised more than 50 percent of all non-*Chaetoceros* diatoms. Oddly, the weakly skeletized tests of *Skeletonema* were not more abundant in younger sediments near the surface of the core. The large accumulation of this genera in core 7706-40 would seem to imply occasionally high primary productivity between 3200-1800 yr. B.P.

Rhizosolenia delicatula and *R. fragilissima*, two species commonly reported in surface waters off the coast of Peru (Guillen, 1969; Sukhanova et al., 1978), were never seen in any of the sediment samples from core 7706-40. However, several other species of *Rhizosolenia*, presumably more resistant forms, were found in low numbers (0-5 percent). Occasionally, at depths of 133, 87, 60, and 24 cm, the abundance of the genus grew by an order of magnitude. Most of the increase is attributable to one species, *Rhizosolenia shrubsolei* (Table 6). Other species of *Rhizosolenia* show different distribution patterns. *R. alata* is virtually absent in the upper 45 cm of the core and at depths greater than 190 cm. *R. bergonii*., an oceanic indicator (Schuette and Schrader, 1979a, b), is present throughout the core but is especially common between 25-18, 55-40, 125-90, 145-140, and 222-190 cm. *R. styliformis* is usually more common at depths greater than 140 cm.

Table 6. Relative abundance and total numbers of *Rhizosolenia* species in core 7706-40.

Depth in Core (cm)	*Rh. alata*	*Rh. shrubsolei*	*Rh. styliformis*	*Rh. bergonii*	Other *Rhizosolenia*	Total Number Counted
0- 5						
10	19	31	44	0	1	16
18	0	40	10	50	0	10
20-25	0	0	0	100	0	5
24	9	85	3	3	0	33
35	0	58	17	25	0	12
40-45	0	0	33	66	0	3
50	40	10	0	50	0	10
56	25	33	25	17	0	12
60	9	61	9	6	15	33
60-65	45	0	33	22	0	9
70	33	16	17	33	0	6
80-85	63	0	0	37	0	8
84	54	25	7	14	0	28
87	28	47	25	0	0	74
93	33	0	0	67	0	9
100	25	19	0	56	0	16
100-105	42	25	0	33	0	12
113	38	12	12	38	0	8
120-125	50	8	17	25	0	12
125	32	42	0	21	5	19
133	23	64	13	0	0	30
140	70	10	0	20	0	10
140-145	17	0	33	50	0	6
153	26	5	64	5	0	19
160-165	50	0	36	7	7	14
170	70	24	6	0	0	17
180-185	50	12	13	25	0	8
200-205	0	0	0	100	0	2
215	31	16	53	0	0	13
215-222	0	0	50	50	0	4

Several diatom species groups, including *Actinoptychus* spp. (a meroplanktic, dissolution resistant genus), *Coscinodiscus nodulifer* + *radiatus* (oceanic, dissolution resistant), and *Asteromphalus* spp. (oceanic) are more common at core depths greater than 60 cm, although the two former groups are also present in moderate numbers between 24-18 cm. The greatest number of *C. nodulifer* + *radiatus* occur between 153-133 cm, sandwiched between sediments containing large numbers of *Skeletonema*. The *Coscinodiscus* valves are equally abundant in both the typical organic muds and in the silt bed between 151-147 cm. Mixing of the *Coscinodiscus* and *Skeletonema* sediments was not evident across the older contact (about 152 cm), but did extend for several centimeters across the younger boundary (135-150 cm).

Pseudoeunotia doliolus, a tropical oceanic species (Zhuse, 1972), and *Thalassiosira eccentrica* 'group', characteristic of subtropical neritic waters (Zhuse, 1972), account for six percent and 16 percent of the diatoms, respectively. The species are generally inversely proportional to each other but show no well-developed downcore trends in abundance. Interestingly, very few *P. doliolus* are found in samples containing high percentages of *Rhizosolenia shrubsolei*.

Cyclotella striata/stylorum, another meroplanktic species resistant to dissolution (Schuette and Schrader, 1979a, b), is most frequently found in the upper 60 cm of core

7706-40 and virtually absent between 125-60 cm. Below 125 cm *Cyclotella* occurs only intermittently.

Silicoflagellates of the genera *Dictyocha* and *Distephanus* were counted on the same slides as the diatoms. Fewer than 20 silicoflagellates were encountered for every 500-2000 diatoms counted. Between 65-0 cm cold-water *Distephanus* spp. (Mandra, 1969) outnumber warm-water *Dictyocha* spp. in all samples except those at 35, 24, and 18 cm (Figure 10). At greater depths in the core there are usually at least as many *Dictyocha* as *Distephanus* tests in each sample. Only at 153, 125, and 84 cm does *Distephanus* significantly outnumber *Dictyocha*.

Downcore Results: Core 7706-37

Fish debris abundance in selected samples from the entire length of core 7706-37 (see Figure 2) is presented in Tables 7 and 8. Scales and vertebrae are reported in Table 7 in numbers per gram of dry sediment because a paucity of radiocarbon dates and profusion of sedimentary unconformities (Figure 5) made sedimentation rate and accumulation rate calculations impossible.

Pb-210 dating (DeMaster, 1979) did indicate a sedimentation rate of 66 cm/1000 years in the upper 15 cm of sediment. A maximum surface C-14 age anomaly of about 1300 years can be inferred from a radiocarbon date of 1328 ±72 yr. B.P. at 0-5 cm (DeMaster, 1979). Below a major

Table 7. Abundance of fish debris (numbers per g dry sediment) in core 7706-37.

Depth in core (cm)	Vertebrae			Scales		
	Anchoveta	Hake	Other	Anchoveta	Hake	Other
0- 5	1.741	.044	.089	1.964	1.250	.313
0-10	20.940	1.316	1.203	1.729	.187	.226
10-15	9.968	.536	.747	2.224	.243	.357
20-25	5.999	.287	.483	.831	.241	.364
35-40[1]	.523	.027	.082	.907	.027	.206
45-50	.420	-0-	.171	2.087	.026	.066
60-65	.258	.013	.077	.824	.335	.064
70-75	.770	.115	.164	.770	.443	.295
75-80	.225	-0-	.045	.900	.255	.796
85-90	.193	.104	.089	.520	.104	.238
100-105	.336	.044	.058	.439	.073	.161
115-120	.232	.065	.052	.490	.039	.090
125-128	.306	.070	.083	.474	.084	.251
140-145	.478	.335	.315	.124	.028	.268
155-160	.244	.058	.070	.232	.186	.232
160-168	.233	.026	.026	.557	.155	.142

[1] Location of unconformity at 500 yr. B.P.

Table 8. Actual counts of scales belonging to rarer species of fishes found in core 7706-37.

Depth in Core (cm)	*Sardinops*	*Cololabis*	*Physiculus*	*Decapterus*	*Trachurus*	Other Carangids	*Scomber*	*Lampanyctus*	*Myctophum*	Other Lanternfish	Scorpaenids	Unidentified Scales
0- 5												5
5-10				3					1		1	2
10-15		2		2					1			3
20-25		2	1	2			11			2		10
35-40		3				5	1	4	1			1
45-50												25
60-65		1		1							3	
70-75		6	1	3		1		1			4	2
75-80		13	3	1		5		2			28	
85-90		1					2		1		5	6
100-105									1	3	3	
115-120									1		3	2
125-130			1			3	3	3			3	
140-145		1		1					1	2	19	3
155-160				1				1			18	
165-168		1		1		2					7	

sedimentary unconformity at 28-37 cm DeMaster measured C-14 ages of 13,060 ±200 yr. B.P. at 35-40 cm and 14,020 ±370 yr. B.P. at 80-85 cm. Thus, the only overlap between cores 7706-37 and 7706-40 lies in the upper 30 cm of the former core. The remainder of core 7706-37 was deposited during late-Pleistocene time.

The Holocene record of core 7706-37 (30-0 cm) is characterized by extraordinarily abundant fish debris primarily composed of sulfide-blackened anchoveta and hake vertebrae and bones. Scales of the anchoveta are also common, although not so numerous as in the upper part of core 7706-40 (Figure 8). A moderate diversity and abundance of scales other than anchoveta and hake is also present (Table 8). However, there is a complete lack of sardine scales in any of the Holocene or late-Pleistocene sediments sampled in the core.

Between 60-37 cm (about 13,000 yr. B.P.), an interval bounded by slump-induced unconformities (Figure 5), anchoveta scales and scales of most other fish are fairly common, but hake scales and vertebrae are virtually absent.

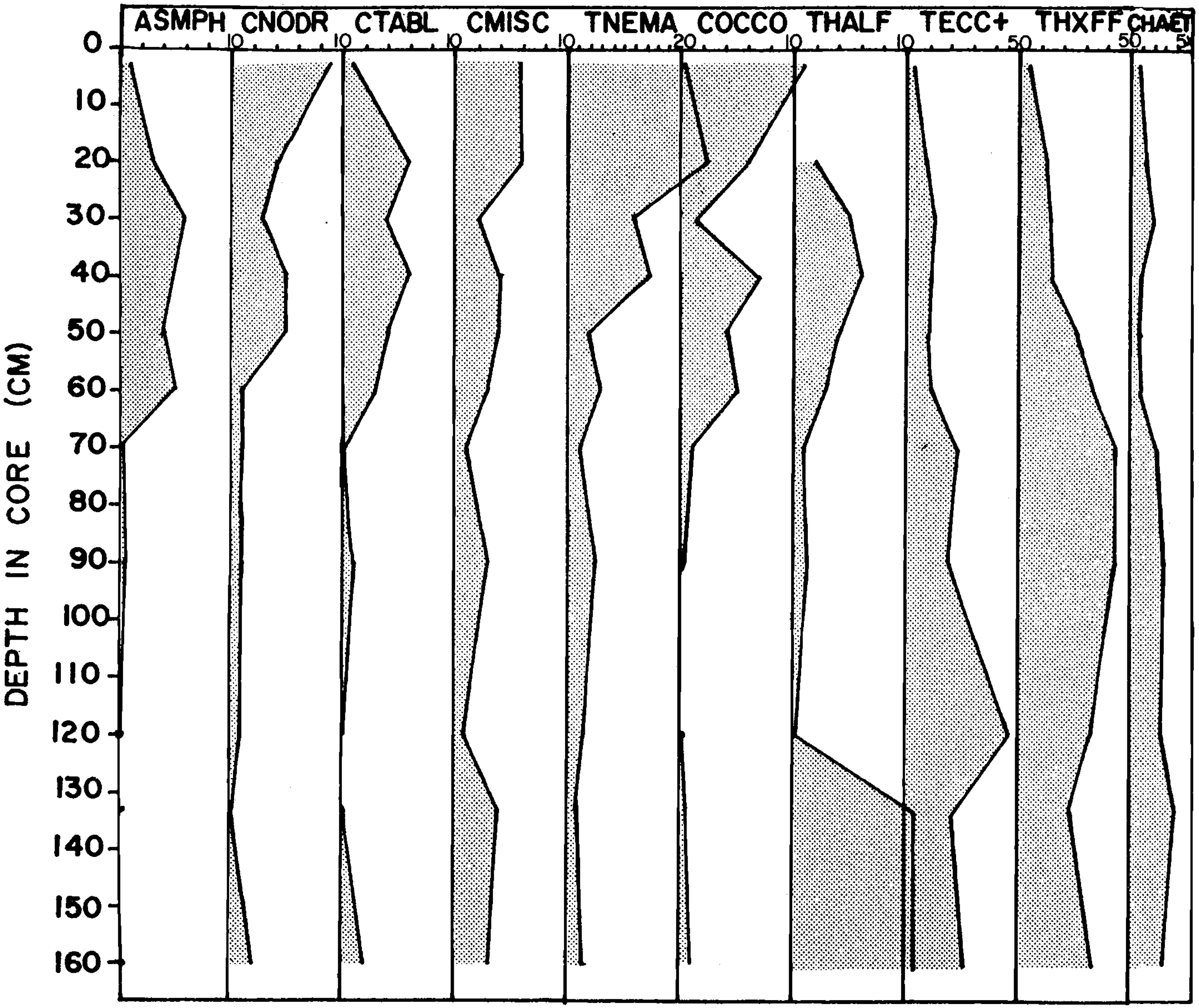
At depths greater than 60 cm a normal assemblage of anchoveta, hake, and other fish scales (sauries, lanternfish, carangids) prevails, with the addition in most samples of many scales tentatively identified as rockfish. Two exceptional short intervals were noted. First, between 80-60 cm (c. 14,000-13,500 yr. B.P.) hake scales are unusually abundant, in both an absolute sense and with respect to the number of anchoveta scales. Secondly, between 160-140 cm the scale:vertebrae ratio, which usually ranges from 1.0 to 5.0, drops below 1.0 for the only time prior to the Holocene accumulation of vertebrae between 30-0 cm.

Further inspection of the coarse fraction of sediment in core 7706-37 gave further evidence of the anomalous nature of the Holocene sediments. Between 0-30 cm the sediment contained several phosphorite pebbles, sand grains of quartz and dark minerals, squid beaks, and large spherical radiolarians, all uncharacteristic of the rest of the core. Below 30 cm the coarse fraction of sediment typically contained fibrous fecal pellets, a few lithified rod-shaped pellets, and occasionally benthic formainifera of the genera *Cancris*, *Valvulineria*, and *Globobulimina* (?). Below 155 cm the sediment contained some elements of the coarse fraction in the upper 30 cm.

Two diatom assemblages were readily identified in core 7706-37 (Figure 11). Between 60-0 cm the flora was dominated by *Asteromphalus* spp., *Coscinodiscus nodulifer* + *radiatus*, *C. tabularis*, *Thalassionema nitzschoides*, and *Cocconeis* spp. All three species of *Coscinodiscus* also appeared more frequently in the sample taken at 160 cm (about 15,000 yr. B.P.). The second assemblage, including *Thalassiosira eccentrica* 'group', *Thalassiothrix frauenfeldii*, and resting spores of *Chaetoceros*, was best developed in the interval 60-120 cm.

Figure 11. Relative abundance of selected diatom species groups in core 7706-37. Column headings abbreviations are as in Figure 10, with the following additions:

CTABL - *Coscinodiscus tabularis*
CMISC - *Coscinodiscus* spp.
TNEMA - *Thalassionema nitzschoides*
COCCO - *Cocconeis* spp.
THALF - *Thalassiosia* species 'F'
THXFF - *Thalassiothrix frauenfeldii*


ASMPH
CNODR
CTABL
CMISC
TNEMA
COCCO
THALF
TECC+
THXFF
CHAET
10
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50
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70
80
90
100
110
120
130
140
150
160
DEPTH IN CORE (CM)

DISCUSSION

The remains of fishes (this study), squid (Ne sis, 1973), benthic foraminifera (Bandy and Rudolpho, 1964; Saidova, 1970; Khusid, 1970, 1974), diatoms (Zhuse, 1972; Schuette and Schrader, 1979a, b), and silicoflagellates (Zhuse, 1972) in marine surface sediments off Peru have been used to characterize present-day benthic and pelagic ecosystems associated with coastal upwelling. Ideally, the downcore distribution of these same organisms should provide a temporal record of the Peruvian upwelling ecosystem and, indirectly, a chronicle of larger-scale atmospheric and oceanic events in the eastern equatorial Pacific Ocean. Unfortunately, straightforward interpretation is not possible because of inadequacies of the sedimentary and fossil record. Among the complicating factors are resolution limitations of the samples, spatial heterogeneity of sedimentation, sedimentary unconformities, physical reworking of sediments, bioturbation, dissolution, and biological decomposition of biogenous debris. Nevertheless, the abundance of fish remains and diatoms in the moderately undisturbed sediments of cores 7706-37 and 7706-40 does allow some interpretation of the Holocene history of upwelling and biological productivity off Peru.

Because of the sampling strategy employed in this study and the lack of a consistently laminated sedimentary record, it was not possible to resolve events of less than 10-20 years duration. Thus, no evidence was found of either seasonal productivity changes or short-lived phenomena such as "El Ninos." Also, it was impossible to detect the recent decline in anchoveta stocks that has been attributed to both overfishing and closely spaced El Nino events (Clark, 1977).

The distribution of nekton and plankton in Peruvian marine sediments must be examined from a geological perspective. In particular, correlations should be looked for between the fossil record and Quaternary climatic events that influenced ocean circulation. The remainder of this discussion will consist of a brief review of the late Pleistocene and Holocene climatic history of the southern Pacific Ocean, followed by a consideration of the nekton and plankton record in light of that history.

Studies of late-Quaternary climate in the circum-South Pacific region are few and far between. Most have involved palynological analysis of lake deposits or stratigraphic reconstructions of glacio-lacustrine deposits (Figure 12).

Heusser (1974) and Mercer (1976) placed the end of the last major glaciation in southern Chile at 13,000-12,000 yr. B.P. Similar ages were arrived at by Scheve-Brinkman (1978) in Columbia and MacPhail (1979) in New Zealand. Heusser (1974) and van der Hammen (1978) also recognized a brief

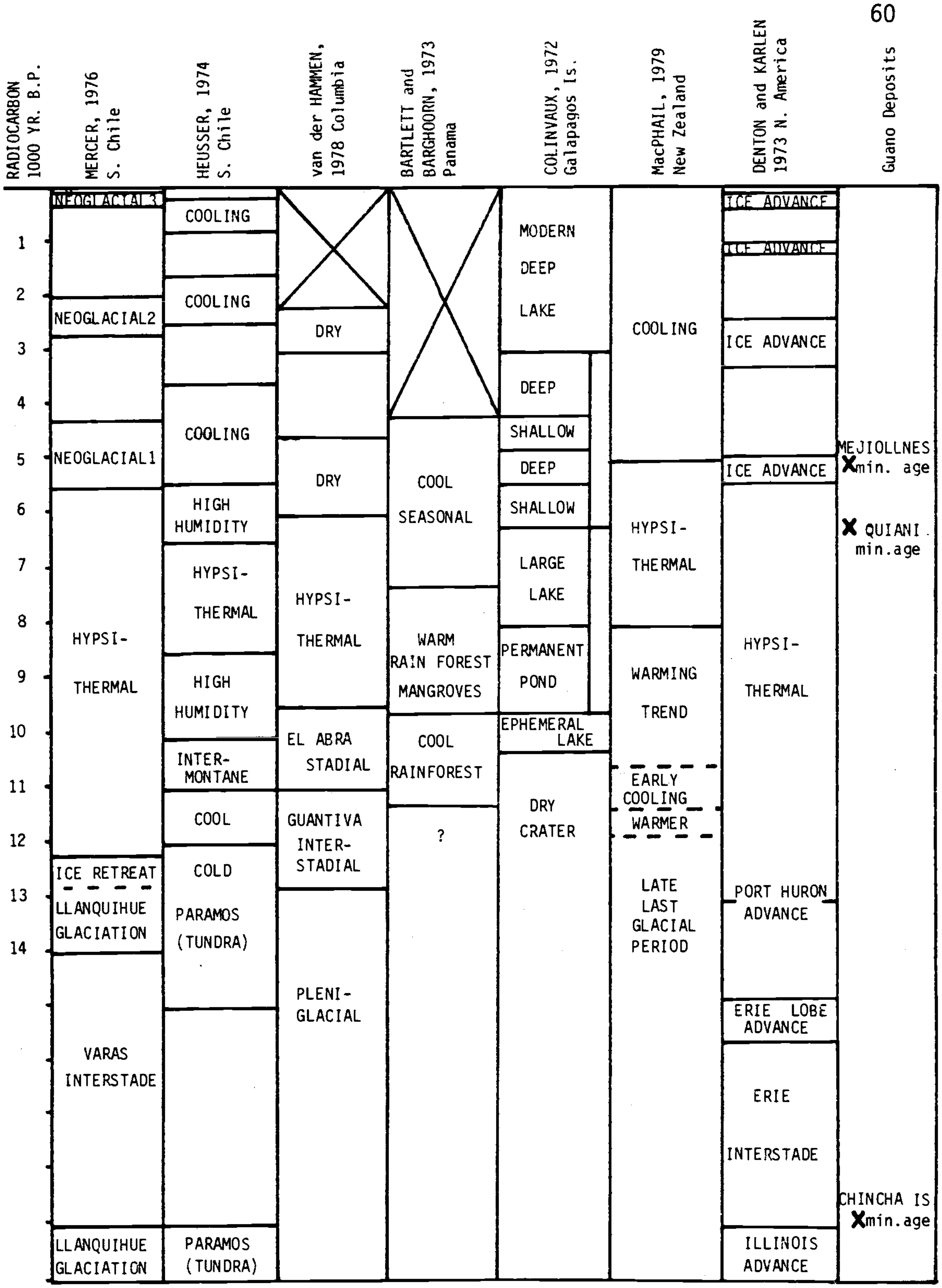

Figure 12. Holocene and late Pleistocene climatic fluctuations inferred from geological and palynological data from around the South Pacific Ocean. Also shown are similar data compiled for North America and minimum ages of fossil guano deposits from southern Peru and northern Chile.

cooling episode between 11,000-9,500 yr. B.P.

Most Quaternary authorities agree that the next two to four millenia were characterized by above average (hypsothermal) temperatures (Figure 12). Since 5,000 or 6,000 yr. B.P., however, there has been a gradual deterioration of the global climate. Major neoglacial advances have taken place between 4,500-4,200 yr. B.P. in southern Chile (Heusser, 1974; Mercer, 1976) and about the same time elsewhere (e.g., the Galapagos Islands, Colinvaux, 1972; Panama, Bartlett and Barghoorn, 1973; Columbia, van der Hammen, 1974), 2,700-2,200 yr. B.P. (Heusser, 1974; Mercer, 1976; van der Hammen, 1974), and 1600-1800 A.D. (Heusser, 1974; Mercer, 1976; Denton and Karlen, 1973; Bjerknes, 1965).

Opinions differ on the response of global circulation to climatic cooling, particularly the response of the equatorial atmosphere and ocean. In South America drier continental conditions prevailed east of the Andes (van der Hammen, 1974; Damuth and Fairbridge, 1970) and in the Galapagos highlands (Colinvaux, 1972) during the last glaciation. However, along the western coast of South America there is some ecological evidence of increasing wetness in the Andean highlands, although the coastal lowlands may have remained arid (Lemon and Churcher, 1961; Churcher, 1966; Simpson, 1975).

The climate of the southeastern Pacific Ocean is largely a function of the cold-water Peru Current flowing northward past Chile and Peru, and the Intertropical

Convergence Zone (ITCZ), presently located at 1-2°N (Newell, 1973). There are two views concerning the position of the ITCZ in the past. Colinvaux (1972) and Fairbridge (1972) proposed that the greater aridity of tropical latitudes 20,000 yr. B.P. could best be explained by a northward migration of the ITCZ. Newell (1973) countered Colinvaux's theory with the argument that today the ITCZ seasonally shifts toward the hemisphere with the greatest thermal gradient, and that at 20,000 yr. B.P., a time of maximum glaciation, the greatest thermal gradient existed in the southern hemisphere. Pejml (1966) also noted that the Galapagos Islands were wetter during the Little Ice Age of the 17th to 19th century A.D., implying that the ITCZ shifted southward at that time. Finally, Hastenrath (1971) observed an increased snowline depression on the western face of the Andes at low latitudes during the Pleistocene, suggesting that precipitation was greater during that time.

Another line of evidence can be developed that oceanic and climatic zones, particularly the upwelling zone off Peru, are capable of shifting or expanding latitudinally. Guano deposits older than 5000 yr. B.P. from northern Chile have been described by Hutchinson (1950) and dated by Buckley and Willis (1969) and Tamers (1971). Guano deposits older than 19,000 yr. B.P. and spanning the time of 2500-0 yr. B.P. have also been found on the Chincha Islands in south-central Peru (14°S) (Kubler, 1948; Arnold and Libby, 1951).

Present-day deposition of guano by seabirds feeding almost exclusively on anchoveta (Jordan, 1967) is restricted to 5-16°S (Hutchinson, 1950). Evidently the high primary and secondary productivity of upwelled waters necessary to sustain such large bird colonies was once located further south than at present. For the moment it cannot be determined whether the northern boundary of guano deposition also shifted southward.

These palynological, geological, and climatological data clearly indicate that the atmospheric circulation over the southeast Pacific Ocean, and presumably the oceanic circulation as well, has fluctuated to some extent over the past 20,000 years; fluctuations over the past 75,000 years have already been documented by Molina-Cruz (1977). How these fluctuations have affected the local, dynamically complex area of coastal upwelling off Peru is not clear. Conceivably, upwelling may have been stronger and El Ninos less frequent under a regime of intensified trade winds and a stabilized pressure system in the South Pacific Ocean during times of global cooling (Quinn, 1971). However, if the ITCZ also shifted southward at the same time, or if the southern ITCZ became more fully developed (Asnani, 1968), then warm equatorial water from the eastward flowing countercurrents lying beneath the northern and southern ITCZ may have directly impinged upon the Peruvian coast. (The exact mechanism whereby warm water accumulates along the coast of Peru during present-day El Ninos is still hotly debated. Sarachik (seminar, Coastal Upwelling Ecosystems Analysis (CUEA) Conference, Corvallis, Oregon, August 15, 1979) presented several competing hypotheses concerning the source of the warmer water, including local warming, decreased upwelling, reversal of northward flowing currents, and onshore drift of a warm tongue of oceanic water lying off the coast of Peru.)

Colder water originating in the austral high latitudes might be expected to persist further northward during times of intensified circulation in the South Pacific Ocean. At the same time, tropical water may have extended further southward as a consequence of a southward shifted ITCZ. Thus, it is conceivable that both unusually warm and unusually cold water were introduced into the region off Peru during periods of global cooling. Evidence for either or both cases may be found in the fossil record of continental margin sediments of Peru. The following explanatory model, developed from the results of this study, supports the theory of southward shifting climatic zones and both warm and cold water incursions along the Peruvian coast during periods of climatic cooling.

The explanation is based on the distribution of flora and fauna between 147-65 cm (2500-1800 yr. B.P.) in core 7706-40. A succession of diatoms, fish scales, and silicoflagellates between 147-100 cm is overlain by the same succession in reverse order between 100-65 cm (Figure 13). It is proposed that this symmetrical arrangement of species represents an advance and subsequent withdrawal of warm tropical waters off Callao, Peru during the second neoglacial period (2700-2200 yr. B.P.; Heusser (1974) and Mercer (1976); the age discrepancy may be attributed to errors in the C-14 model age or a lag in the response of the local oceanographic regime to climatic changes elsewhere). Additionally, it is hypothesized that the initial invasion and final retreat of the warm water mass is associated with phytoplankton blooms that may reflect less intensive upwelling episodes and mixing of warm and cold waters. The following evidence is offered in support of the model.

1. The two maxima of sardine scales nearly coincide with occurrences of saury scales (Figure 13). Both species spawn in warmer waters than the anchoveta, and in the case of the former, further offshore (Sanchez, 1966; Santander and Castillo, 1977; Novikov, 1974). Anchoveta were not absent during times of maximal sardine abundance, for their scales occur in large numbers before, during, and immediately after the older sardine maximum and during and immediately after the younger sardine maximum (Figure 9).

The nearest major population of sardines to Callao today is off northern Peru (Santander and Castillo, 1977) (Figure 4). This population may have expanded to the south

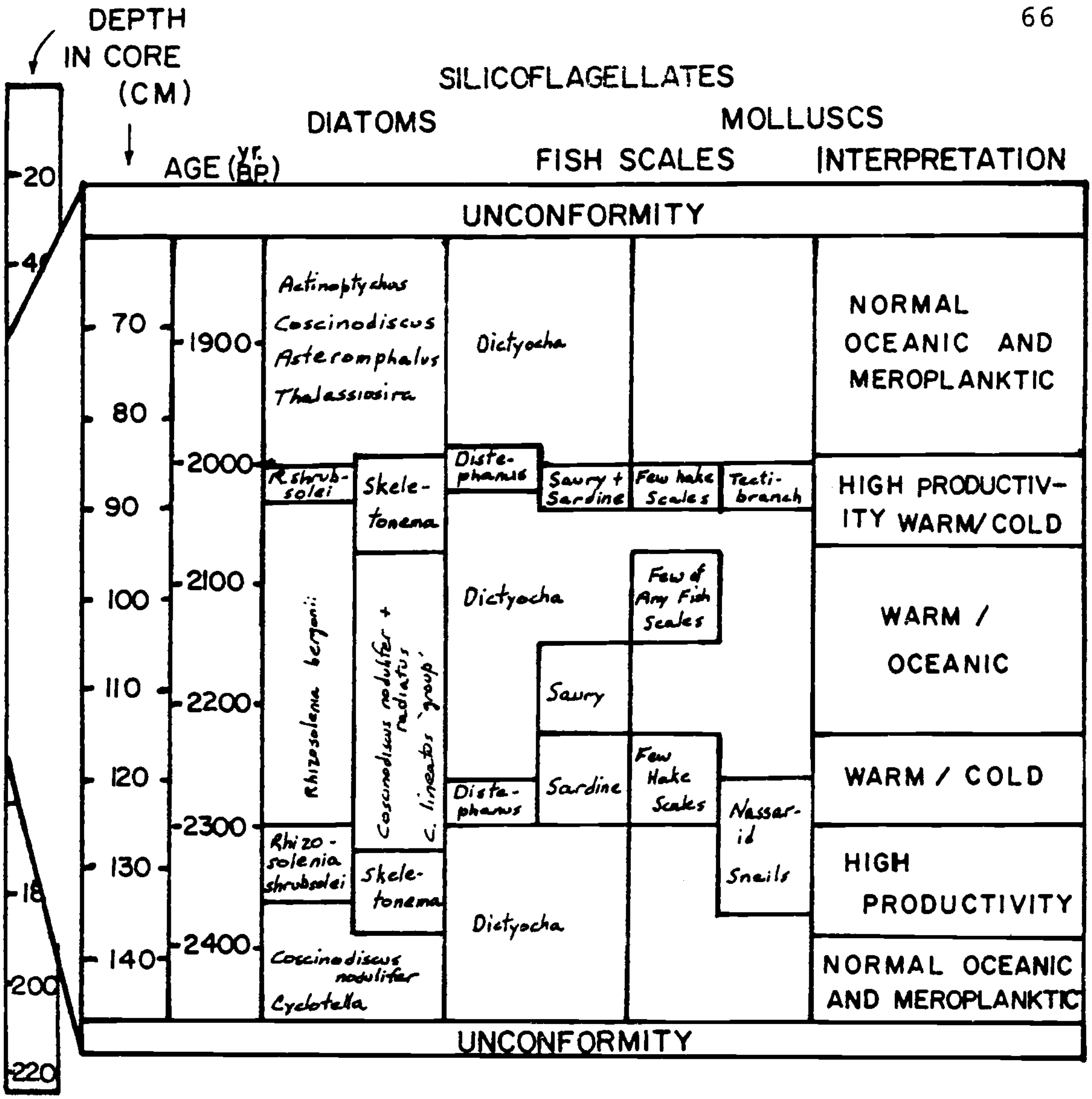

Figure 13. Symmetrical distribution of fish debris, diatoms, and silicoflagellates between 147-65 cm (2400-1700 yr. B.P.) in core 7706-40 upon which is based the model of warm water incursion during periods of global cooling.

between 2350 and 200 yr. B.P. Sardines from a southern population off northern Chile may have migrated northward to 11°S., but the much greater distance of the Chilean population and the total absence of sardine scales in any of the samples from core 7706-37 (13°37'S.) (Table 8) makes this alternative less likely.

2. Between the two sardine scale maxima (115-90 cm) a warm water/oceanic assemblage of *Coscinodiscus nodulifer* + *radiatus*, *Coscinodiscus lineatus* 'group', *Rhizosolenia bergonii*, and *Dictyocha* spp. predominates. Between 105-95 cm, the zone of maximum *R. bergonii* abundance, few scales of any fish species are found. The bioturbate nature of the interval suggests that the scales may have suffered accelerated dissolution or decomposition. The bioturbation also indicates that benthic fauna were not excluded from the upper slope by anaerobic waters of the oxygen minimum zone at that time.

3. *Skeletonema costatum* occurs in tremendous numbers in sediments deposited before the older and during the younger sardine scale maximum. This diatom genus is typically found in coastal upwelling waters off Peru (de Mendiola, unpublished), and in a band of sediments along the upper slope off Peru (Schuette and Schrader, 1979a, b). The occurrence of *Skeletonema* in such great numbers, despite the sensitivity of its skeleton to dissolution, indicates a very high productivity between 2380-2330 and 2080-1990 yr. B.P.

4. Large accumulations of *Rhizosolenia shrubsolei* valves are found together with the *Skeletonema* valves. More delicate forms of the genus periodically bloom in the upwelling waters off Peru (Sukhanova et al., 1978). The valves of *R. shrubsolei* may be the remnants of former blooms that were also responsible for the production of such large quantities of *Skeletonema*.

5. Tests of the cool-water silicoflagellate, *Distephanus*, occur in elevated numbers in the intervals also containing sardine scales (indicative of warmer water), and in one of the two cases, the high productivity interval containing *Skeletonema* and *R. shrubsolei*. The coincidence of cool and warm water species may indicate alternating periods of strengthened upwelling of cold water or intensified northward flow of the Peru Current, and periods of decreased upwelling and/or invasion of tropical water from one of several hypothetical sources already mentioned.

6. Between 151-133 cm the sediment is characterized by a mixed oceanic/meroplanktic diatom assemblage of *Coscinodiscus nodulifer* + *radiatus*, *Cyclotella striata/stylorum*, and *Dictyocha* spp. Between 80-65 cm an oceanic assemblage of *C. nodulifer* + *radiatus* and *Asteromphalus* spp. is found mixed with a coastal/meroplanktic assemblage of *Actinoptychus* spp. and *Thalassiosira excentrica* 'group'. These mixed assemblages are indicative of an environment not characterized by extremes of temperature or primary productivity.

A progression can be seen between 147-100 cm of a mixed assemblage of oceanic and coastal/meroplanktic siliceous microfossils and abundant anchoveta scales to a high productivity, cool-water assemblage of diatoms and silicoflagellates, followed by a warm-water assemblage of fishes and diatoms, represented in the extreme by R. bergonii. The order of assemblages reverses from 100-65 cm.

Two additional features of this model need mention. First, hake scale abundance is strongly negatively correlated with sardine scale abundance (Figure 9). Hake undertake diurnal vertical migrations to feed upon sardines, anchoveta, and crustaceans (Poulsen, 1958; Machii, 1972; Wrzesinki, 1975). They also migrate along the coast for hundreds of kilometers (Gulland, 1971), possibly to avoid hypoxic waters of the oxygen minimum zone (Brandhorst, 1959). The high biological productivity connected in some way with the initial passage of equatorial waters through the area around Callao may have discouraged the hake from feeding in that area because of a strengthened oxygen minimum layer and/or warmer temperatures.

The second feature to be noted is the occurrence of a nassarid mollusc assemblage in the same interval as the earlier sardine scale maximum and a tectibranch-scaphopod mollusc assemblage in the same interval as the latter sardine scale maximum. How these molluscs survived if the oxygen minimum was strengthened at such times and the significance of the two different assemblages is not known.

Another sardine maximum in core 7706-40 (60-50 cm) is also characterized by the presence of saury scales, few hake scales, *Distephanus speculum*, and *R. shrubsolei*. It is followed at 35-18 cm by a weakly developed oceanic assemblage of *C. nodulifer* + *radiatus*, *R. bergonii*, *Dictyocha* spp., and reduction in the numbers of anchoveta scales that may be correlated with the timing of the Little Ice Age (Bjerknes, 1965). The distribution of flora and fauna in this interval is generally consistent with the proposed model of warm-water incursions from the north, although the brevity and weakness of the third neoglacial advance did not produce a well-defined pattern of advance and retreat of assemblages.

The only other post-early Holocene sardine scale maximum (185-175 cm) is also associated with saury scales, *Distephanus speculum*, and *Skeletonema*, but *R. shrubsolei* was not especially common. It is interesting that the 'model assemblages' overlap an interval (190-170 cm) previously characterized in this paper as 'allochthonous' yet they retain their identity. Apparently, the signal of biological production was faithfully overprinted upon another signal of physical sediment reworking.

The increase of sardine scales and scarcity of anchoveta and hake scales 11,700-11,400 yr. B.P. (222-190 cm), a time of post-glacial warming but nonetheless very cool temperatures (Heusser, 1974), is another bit of evidence favoring the theory that warmer waters were more prevalent off the coast of Peru when the climate was cooler than it is today. The absence of sardine scales in core 7706-37, however, indicates that the warm water influence did not extend as far south as 13°37'S.

The distribution pattern of flora and fauna in core 7706-37 is different than core 7706-40 but comparison of the two cores is difficult because temporal overlap is minimal. In core 7706-37 the past 500 years and 13,500-13,000 yr. B.P. are characterized by an oceanic/dissolution resistant assemblage of diatoms. The latter interval, deposited as laminations at the peak of the last major glaciation in South America, contains very few hake scales. The former interval, bioturbated, contains anomalously high numbers of fish debris of all species. It may have been subject to extensive winnowing by bottom currents. Between 17,000 (?)-14,000 yr. B.P., before the period of maximum cooling, an assemblage of high productivity/coastal diatom species replaces the oceanic assemblage. Anchoveta and hake scales occur in moderate numbers in the older sediment.

Without a temporally and spatially expanded data base, it is premature to speculate upon the causes of changes in the fossil record in core 7706-37. However, it is possible that the changes may be due to latitudinal shifts of upwelling centers and centers of high primary productivity.

The explanation involving a warm water invasion along the coast of Peru during periods of global cooling needs to be clarified in several respects. Foremost, the high-productivity, warm-cold intervals need to be examined more carefully. Normally, warm water incursions occasioned by El Nino events diminishes productivity off Peru (Clark, 1977), with drastic consequences on seabirds and canneries. Under these circumstances the presence of sardines in the geological record is understandable, since sardines were also observed following the El Ninos of 1972 and 1976 and the demise of the anchoveta in Peruvian coastal waters between 1972-1976 (Kesteven, 1976). On the other hand, the presence of a high productivity indicator, Skeletonema, and a cool water indicator, Distephanus, together with the sardines is perplexing. It has recently been recognized, however, that maximum productivity is not associated with maximum upwelling (Huntsman and Barber, 1977; Jones, 1978). Rather, the shallower mixed layer present during times of mild or moderate upwelling is more conducive to primary production. Thus, a complex environment of local and perhaps short-lived episodes of strong (?) upwelling bringing very cold water to a surface generally dominated by water derived from a more tropical source may explain the strange biotic assemblage. More puzzling is the frequent occurrence of the benthic foraminifera, Cancris inflatus, in samples of core 7706-40 that also contained the cool-water Distephanus speculum, since Smith (1964) claimed that large Cancris were indicators of warm water off Central America. If the correlation can be shown to be indeed valid, then some complexity of surface and subsurface counterflow and periodicity of upwelling is likely involved. Whatever the real explanation might be, a detailed stratigraphy of microfossils could be the key to understanding the high-productivity intervals.

It is imperative to obtain cores from other latitudes off Peru to confirm the model proposed here. Conclusions about latitudinal shifts of climate, water masses, and productivity are at best inferential if they are based on only one or two cores. Additional cores from 6-11°s. would be immeasurably helpful in defining the shifts that have been hypothesized in this model.

CONCLUSIONS AND SUMMARY

On the basis of the preceding discussion of the results, the following conclusions may be drawn.

1. The scales and vertebrae of the anchoveta (*Engraulis ringens*) are the most abundant constituent of fish debris in marine sediments deposited on the upper continental slope off Peru. Together with the scales and vertebrae of the hake (*Merluccius gayi peruanus*), they comprise at least 95 percent of all fish debris in all of the cores that were studied.

2. Fish debris is most abundant in sediments at water depths less than 600 m. In deeper water the fish debris appears to be more subject to degradative processes involving dissolution and physical reworking of the sediment.

3. The distribution of anchoveta and hake fish debris in surface sediments roughly parallels the distribution of modern day living populations.

4. The downcore distribution of fish debris and diatoms together provide a record of primary and secondary productivity in the neritic and epipelagic realm off Peru. Knowledge of the ecology of fish and diatom species preserved in the marine sediments can be used to infer certain oceanographic conditions of the past.

5. An explanation of Holocene biological productivity

and upwelling has been developed based on the presence of mixed warm and cold water faunal and floral assemblages that precede and follow an interval in the sediment characterized by a warm water, oceanic, low productivity assemblage of organisms. It is proposed that intensification of circulation in the southern hemisphere and a southward shift of the intertropical Convergence Zone during times of neoglacial and late glacial cooling could induce stronger, episodic periods of upwelling just prior to an incursion of warm, tropical water from the north.

6. Evidence from earliest Holocene sediments indicates that warm water may have been present as far south as 11°S. about 11,500 yr. B.P. Older sediments (13,500-13,000 yr. B.P.) at 13°S. contained an oceanic assemblage of diatoms mixed with a coastal, meroplanktic assemblage similar to that of today, but no signs were seen of a distinctly warm water assemblage.

This study is the first to use siliceous microfossils and nekton remains together to study Holocene paleoclimate and paleooceanography. The use of many taxa inhabiting widely different ecological niches provides a finer resolution of past environments and allows one to check the conclusions drawn from one group of organisms (e.g., fishes) to be compared with conclusions based on another group (e.g., diatoms).

It is evident from this study that the record of nekton and plankton remains in marine sediments off Peru is greatly affected by post-depositional processes. Thus, any effort to interpret the record must take into account such problems as discontinuous sedimentation, sediment sorting by currents, dissolution, and biological degradation. These problems are widely recognized by people engaged in diatom research; equal care must be taken with the fish debris record.

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