Oil & Chemical Pollution **6** (1990) 195–240

Monitoring Long-Term Effects of Offshore Oil and Gas Development Along the Southern California Outer Continental Shelf and Slope: Background Environmental Conditions in the Santa Maria Basin

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(Received 8 November 1989; accepted 2 December 1989)

ABSTRACT

Potential environmental impacts of materials discharged from oil and gas development and production platforms off the coast of southern California (Santa Maria Basin) are being monitored during an ongoing, long-term (five-year) field program. The study combines hypothesis testing of platform effects with basic research on the structure and dynamics of the regional ecosystem over a time series encompassing both seasonal and repeated annual scales. Oceanographic features and processes that are being measured focus on the benthos and include biological community indices and species abundances for hard-bottom and soft-bottom (macroinfauna and meiofauna) assemblages; levels and distributions of trace metals and hydrocarbons in bottom sediments, suspended particulates, animal tissues, and pore waters; water currents and other physical-oceanographic features; various sedimentological properties (sediment grain size, total organic carbon, shear strength,

Oil & Chemical Pollution 0269–8579/90/$03.50

distribution of mineral types, radioisotope profiles, and degrees of sediment mixing as a result of bioturbation); sediment and pollutant-transport processes; and animal–sediment–pollutant interactions. Synoptic measurement of these different environmental variables over the extended sampling period provides an opportunity to examine long-term variability in the benthic environment with respect to both natural and anthropogenic causes. Efforts to distinguish between natural variability and low-level cumulative impacts of drilling are given special attention.

Results obtained during the first two years of sampling provide a basis for beginning to understand environmental processes and relations important in detecting and interpreting any subsequent impacts caused by drilling activities in this complex and productive region of the California outer continental shelf and slope. Background chemical, physical, and biological data generated during this period demonstrate that impacts of discharges from oil and gas operations should be detectable, if they occur, and should be distinguishable from natural environmental variability. Small inputs of barium and petroleum hydrocarbons have been detected and appear to be associated with the minor drilling activities that have occurred in the area thus far; however, these initial inputs have not led to any noticeable biological impacts. These initial results are hopefully of value for two reasons: (1) in providing a summary of basic chemical, physical, and biological features of the benthic environment within the Santa Maria Basin; and (2) in presenting information on research strategies that should be considered in designing studies dealing with similar resource-management problems in other parts of the world.

INTRODUCTION

This paper describes the objectives, research approaches, and important initial results of the California OCS Phase II Monitoring Program (CAMP). CAMP is a five-year, multidisciplinary study designed to monitor potential environmental changes resulting from oil and gas development and production in the Santa Maria Basin region of the California OCS. This ongoing study began in July, 1986 and is scheduled to continue through to July, 1991. Because, to date, development and production activities have been minimal throughout the study region, results presented here represent samples collected during predrilling phases for most stations. Thus these initial results are used to present an overview of the natural physical, chemical and biological conditions of the study area and to evaluate the ability to monitor potential long-term environmental impacts throughout this region in light of observed background oceanographic features and processes.

CAMP, which is sponsored by the Minerals Management Service (MMS) of the US Department of the Interior, originated in response to requirements under the 1978 OCS Lands Act Amendments (43 USC-

1346) for MMS (then the Bureau of Land Management) to implement studies designed to evaluate environmental impacts of oil- and gas-development activities on human, marine, and coastal resources of the US OCS. Three additional factors have contributed to the decision to implement this particular study. These factors are: (1) the great potential for extensive production of oil and gas from this region of the California OCS; (2) the concern that development of, and production from, a major new oil field on the US OCS may result in cumulative, long-term adverse impacts on the marine environment; and (3) the lack of previous oil and gas production activities or other major anthropogenic influences in the area.

In consideration of these factors, the program was established to address two broad objectives: (1) to detect and measure potential long-term (or short-term) chemical, physical, and biological changes around oil and gas platforms in the Santa Maria Basin; and (2) to determine whether the observed changes are caused by drilling-related activities or are the product of natural processes.

The long-term nature of this program is a unique feature allowing investigators to make comprehensive assessments of the structure of the regional ecosystem and the dynamics of physical, chemical, and biological processes over a time series encompassing both seasonal and repeated annual scales. As a result, knowledge gained from these assessments can be used to accomplish the important objective of separating natural background variation from potential low-level cumulative environmental impacts caused by drilling-related activities. Such an approach to offshore monitoring has been supported strongly by various scientific advisory committees serving the marine research and management communities (National Research Council, 1983; Boesch & Rabalais, 1987).

METHODS

The program objectives described above are being addressed through time-series monitoring of a number of environmental parameters before and after initiation of drilling at various monitoring sites throughout the study area, including control sites and sites where environmental impacts are more likely to occur. An optimal-impact study design (Green, 1979) and *a priori* hypothesis-testing approaches are also being applied in the process of addressing these objectives, so that any conclusions regarding environmental changes can be stated within established levels of statistical confidence.

Monitoring efforts focus on the benthos. The emphasis has been

placed here for two reasons: (1) benthic environments are suspected sinks for the accumulation of discharged drill materials; and (2) because of their relative immobility, benthic organisms should be susceptible to exposure to any drilling-related materials that may accumulate on the bottom. Although potential effects of drilling on planktonic and pelagic systems should not be ignored, the temporal and spatial variability in these more ephemeral assemblages, relative to the benthos, make hypothesis testing for effects much more difficult (Boesch *et al.*, 1987).

Specific parameters that are being addressed as part of the time-series monitoring, consist of biological community indices and species abundances for hard-bottom and soft-bottom (macroinfauna and meiofauna) benthic assemblages; levels and distributions of trace metals and hydrocarbons in bottom sediments, suspended particulates, animal tissues, and pore waters; water currents and other physical-oceanographic features; and various sedimentological properties (sediment grain size, total organic carbon, shear strength, distribution of mineral types, radioisotope profiles, and degrees of sediment mixing as a result of bioturbation). Synoptic measurements of these various parameters permit examination of biological changes in relation to concomitant chemical or physical changes linked to specific drilling events. Additional companion studies focus on animal–sediment–pollutant interactions (see, for example Butman *et al.* 1988; Grassle & Butman, 1989; Webb, 1989 for some initial reports) and sediment-transport processes. Further details of the procedures used to collect and analyze the various types of samples or measurements can be found in Hyland and Neff (1988).

The station design for this program consists of a series of regional stations and two additional arrays of site-specific stations each located at the site, or proposed site, of an oil-production platform (Fig. 1). The regional stations consist of three cross-shelf transects of three stations each (encompassing water depths of about 90 to 410 m) and an additional station located approximately 50 km west of Point Sal, in a suspected offshore depositional area. Regional stations were selected with two major objectives in mind: 1) to provide an opportunity to compare ecological conditions and potential responses to drilling-related impacts over broad regional areas and bathymetric zones; and 2) to revisit, wherever possible, sites sampled during an earlier, 1983–1984, Phase 1 Reconnaissance Survey (SAIC, 1986) to maximize use of historical data. All regional stations are dominated by soft-bottom infaunal assemblages inhabiting silty sand to clayey silts.

One of the two site-specific sampling arrays is located in soft-bottom substrates offshore of Point Sal, at the anticipated site for Shell Western

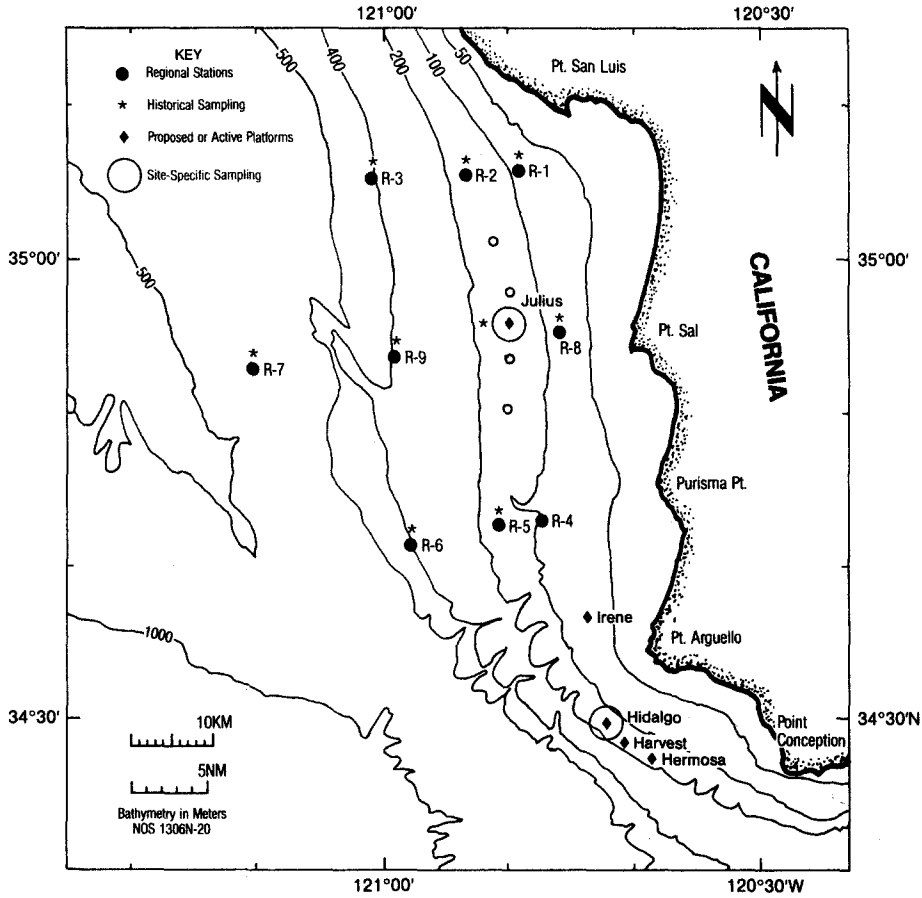

Fig. 1. Study area and station design.

Exploration and Production's Platform Julius (Fig. 2). This sampling array is designed to examine potential nearfield impacts and possible impact gradients extending outwardly from the point source of pollutant discharge. This sampling array incorporates two important features: (1) a semi-radial station pattern to help detect nearfield effects that might occur in any one of several directions; and (2) an oversampling approach within a relatively confined area, to help define the spatial scale of detectable nearfield impacts. This type of design was used successfully in a related offshore monitoring program conducted on Georges Bank in the vicinity of exploratory drilling operations (Neff *et al.*, 1989). The array consists of nineteen stations that were sampled during the first year of the program (i.e. October 1986, January 1987, and May 1987). Because of drilling-schedule delays for this platform, station numbers were reduced

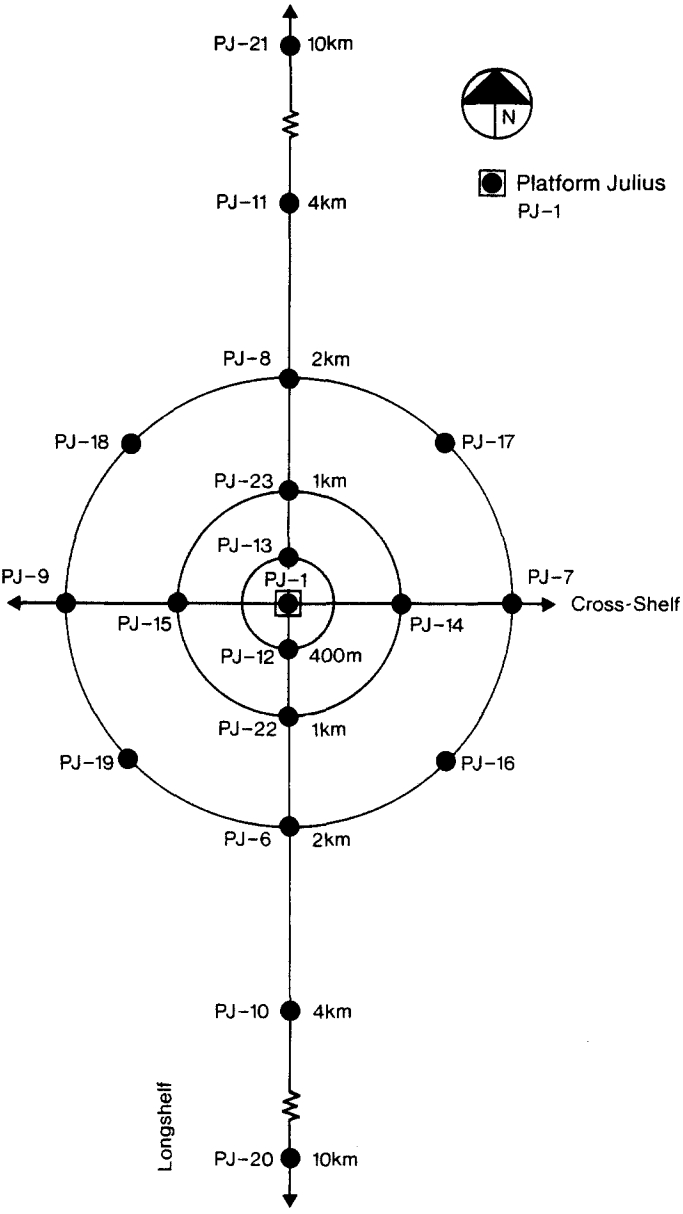

Fig. 2. Site-specific sampling array near future site for Platform Julius.

to three (PJ-1, PJ-10, and PJ-11) during the October 1987 and January 1988 sampling occasions and to one station (PJ-1) beginning in May, 1988.

The second site-specific sampling array is located offshore of Point Arguello, in the vicinity of Chevron's Platform Hidalgo (Fig. 3).

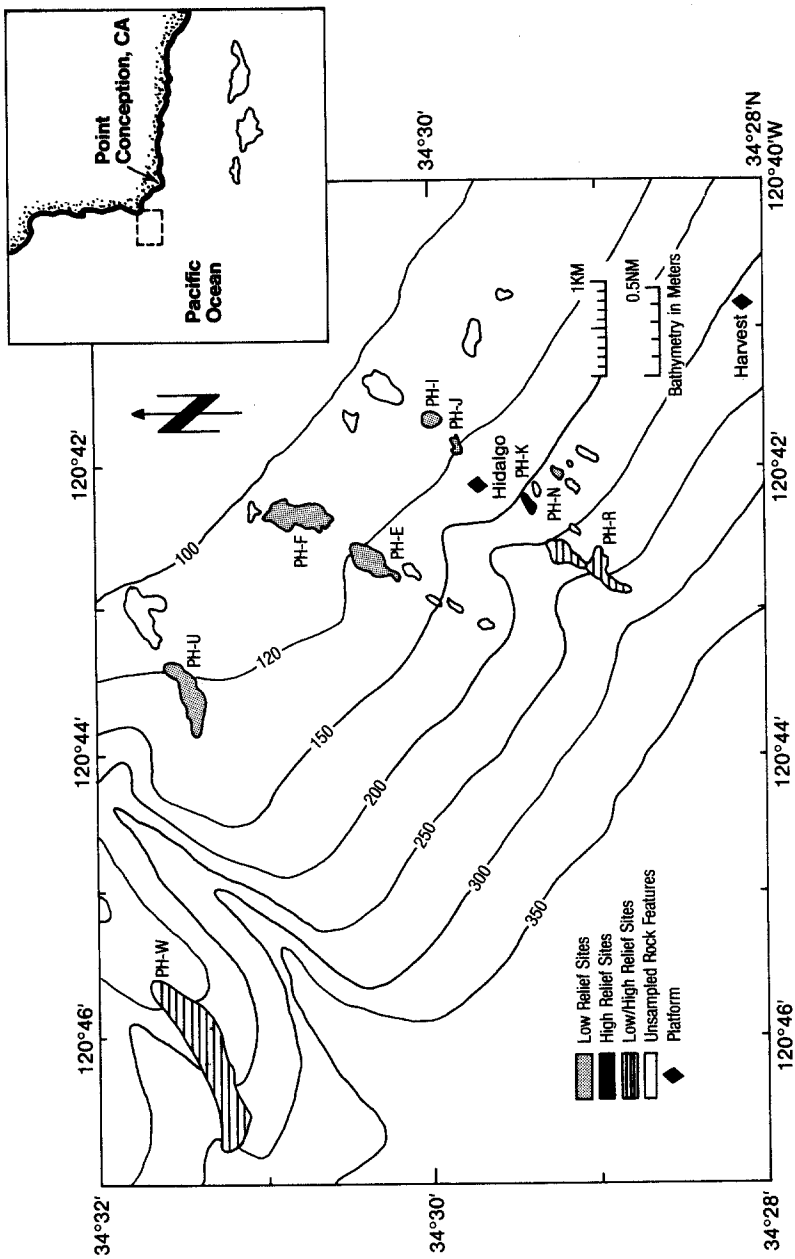

Fig. 3. Site-specific sampling stations near hard-bottom features in vicinity of Platform Hidalgo.

Monitoring efforts at these sites focus on rock features inhabited by hard-bottom epifaunal and floral assemblages. There are two important aspects concerning these stations: (1) stations consist of both 'high-relief' substrates (defined operationally as substrates higher than one meter) and 'low-relief' substrates, so that assemblages inhabiting both types of substrates can be monitored to compare their relative susceptibilities and sensitivities to potential impacts; and (2) for each type of substrate, stations have been positioned at varying distances away from the platform so that effects can be monitored along possible 'dose-response' gradients.

The current sampling schedule is shown in Table 1. The frequency of sampling at both soft-bottom and hard-bottom stations was originally designed to span five years including predrilling and postdrilling periods, each having within-year repeated sampling intervals. This sampling schedule was adopted on the assumption that drilling would begin at Platform Julius at least by January, 1990 and at Platform Hidalgo in November, 1987. Although drilling at Platform Hidalgo did begin as scheduled, information now indicates that drilling at Platform Julius will not begin until April–June, 1991, to late 1992. To accommodate the extended delay in drilling at Platform Julius, sampling at all soft-bottom stations after May, 1989, has been discontinued until further notice. Sampling at hard-bottom stations near Platform Hidalgo will continue, however, through October, 1990.

RESULTS AND DISCUSSION

Physical oceanography

Current-meter records from instrumented moorings deployed at the Platform Julius and Platform Hidalgo study sites confirm predictions of a mean along-shelf surface flow in both an upcoast and downcoast direction. Current speeds are typically 10–20 cm/s but can build to approximately 100 cm/s. These along-shelf patterns are interrupted periodically by cross-shelf flows that are up to several days in duration and are associated with traveling eddies seen in auxiliary satellite images. Observed variations in the direction of mean-current flow support earlier decisions to select a semi-radial station design for the soft-bottom sampling array, consisting of a greater concentration of stations along isobaths parallel to the mean predicted current flows, but including additional stations at both deeper and shallower locations to allow detection of possible contaminant movement across the shelf (Fig. 2).

TABLE 1
Sampling Schedule

Year	*Soft-bottom cruises*	*Hard-bottom cruises*
1	Oct. 86	Oct. 86
	Jan. 87	May to July 87
	May 87	
2	Oct. 87	Oct. to Nov. 87
	Jan. 88	(Hidalgo spudded: Nov. 87)
	May 88	
3	Oct. 88	Oct. 88
	May 89	May 89
4	—	Oct. 89
5	—	Oct. 90
	(Julius to be spudded: April–June 1991 to late 1992)	

Both speed and direction of currents can vary considerably between the two current-meter sites. The typical annual cycle of surface flow at Platform Julius consists of a weak northward flow in the December–February period, a strong southward flow during the spring, and a weak and variable flow from about July to November. There is substantial variation, however, in the timing and duration of this general pattern. Surface currents are usually more irregular at Hidalgo, without obvious seasonal shifts in the along-shelf mean flow. Hidalgo is near the confluence of two opposing flows, one moving southward along the coast and the other moving westward from the Santa Barbara Channel. Also, Hidalgo is located in an area where both clockwise and counter-clockwise eddies are prominent, as seen in the satellite imagery.

Mid-depth currents generally follow the surface-current patterns at both platform sites. Bottom currents, however, typically flow to the northwest (see also next section). Current records from all three depths display a strong cross-shelf component due to tidal influences, particularly near the bottom.

Several prominent upwelling events (e.g. two in March and April 1987) have been documented through satellite imagery and temperature time-series records. These particular events were more intense at the Platform Julius site than at the Platform Hidalgo site, as evidenced by greater declines in both surface and bottom temperatures. Nutrient and dissolved oxygen concentrations, however, are similar between the two study sites and do not provide evidence for this pattern. Regardless of location, silicate and nitrate concentrations are generally higher in surface waters during the spring when upwelling events are more common.

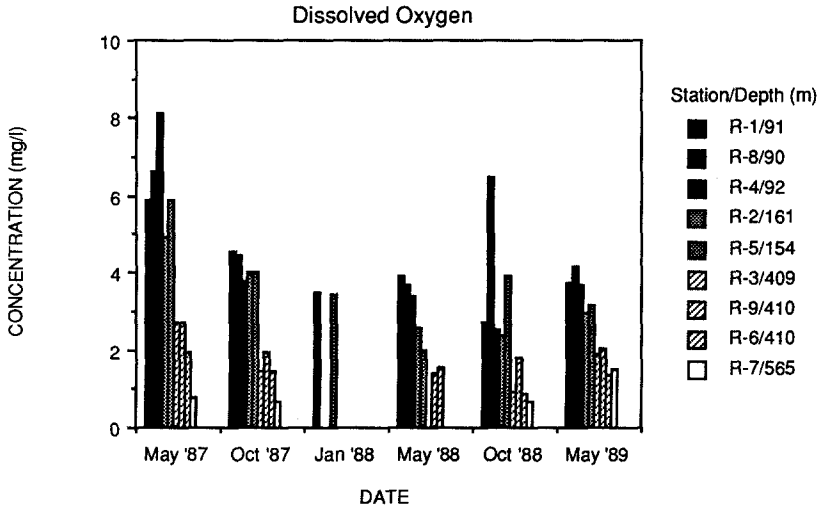

Fig. 4. Dissolved oxygen concentrations in water samples collected within 3 m of the bottom at regional soft-bottom stations.

Dissolved oxygen concentrations in near-bottom waters (approximately 1–3 m above bottom) decrease with depth (Fig. 4). This pattern has persisted over spring and fall sampling periods throughout the first two years of study and may explain other depth-related patterns in faunal abundances and numbers of species.

Sediment-transport processes

During the spring of 1987 and the winter of 1988/89, GEOPROBE bottom tripods (Cacchione & Drake, 1979) were deployed at stations R-8 and PJ-1 and current meter/transmissometer moorings (designed by B. Butman and W. Strahle, US Geological Survey, Woods Hole, MA) were deployed at R-8, PJ-1 and R-9 to investigate seasonal variability in the bottom currents and the processes and rates of sediment erosion and transport. In addition, shipboard site surveys using side-scan sonar were repeated during each deployment and recovery cruise, and hydrographic data were collected along a cross-shelf transect through stations R-8, PJ-1 and R-9 using a Neil Brown CTD (EG & G, Inc., Cataumet, MA) equipped with a 25-cm pathlength Sea Tech transmissometer (Sea Tech, Inc., Corvallis, OR).

The side-scan sonographs reveal both natural and man-made bottom features. Features produced by natural processes include: irregular patches of wave-rippled sand at depths of 70–80 m near R-8; common

groups of sea floor 'gouges' (1 m wide and 3–5 m in length) between R-8 and PJ-1, which are believed to be caused by migrating grey whales (Cacchione *et al.*, 1987) that occasionally 'test' the bottom for food; and, in the vicinity of Site R-9, sea floor craters, up to 100 m in diameter and 10 m deep, that overlie an area of gas-charged sediment. The craters form as gas is vented through the sediment to the water column.

Bottom features caused by man primarily consist of long, linear trawl marks (depressions of at least 20–30 cm) which are especially common near PJ-1 in a region of active commercial fishing.

The time-series GEOPROBE data on the near-bottom currents, surface-wave generated oscillatory currents, and the concentration of suspended particulate matter (1 m above the bottom) show that erosion events at R-8 and PJ-1 were infrequent and minor during May–July 1987 (Fig. 5). Threshold shear stress (U^*_t) for the silt component of the sediment at R-8 is approximately 0·7 cm/s and an analysis of the GEOPROBE data using the combined-flow bottom boundary layer model of Glenn and Grant (1987) shows that the currents and waves exceeded the threshold during 17–21 May and 2–3 June. Suspended-matter concentrations at 1 m above the bottom never exceeded 4 mg/litre, however, and average concentrations were less than 1 mg/litre at both sites.

Low-pass filtered current velocity, 6 m above the bottom at R-8 (Fig. 6) and also at PJ-1, reveals a persistent low-frequency mean flow toward the north and offshore during the spring and summer of 1987 (B. Butman, pers. comm.). This current has been called the poleward undercurrent and it is typically present over the outer shelf or upper slope from southern California to Oregon (Hickey, 1979). Bed sediment resuspended by occasional periods of large, wave-generated currents will be moved upcoast and offshore by this flow at speeds of about 5–10 cm/s. Anti-clockwise Ekman turning in the bottom boundary layer of this current causes the westward-flow component (Kundu, 1976).

In addition to sediment that has been suspended by the oscillatory bottom currents produced by surface swell, CTD and light transmission data collected over the shelf and slope in May 1987 and in February 1989 (Fig. 7) reveal a 20-m thick turbid bottom layer between about 100 m and 230 m water depth. This layer is clearly separated from the turbid bottom layer on the inner shelf and may be related to erosion of the sea floor by the undercurrent or by a combination of internal tide-generated currents and the low-frequency flow. Our preliminary analysis of the 1987 current-meter data and the hydrographic data collected in February 1989 suggest that internal waves of the tidal period impinge on the outer shelf and, in combination with the mean flow, may result in cross-shelf flow

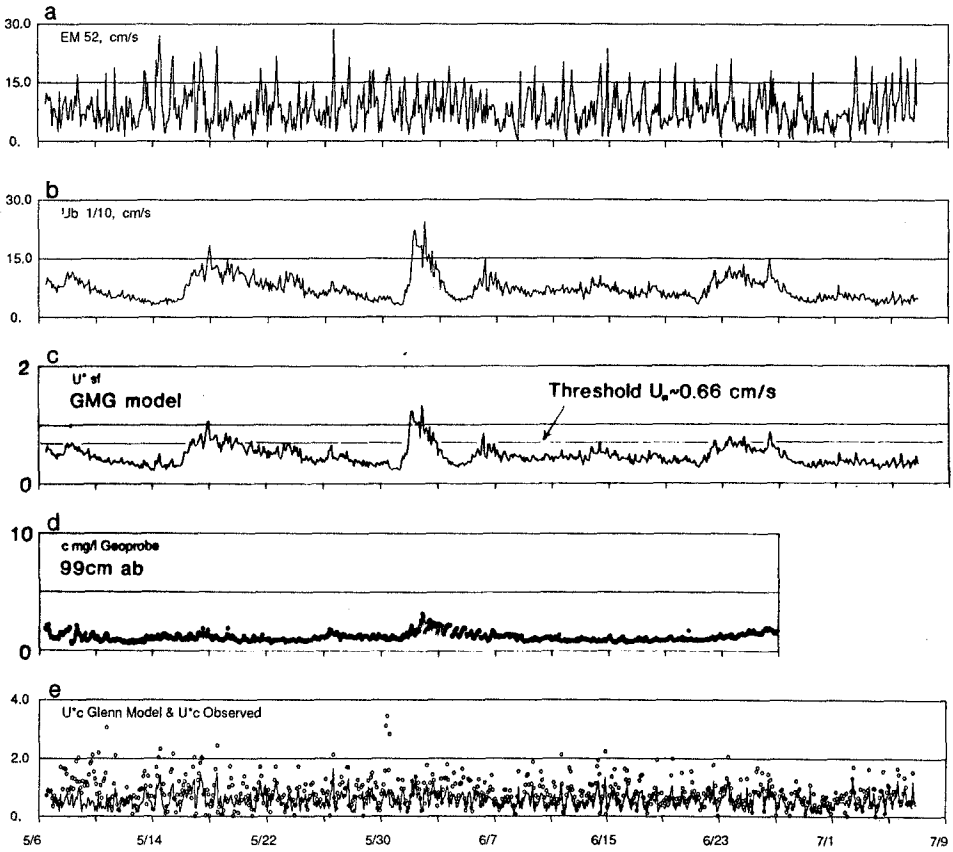

Fig. 5. GEOPROBE measurements at CAMP site R8 during 6 May 1987–7 July 1987: a) current speed at 0·52 meters above the bottom; b) oscillatory bottom current generated by the 1/10 highest surface gravity waves; c) the skin friction shear velocity (cm/s) computed by the combined flow boundary layer model of Glenn and Grant (1987); d) observed concentration of suspended sediment (mg/l) at 0·99 meters above the bottom; e) observed (open circles) and computed (solid line) shear velocity (cm/s) for the current above the wave boundary layer.

components of nearly 40 cm/s at 6 m above the bottom and 25 cm/s at 0·5 m above the bottom at R-8 (Figs 5 and 6). Current speeds of this magnitude may not erode large amounts of sediment, but they are certainly capable of maintaining silt and clay in suspension.

In summary, sediment transport in the bottom waters over the outer shelf and upper slope of the Santa Maria Basin during spring and summer seasons is characterized by northwestward advection of a small amount of suspended material that is periodically eroded from the sea bed by the oscillatory currents produced by surface waves, and possibly by lower-frequency currents associated with internal tides and the

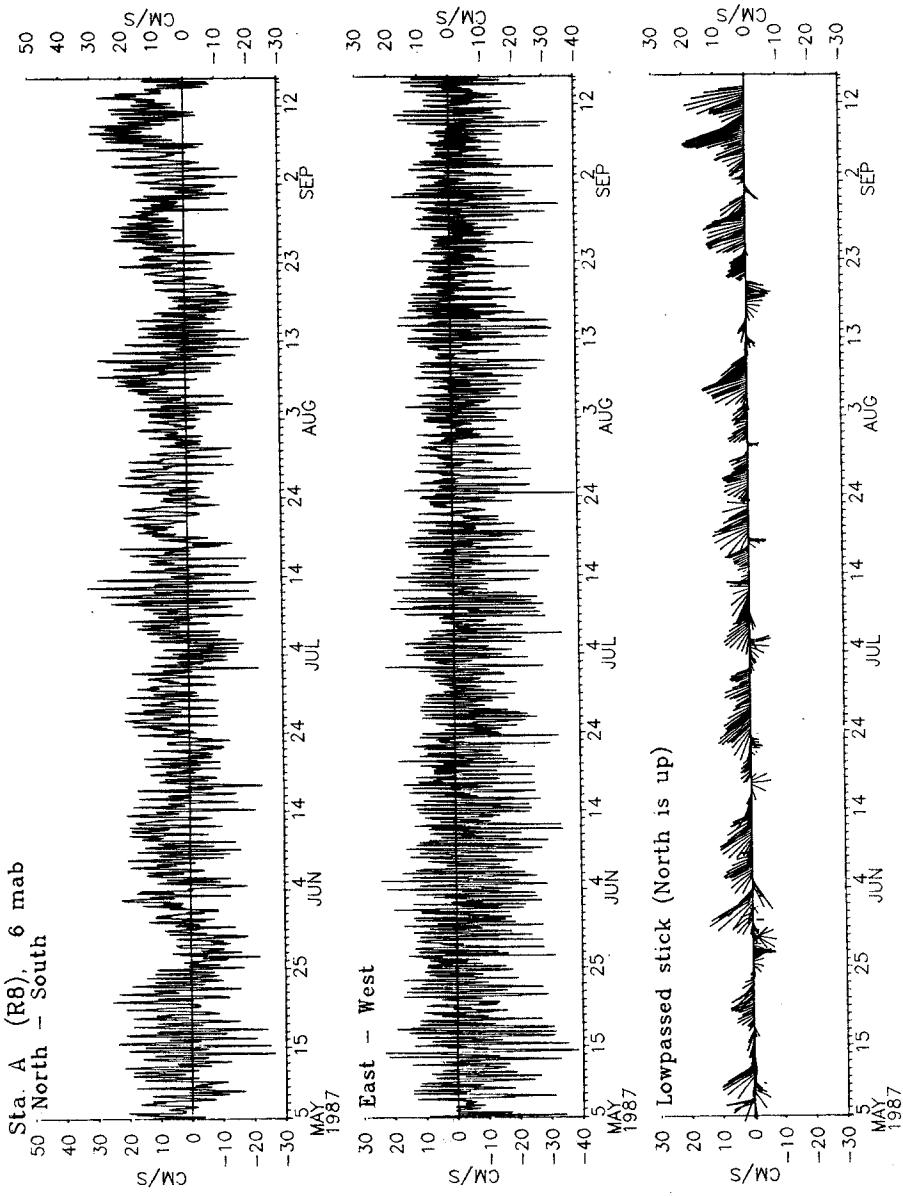

Fig. 6. North–South and East–West unfiltered current speeds at 6 meters above bottom, site R-8. Low-passed current vectors are shown in the third panel.

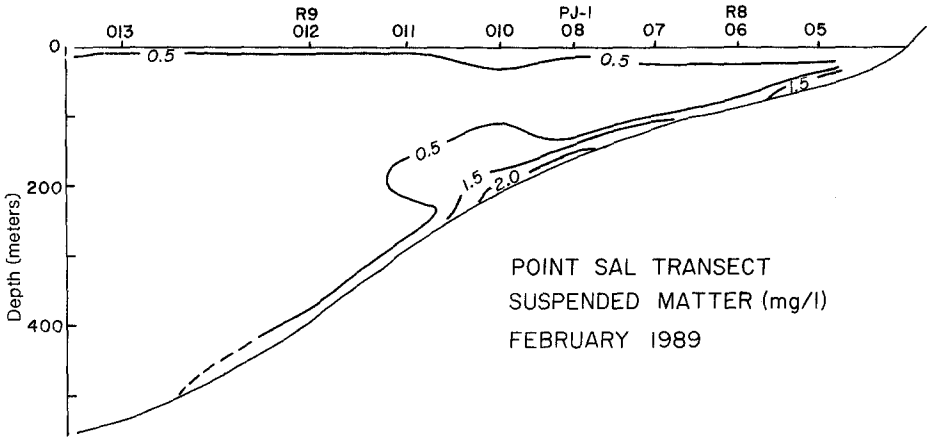

Fig. 7. Distribution of suspended matter along the hydrographic transect through R-8, PJ-1 and R-9, February 1989 (internal hydrographic station codes, 05 through 013, are also shown). The concentrations (mg/l) were determined through calibration curves for the 25-cm pathlength Sea Tech transmissometer used with a Neil Brown CTD system.

poleward undercurrent. The substantial (20–30°) leftward Ekman turning that occurs in the bottom boundary layer of the poleward mean current is certain to be an important factor in moving fine-grained sediment across the outer shelf to sites of accumulation on the slope. The occurrence of a bottom nepheloid layer on the outer shelf/upper slope near PJ-1 is an intriguing aspect of these findings. Internal waves may be involved in the generation of this turbid water but the importance of this process relative to winter storm events will not be known until our analysis of both the summer (1987) and winter (1988/89) data sets is completed.

Sedimentology

Grain-size distributions, percent total organic carbon (TOC), distribution of mineral types, shear strength, and Pb-210 profiles have been measured in sediment samples collected on all cruises between October 1986 and October 1988 (Table 1). Sediments from regional stations and the Platform Julius site-specific array were collected with the 0·25-m^2 box corer used for soft-bottom macroinfaunal sampling; sediments near rock features within the Platform Hidalgo sampling area were collected with a 0·1-m^2 modified vanVeen grab. These different sediment properties are being measured primarily for the purpose of providing a basis for interpreting patterns in the chemical and biological data.

Grain-size distributions in the Platform Julius study area range from

silty sands to clayey silts. Generally, the samples consist of greater than 50% silt and clay, with higher percentages of clay at deeper stations. Sediments from the deepest station (R-7) are approximately 40% clay.

TOC ranges from approximately 0·5% to over 2%. As with the grain-size distributions, TOC appears to vary with depth. Generally, the highest TOC values occur at the deeper stations.

The two deepest stations on the southern regional transect (R-5 and R-6) do not follow the trend of increasing clay and TOC content with depth. These two stations have among the lowest percentages of clay (3·9–6·2%) and TOC (0·41–0·62%). In contrast, other stations at similar depths have percentages of clay and TOC that range from 11·7 to 27 and 1·15 to 1·81, respectively. The shallowest station on the southern regional transect (R-4) has approximately 10% clay and 0·75% TOC. These data suggest that Stations R-5 and R-6 are in a less depositional area than the other stations of similar depths and probably experience stronger currents.

The sediments near rock features at the Platform Hidalgo site also do not seem to conform to the pattern of greater clay and TOC content with increasing depth. Stations PH-K, PH-N and PH-R generally have clay contents of less than 10%, whereas the other stations, including shallower ones, generally have higher clay contents of approximately 20%. The TOC content of sediments from these three stations is approximately 0·5%, whereas other shallower stations have TOC contents that often exceed 1·0%.

The shear strength of sediments in the Platform Julius area increases with sediment depth. Subsurface layers (<5 cm) also show decreases in shear strength with increasing station depth. Shear-strength values range from 0·03 to 0·06 kg/cm^2 at the 2-cm sediment-depth interval over all the regional stations. At the shallow regional stations (R-1, R-8 and R-4), shear-strength values for the 5-cm depth interval range from 0·14 to 0·25 kg/cm^2. At most deeper stations (R-2, R-3, R-9, and R-7) values for the 5-cm depth interval range from 0·06 to 0·13 kg/cm^2. Ranges of shear strength for the 8-cm depth interval are from 0·26 to 0·41 kg/cm^2 and 0·08 to 0·19 kg/cm^2 for shallow and deep regional stations, respectively. Two stations (R-5 and R-6) do not follow the pattern of decreasing shear strength for subsurface sediment layers with increasing station depth. These two deep stations have shear-strength values ranging from 0·17 to 0·22 kg/cm^2 for the 5-cm interval and from 0·32 to 0·36 kg/cm^2 for the 8-cm interval, which fall within the ranges for the shallower stations. Station R-7 has the lowest shear-strength values for all sediment-depth intervals.

X-ray diffraction analysis of the fine fraction of surficial sediments

throughout the area suggests three distinct provinces based upon the percentages of four clay minerals. The northern province includes the northernmost regional transect and some of the site-specific stations at Platform Julius, and is characterized by clay consisting of 40% chlorite plus kaolinite, 35% illite, and 25% smectite. The southernmost province includes sediments adjacent to the hard-bottom stations at Platform Hidalgo, and is characterized by clay consisting of 25% chlorite plus kaolinite, 30% illite, and 45% smectite. The middle province consists of the middle and southern regional transects at the Platform Julius site, and is characterized by clays with compositions intermediate to the other two provinces. Dominant minerals, in addition to the clay components, in bulk sediment samples throughout the study region include quartz, feldspar, and amphibole.

Pb-210 dating of sediment cores indicates that sediments in the study area are actively accumulating suspended particulate matter from the overlying water column; thus they can be expected to accumulate solids from platform discharges. Estimated sedimentation rates at the Platform Julius site, based on Pb-210 dating, are in the range of 0·2–0·3 cm/year. Pb-210 profiles also show a mixed surface-sediment layer that extends to a depth of about 8–10 cm, indicating substantial vertical mixing of sediments.

In addition to sampling bottom sediments, suspended particulate matter is being collected with sediment traps (6·6 cm inside diameter) deployed within 1 m of the bottom, near the Platform Hidalgo hard-bottom stations. Data from traps deployed between January and October 1988 have been analyzed thus far. Estimated sediment flux, averaged over this 10-month period, ranges from 20·6–32·0 g/m^2/day. A linear regression performed on these data suggests that estimated sediment flux is negatively correlated with station depth (r^2 = 0·785).

Sediment accumulation rates estimated from the Pb-210 data for the Platform Julius area were compared to the sediment flux rates estimated from the sediment-trap data for the Platform Hidalgo area. Assuming an average density of approximately 2 g/cm^3 for finer resuspended sediment, a sedimentation rate of 0·2–0·3 cm/year converts to a range of 11–16 g/m^2/day, which is about half the estimated sediment flux at the Platform Hidalgo site. The presence of rocks near Platform Hidalgo suggests that it is not a site of net sediment deposition, therefore the sediment accumulation rate here (although not measured) is probably lower than at Platform Julius. Nevertheless, if it is assumed that the suspended particulate concentrations at each study site are approximately similar, and that the sediment traps at Platform Hidalgo accurately reflect those concentrations, then about half of the suspended sediments passing the

Platform Julius site may be expected to accumulate there, with the remainder being advected out of the area.

Hydrocarbon chemistry

Hydrocarbons have been analyzed in surface-sediment (0–2 cm), subsurface-sediment (2–10 cm), sediment-trap, and animal-tissue samples collected at regional and site-specific stations on surveys between October 1986 and October 1988 (Table 1). Analyses have focused on determination of total hydrocarbon content as well as on detailed distributions of 48 targeted saturated and aromatic hydrocarbons. Saturated hydrocarbons (normal C_{10} to C_{32} alkanes and selected isoprenoids) and two- to five-ring polynuclear aromatic hydrocarbons (PAHs) were identified and quantified by gas chromatography coupled with mass selective detection (GC/MSD). Key interpretive parameters include: 1) total hydrocarbons (TOT) — sum of resolved and unresolved saturated and aromatic hydrocarbons; 2) total alkanes (TALK) — sum of n-C_{10} to n-C_{34} alkanes; used to quantify both lower-molecular-weight petroleum components and higher-molecular-weight, plant-derived components characteristic of background concentrations; 3) low-molecular weight alkanes (LALK) — sum of n-C_{10} to n-C_{20} alkanes, generally indicative of unweathered petroleum; 4) LALK/TALK — compositional ratio used to determine the relative quantity of petroleum-derived alkanes to total alkanes present in a sample; and 5) sum of two- to five-ring polynuclear aromatic hydrocarbons (ΣPAH), which include PAHs that are both petrogenic and pyrogenic in origin.

Two-year ranges of these parameters in the various types of sediment samples are summarized in Table 2. Mean TOT concentrations in surface sediments from the regional cross-shelf transects and Platform Julius stations range between 13 and 235 μg/g. The widest ranges in concentration occur among stations in the northern and middle cross-shelf transects that encompass water depths between 90 and 560 m. The general trend of increasing sediment hydrocarbon concentrations with increasing water depth along these transects appears to be correlated with other depth-related patterns in grain-size composition and organic content (TOC). As discussed above in the sedimentology section, bottom sediments in this region generally follow a trend of increasing clay content and TOC with increasing depth and distance from shore. In surface sediments, highest concentrations of hydrocarbons are often associated with the deepest station location (Station R-7) where sediments are typically 40% or more clay. A similar relationship is observed for most trace metals detected in surface sediments (see next

TABLE 2
Range of Mean Hydrocarbon Concentrations and Parameter-Ratio Values for Surface, Subsurface, and Sediment-Trap Samples Collected Between October 1986 and October 1988

Parameter	*Station groups*	*Concentration range (μg/g)*		
		Surface sediment	*Subsurface sediment*	*Sediment traps*
TOT	Platform Hidalgo Stations	24–154	—	82–475
	Northern Cross-Shelf Transect	13–212	—	—
	Middle Cross-Shelf Transect	13–235	13–88	—
	Southern Cross-Shelf Transect	15–76	—	—
	Long-Shelf Transect (at Julius)	26–69	17–166	—
	Platform Julius Array	22–193	—	—
TALK	Platform Hidalgo Stations	0·7–2·8	—	3–23
	Northern Cross-Shelf Transect	0·6–7	—	—
	Middle Cross-Shelf Transect	0·6–4	0·9–4	—
	Southern Cross-Shelf Transect	0·4–3	—	—
	Long-Shelf Transect (at Julius)	0·9–15	1·3–2·7	—
	Platform Julius Array	0·8–15	—	—
LALK	Platform Hidalgo Stations	0·10–0·89	—	0·7–4
	Northern Cross-Shelf Transect	0·07–0·96	—	—
	Middle Cross-Shelf Transect	<DL[a]–0·65	0·04–0·37	—
	Southern Cross-Shelf Transect	<DL–1·20	—	—
	Long-Shelf Transect (at Julius)	0·12–0·40	0·11–0·38	—
	Platform Julius Array	0·10–0·53	—	—
LALK/TALK	Platform Hidalgo Stations	0·09–0·39	—	0·05–0·41
	Northern Cross-Shelf Transect	0·06–0·26	—	—
	Middle Cross-Shelf Transect	0·08–0·32	0·04–0·33	—
	Southern Cross-Shelf Transect	0·06–0·39	—	—
	Long-Shelf Transect (at Julius)	0·01–0·21	0·06–0·18	—
	Platform Julius Array	0·01–0·25	—	—
ΣPAH	Platform Hidalgo Stations	0·03–1·5	—	0·01–1·1
	Northern Cross-Shelf Transect	<DL–0·43	—	—
	Middle Cross-Shelf Transect	<DL–0·68	<DL–0·12	—
	Southern Cross-Shelf Transect	<DL–0·17	—	—
	Long-Shelf Transect (at Julius)	0·01–0·21	0·02–0·16	—
	Platform Julius Array	0·02–0·36	—	—

[a]DL = Detection Limit.

section). The offshore effect, however, is much less apparent at the southern cross-shelf transect (Stations R-4, R-5, and R-6) where higher hydrocarbon levels are commonly associated with the shallowest and most inshore station (R-4). Because sediments from the deepest stations

in this transect (Stations R-5 and R-6) are distinguished by anomalously low clay content (4–6%), these stations appear to be less depositional than other stations at similar water depths. Total hydrocarbons in surface sediments from the long-shelf Platform Julius transect, located generally along the 150-m isobath, have a more narrow range (26–69 μg/g) than in sediments from cross-shelf transect stations (PH-11, PH-8, PH-1, and PH-10). These stations are located in similar sediment grain-size regimes, dominated by fine-grained silts.

By examining the range of normal (unbranched) alkane concentrations within a station over time, it is apparent that surface sediments from Platform Hidalgo stations have a narrower range of mean TALK and LALK levels (factors of 2–4 and 2–7, respectively) than sediments from the cross-shelf stations. At the cross-shelf stations, the within-station ranges of mean TALK and LALK concentrations in sediments vary over time by factors of 2–9 and 3–24, respectively. Inspection of the LALK/TALK ratio within stations, however, indicates a narrow range over time at both regional stations and Hidalgo sites (factors of 2–6 and 2–3, respectively). Although absolute concentrations of TALK and LALK are variable, the LALK/TALK ratio indicates that, compositionally, surface sediments are generally similar and are dominated by higher-molecular-weight, terrigenous plant-derived alkanes. Exceptions to this trend were noted at regional Station R-5 and at Hidalgo Station PH-R, where LALK/TALK was 0·39. This phenomenon, however, was not observed consistently in sediments collected from these stations during all surveys. The LALK/TALK diagnostic ratio is useful for monitoring impacts associated with oil exploration and development activities because it determines the relative amounts of low-molecular-weight alkanes, which are indicative of unweathered petroleum, to total amounts of alkanes (both petrogenic and biogenic materials) present in a sample. In 'clean' sediments, LALK/TALK is generally very low (0·01–0·3), reflecting the relatively small contribution of petrogenic compounds compared to TALK. As the inputs of petrogenic materials increase, LALK/TALK approaches 1·0, depending on the nature of the petroleum materials being added. For contaminated surface sediments collected nearby in the vicinity of the *Pac Baroness* oil spill off Point Conception, LALK/TALK ranges between 0·37 and 0·73 (Hyland *et al.*, 1989).

Concentrations of ΣPAHs in surface sediments are typically very low (e.g. <0·2 μg/g) throughout the study area. However, slightly elevated levels of PAHs were detected in several samples collected from Platform Hidalgo stations in October 1986. ΣPAHs in surface sediments from Stations PH-J, PH-K, and PH-R were 1·5, 0·37, and 1·4 μg/g, respectively. In addition to the absolute concentrations of PAHs in these samples,

compositional patterns of PAHs (e.g. phenanthrene/dibenzothiophene and naphthalene/phenanthrene ratios) also provide some evidence of petrogenic inputs at these stations. Because these stations were sampled prior to the initiation of drilling at Platform Hidalgo, the small but readily detectable inputs of hydrocarbons may be associated with platform siting and predrilling activities at Hidalgo or with drilling activities from other platforms in the area.

Subsurface sediment cores (2–10 cm) were collected at stations in the middle cross-shelf and long-shelf transects. Concentrations of total hydrocarbons, alkanes, and PAHs in these sediments are in the same ranges as detected in the corresponding surficial sediments for respective parameters (Table 2). Because there are no consistent differences between hydrocarbon levels in surface sediments compared to subsurface layers, it would appear that the 2–10 cm sediment interval is well mixed by physical or biological processes. This hypothesis is supported by the results of trace metal analyses and by the Pb-210 profiles measured in cores (see next section).

As indicated in Table 2, samples from sediment traps deployed at the Platform Hidalgo locations are generally characterized by higher absolute concentrations of total and saturated hydrocarbons (TOT, TALK, and LALK) than the surface sediments collected from these areas. PAH concentrations, in contrast, fall within approximately the same range for both sediment traps and surface sediments. Table 2 also shows similar ranges of LALK/TALK for sediment traps and surface sediments in the Platform Hidalgo area. However, when data from sediment traps and corresponding surface sediments from the same station are compared, the former samples generally have the higher LALK/TALK ratios. This result indicates that at some stations, particularly PH-I and PH-J, suspended sediments are relatively more enriched in petrogenically derived alkanes in comparison to surface sediments. At these two stations, mean values of LALK/TALK range from 0·32–0·38 for the May 1988 and October 1988 sampling periods, which can be compared to a predrilling value of 0·17 for Station PH-I in May 1987.

Benthic animals were collected at both soft-bottom and hard-bottom locations throughout the two-year monitoring period. Of the total animal species collected, only an opisthobranch mollusc (*Pleurobranchaea californica*) and a decapod crustacean (*Cancer* sp.) were trapped consistently and in adequate numbers for chemical analyses. Each individual of these two species collected at a station was treated as a replicate sample. The soft tissue was split for paired hydrocarbon and trace metal analyses. In general, there was little variability in hydrocarbon

levels among replicate species from a station. Both saturated and hydrocarbon concentrations in the tissues were significantly lower than in surface or subsurface sediments from corresponding stations and, in many samples, concentrations of PAH compounds were below detection limits.

The data from two years of monitoring indicate that concentrations of hydrocarbons in surface and subsurface sediments are generally low and characteristic of background fine-grained sediments common throughout much of the region. Similar concentrations were reported during the Phase I Reconnaissance Study (SAIC, 1986) and at control stations sampled during the recent *Pac Baroness* oil spill study (Hyland *et al.*, 1989). Because background levels of hydrocarbons are generally very low, potential impacts from future drilling activities should be readily detectable through examination of sensitive hydrocarbon parameters and diagnostic ratios. Within the two-year data set (October 1986 to October 1988), consistent seasonal trends in hydrocarbon levels have not yet emerged. In the vicinity of Platform Hidalgo, some sediment-trap samples indicate slightly elevated levels of petrogenic alkanes (based on the LALK/TALK ratio). Monitoring in this region will continue so that potential environmental impacts can be comprehensively assessed.

Trace-metal chemistry

Trace metals have been analyzed in samples of surface and subsurface sediments, sediment traps, pore waters, and tissues collected on all cruises from October 1986 to October 1988 (Table 1). Data from these samples have been used to examine spatial and temporal trends and regional variability in the concentrations of 11 metals. The distribution of the radionuclide Pb-210 in selected sediment cores has also been examined to estimate rates of sedimentation and sediment mixing.

Concentrations of the 11 metals in surface sediments (0–2 cm) collected in May 1987, which is representative of the other sampling occasions, are presented in Table 3. Each value is the mean of three replicate samples analyzed by either energy dispersive X-ray fluorescence (Nielson & Sanders, 1983) or by Zeeman graphite-furnace atomic absorption spectrometry. The concentrations of these trace metals in surface sediments are similar to average concentrations in crustal rocks and are characteristic of uncontaminated fine-grained sediments. Previous studies have reported similar concentrations of trace metals in southern California coastal sediments (Bruland *et al.*, 1974; Chow & Earl, 1979; Katz & Kaplan, 1981; Hershelman *et al.*, 1983; SAIC, 1986).

Trace-metal concentrations are essentially identical in surface (0–2 cm)

TABLE 3
Concentrations of Metals in Samples Collected in May 1987 (Unless Otherwise Indicated)

Station	*As*	*Ba*	*Cd*	*Cr*	*Cu*	*Pb*	*Hg*	*Ni*	*Ag*	*V*	*Zn*
Sediments at Soft Bottom Regional Stations (μg/g dry wt)											
R-1	6	688	0·47	174	14	14	0·091	38	0·09	71	58
R-2	7	627	0·57	121	20	15	0·091	50	0·12	63	81
R-3	6	609	1·09	101	24	13	0·105	52	0·15	67	89
R-4	7	805	0·41	95	15	16	0·082	43	0·11	48	64
R-5	9	792	0·45	315	8	14	0·075	28	0·08	<50	54
R-6	5	771	1·39	103	12	13	0·071	31	0·11	<34	54
R-7	7	604	1·79	139	38	12	0·091	61	0·28	63	116
R-8	5	829	0·29	50	10	15	0·066	19	0·08	<43	43
R-9	6	640	1·06	94	20	12	0·112	45	0·14	68	76
Sediments at Selected Site-Specific Stations Near the Proposed Platform Julius Site (μg/g dry wt)											
PJ-1	5	741	0·46	78	15	16	0·121	33	0·11	48	59
PJ-8	5	707	0·47	69	16	15	0·088	34	0·12	46	60
PJ-10	6	784	0·41	90	13	15	0·075	28	0·09	<51	53
PJ-11	7	723	0·45	82	17	17	0·068	37	0·11	52	65
Sediments at Platform Hidalgo Stations (μg/g dry wt)											
PH-E	7	1 012	0·59	128	19	17	0·102	53	0·15	<77	80
PH-F	7	770	0·56	112	18	14	0·069	50	0·16	<65	74
PH-I	6	863	0·57	106	21	18	0·102	49	0·16	53	75
PH-J	6	877	0·60	96	18	16	0·090	48	0·16	<54	71
PH-K	14	644	0·48	134	12	11	0·221	29	0·11	<64	94

PH-N	15	670	0·44	132	13	11	0·085	24	0·10	<56	85
PH-R	6	895	0·90	119	13	15	0·059	34	0·12	<50	62
PH-U	7	761	0·57	107	18	15	0·066	48	0·15	<70	72
PH-W	7	774	0·62	143	15	14	0·065	41	0·13	<44	60
Selected Sediment Traps Near Platform Hidalgo (μg/g dry wt)											
PH-U	7	652	0·46	101	19	14	0·072	53	0·15	64	80
PH-I	9	664	0·47	107	22	13	0·072	53	0·16	70	88
Pore-Water Samples at Platform Julius Stations (μg/L)											
PJ-10	8·0	16	0·28	0·9	0·8	0·11	<0·000 8	1·5	0·006	—	3·7
PJ-8	7·3	16	0·22	0·5	1·5	0·18	<0·000 8	1·1	0·005	—	5·0
PJ-1	8·8	12	0·23	0·2	0·5	0·11	<0·000 8	0·9	0·006	—	5·4
PJ-11	7·8	19	0·24	0·3	1·0	0·28	<0·000 8	1·5	0·010	—	10·1
Seawater[a]	1·5	15	0·05	0·1	0·3	0·05	0·001	0·4	0·002	—	1·0

Tissues Collected Near Platform Hidalgo (μg/g dry wt)[b]

	Station	*Replicates*	*Ba*	*Cr*	*Pb*	*Hg*
Pleurobranchaea	PH-1	5	16	1·82	0·91	0·17
	PH-2	2	15	1·41	0·99	0·19
	PH-3	2	<6	1·30	<0·25	0·19
Cancer Crab	PH-1	2	<4	0·39	<0·07	2·09
	PH-2	3	<4	1·07	<0·23	1·63

[a] Southern California, Santa Barbara Area.
[b] Samples collected in October 1986.

and subsurface (2–10 cm) sediments. This result is consistent with results of Pb-210 profiles measured in sediment cores from some of these stations, which indicate that mixing processes in the sediment have homogenized Pb-210 concentrations in the upper 8 cm.

The mean concentrations of trace metals in surface sediments among regional stations do not show any consistent temporal differences between October 1986 and October 1988. However, there is a definite onshore–offshore spatial trend for 10 of the 11 metals throughout all sampling periods. The regional transects show a pattern of increasing concentration of several metals with increasing water depth and distance from shore. Metals that increase with water depth are Ag, Cd, Hg, Cu, Cr, Ni, V, and Zn. Barium and Pb decrease with water depth, while As shows no change. These trends may be caused partly by changes in sediment grain size, which generally show a pattern of increasingly finer sediments with depth and distance from shore.

There are no significant longshelf patterns of metal concentrations in sediments, except for Cr at Station R-5, which is usually high for all sampling periods. Station R-5 is relatively sandy and may contain chromite as suggested by Chow and Earl (1979). The previous Cr survey in this area did note some locally high Cr concentrations, probably due to stream drainage of mineralized areas in the neighbouring coastal mountain ranges (SAIC, 1986).

Trace-metal concentrations are highly uniform among samples analyzed from the Platform Julius array of stations. Thus this site is ideal for monitoring potential changes related to offshore drilling. All samples are from a narrow range of water depths and have approximately the same grain size. Chromium and Hg vary by as much as a factor of two between several stations (which are not all included in Table 3); however, the other trace metals are much less variable.

The variance in Ba concentrations at Platform Julius stations has also been examined to evaluate the effectiveness of this metal as a tracer of drilling inputs. Barium levels at 13 stations were compared between October 1986 and January 1987. A paired T-test was used to determine whether the mean Ba concentrations for the 13 stations were different between the two periods. The means were not significantly different at an alpha level of 0·05. Assuming that the variance in these data is a good estimate for future differences between these stations, an absolute difference of about 25 μg/g Ba, or a 4% change in Ba, would be detectable with an alpha level of 0·01 and statistical power of 0·95. Barium has been shown to act as a good tracer of offshore drilling inputs in other regions (Trocine & Trefry, 1983; Neff *et al.*, 1989).

Surface sediments were collected four times between October 1986 and

October 1988 at nine stations near hard-bottom features chosen for site-specific monitoring in the vicinity of Platform Hidalgo. These nine stations, coded PH-E, PH-F, PH-I, PH-J, PH-K, PH-N, PH-R, PH-U, and PH-W, are distributed over a much greater range of water depth and sediment type than are stations within the Platform Julius array. Consequently, trace-metal concentrations in sediments near Platform Hidalgo are much more variable (Table 3).

With the exception of Ba, concentrations of trace metals in sediments near Platform Hidalgo have remained relatively uniform throughout the first two years of the monitoring program (October 1986–October 1988). However, concentrations of Ba have increased significantly during this period (Fig. 8). Because part of this increase occurred prior to initiation of drilling at Platform Hidalgo (November 1987), the probable cause of this increase is the drilling activity at both Platform Hidalgo and nearby Platform Harvest (at which drilling began just after our initial sampling in October 1986). Partial inputs from Platform Hidalgo are indicated by the additional rise in sediment concentrations of Ba after drilling began at this platform. Stations closest to Platform Hidalgo (PH-I and PH-J)

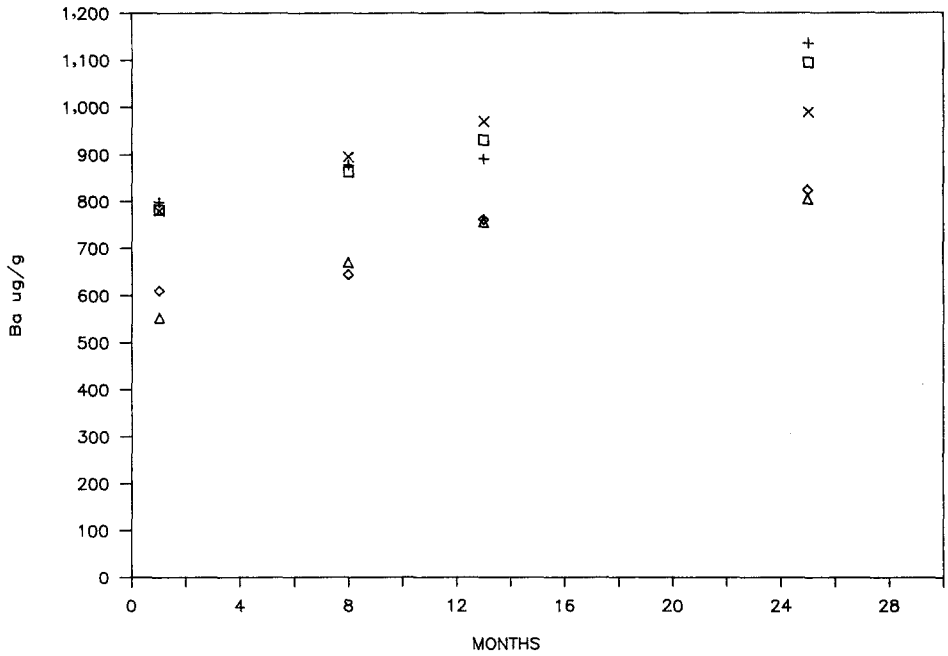

Fig. 8. Barium concentrations in sediment versus time at five stations near Platform Hidalgo beginning with field samples collected in October 1986. ◇ = PH-K; △ = PH-N; □ = PH-I; + = PH-J; × = PH-R.

show the sharpest rises after initiation of drilling. Furthermore, material collected in sediment traps at five sites (PH-K, PH-N, PH-I, PH-J, PH-R) deployed between January 1988 and May 1988 near Platform Hidalgo contained approximately 2 400 μg/g Ba compared to 660 μg/g Ba for predrilling trap samples.

The concentration of trace metals in pore-water samples collected in May 1987 at stations near the proposed Platform Julius site are presented in Table 3. Also presented are typical concentrations of trace metals in coastal seawater (Richard Zimmer-Faust pers. comm.). These pore-water samples were extracted on shipboard by squeezing the sediment under nitrogen gas. Metal concentrations were determined by several techniques: Cd, Cu, Ni, and Ag were analyzed by Zeeman graphite-furnace atomic absorption, following a preconcentration step (Bloom & Crecelius, 1984); arsenic was analyzed by hydride-generation atomic absorption; Hg was analyzed by cold-vapor atomic absorption (Bloom & Crecelius, 1983); Cr, Ba, and Zn were analyzed by Zeeman graphite-furnace atomic absorption without preconcentration. The data show that several of these trace metals — As, Cr, Cd, Cu, Pb, Ag, Zn, and Ni — are elevated by approximately a factor of two or more compared to coastal seawater. Thus metals are being desorbed from the sediments and are accumulating in the pore waters at concentrations greater than in the overlying seawater.

Animals collected in baited traps were analyzed for Ba, Cr, Pb, and Hg to establish the baseline concentrations of these metals for subsequent chemical body-burden analysis. Barium was determined by neutron activation and the remaining metals were analyzed by atomic absorption after initial digestion of tissues with HNO_3 under microwave heat. The two species that were collected initially in adequate numbers for chemical analyses consist of the opisthobranch mollusc *Pleurobranchaea californica* and the decapod crustacean *Cancer* sp. Concentrations of trace metals in these species for the first sampling period (October 1986) are presented in Table 3. Each replicate is the analysis of the soft tissue of one individual. Based on this limited data set, it is not yet possible to examine differences between stations or regions. However, there is a detectable difference between the concentrations of Cr and Hg in the two species. We are not aware of either published or unpublished trace-metal data for these particular species; however, the concentrations are similar to those reported for other marine animals including amphipods and bivalves (Boehm *et al.*, 1987). Data from additional species and sampling occasions will be examined subsequently as part of this program.

Lead-210 in selected sediment cores was determined by alpha

spectrometry of the granddaughter isotope Po-210 after acid digestion of the sediment and spontaneous deposition on silver discs. Polonium-208 was used as a yield tracer. The activities of Pb-210 range between 2 and 28 dpm/g, which are characteristic activities for fine-grained coastal sediments. In most of the cores, the Pb-210 activity is relatively uniform in the upper 8 cm and then decreases with depth in the cores. This type of Pb-210 profile is typical of sediments that have relatively low sedimentation rates and relatively high mixing rates caused by bioturbation. Nittrouer *et al.* (1984) report that a typical Pb-210 profile from the Washington shelf has a surface mixed layer 8 cm thick and that Pb-210 activity reaches a background or supported level at a depth of 20–25 cm.

Soft-bottom macroinfaunal assemblages

The Santa Maria Basin supports a very abundant and highly diverse benthic macroinfauna (animals larger than 0·5 mm) (Table 4). Densities at various regional stations range from 2 839–26 922 individuals/m^2, exceeding previously reported values for the same area (SAIC, 1986) by a factor of four. Total numbers of species from individual stations (represented typically by three replicate, 0·1 m^2 samples obtained on each of seven sampling occasions) range from 111 to 406. A total of 759 species (representing 14 phyla) have been identified from all samples (314) collected and analyzed thus far throughout the region. The most diverse taxa are polychaetes (43% of species) and crustaceans (34%). Approximately 50 of these species (mostly cumaceans) are new to science.

Species abundances and diversity (numbers of species) both decrease with increasing water depth. These same patterns were reported earlier during the Phase I Reconnaissance Study (SAIC, 1986). However, the pattern of species diversity is at variance with results obtained from other studies conducted in the western North Atlantic (e.g Maciolek *et al.*, 1986*a, b*; Blake *et al.*, 1987). Such differences show that efforts to predict patterns of species diversity in relation to depth in the ocean must take into account sources of variation on local or regional scales.

The patterns of decreasing macroinfaunal abundances and diversity with depth appear to be correlated with other depth-related changes in sediment grain size and dissolved-oxygen levels. Sampling has also revealed patterns of increasingly finer sediments and decreasing levels of dissolved oxygen (bottom water layer) with depth. Figure 9 reveals the close correlation between depth-related patterns in macroinfaunal density and levels of dissolved oxygen. Other factors not measured in this

TABLE 4
Dominant Macroinfaunal Species of the Santa Maria Basin

	Northern transect			Middle transect			Southern transect		
	Species	*IND/M²*	*CUM%*	*Species*	*IND/M²*	*CUM%*	*Species*	*IND/M²*	*CUM%*
	Station R-1			*Station R-8*			*Station R-4*		
	Mediomastus ambiseta (P)	1 919	14·7	*Minuspio lighti* (P)	2 364	14·0	*Photis lacia* (A)	2 908	10·8
	Chloeia pinnata (P)	1 129	23·3	*Pholoe glabra* (P)	1 589	23·4	*Chloeia pinnata* (P)	2 431	19·8
	Minuspio lighti (P)	808	29·5	*Chloeia pinnata* (P)	1 468	32·1	*Mediomastus ambiseta* (P)	2 295	28·3
	Cossura pygodactylata (P)	658	34·5	*Mediomastus ambiseta* (P)	1 371	40·2	*Myriochele* sp. M (P)	1 559	34·1
90–92 m	*Pholoe glabra* (P)	651	39·5	*Nephtys cornuta* (P)	836	45·2	*Photis* spp. (A)	1 371	39·2
Stations:	*Nephtys cornuta* (P)	542	43·7	*Amphiodia urtica* (Op.)	601	48·8	*Photis californica* (P)	948	42·7
	Levinsenia gracilis (P)	540	47·8	*Cossura pygodactylata* (P)	515	51·8	*Spiophanes missionensis* (P)	862	45·9
	Amphiodia urtica (Op.)	538	51·9	*Levinsenia gracilis* (P)	421	54·3	*Typhlotanais* sp. A (T)	798	48·9
	Typhlotanais sp. A (T)	342	54·5	*Parvilucina tenuisculpta* (B)	373	56·5	*Praxillella pacifica* (P)	717	51·6
	Praxillella pacifica (P)	277	56·6	*Tharyx* spp. (P)	342	58·5	*Minuspio lighti* (P)	708	54·2
	All Fauna (333 species)[a]	13 063	100·0	All Fauna (376 species)[c]	16 847	100·0	All Fauna (406 species)[a]	26 922	100·0
	Station R-2			*Station PJ-1*			*Station R-5*		
	Mediomastus ambiseta (P)	1 664	18·8	*Mediomastus ambiseta* (P)	1 931	14·8	*Mediomastus ambiseta* (P)	2 568	15·8
	Levinsenia gracilis (P)	674	26·4	*Chloeia pinnata* (P)	1 142	23·5	*Chloeia pinnata* (P)	1 278	23·6
	Minuspio lighti (P)	589	33·0	*Minuspio lighti* (P)	765	29·3	*Tharyx* spp. (P)	946	29·4
	Tectidrilus diversus (O)	571	39·4	*Cossura pygodactylata* (P)	550	33·5	*Photis californica* (A)	884	34·8
145–161 m	*Cossura pygodactylata* (P)	463	44·6	*Exogone lourei* (P)	548	37·7	*Minuspio lighti* (P)	673	38·9
Stations:	*Nephtys cornuta* (P)	367	48·7	*Levinsenia gracilis* (P)	508	41·6	*Photis lacia* (A)	545	42·2
	Chaetozone nr. setosa (P)	343	52·6	*Spiophanes berkeleyorum* (P)	467	45·2	*Spiophanes berkeleyorum* (P)	520	45·4
	Spiophanes berkeleyorum (P)	341	56·4	*Nephtys cornuta* (P)	379	48·1	*Prochelator* sp. A (I)	484	48·4
	Acila castrenis (B)	275	59·5	*Typhlotanais* sp. A (T)	343	50·7	*Levinsenia gracilis* (P)	478	51·3
	Trachyleberis simiensis (Ost.)	267	62·5	*Prochelator* sp. A (I)	330	53·2	*Spiophanes missionensis* (P)	461	54·1
	All Fauna (265 species)[a]	8 862	100·0	All Fauna (311 species)[a]	13 073	100·0	All Fauna (351 species)[a]	16 273	100·0

	Station R-3			Station R-9			Station R-6		
409–410 m Stations:	*Chloeia pinnata* (P)	1 108	23·1	*Chloeia pinnata* (P)	1 038	25·8	*Chloeia pinnata* (P)	2 409	34·8
	Levinsenia gracilis (P)	848	40·8	*Nephtys cornuta* (P)	841	46·7	*Nephtys cornuta* (P)	800	46·4
	Nephtys cornuta (P)	689	55·1	*Tectidrilus diversus* (O)	369	55·9	*Tectidrilus diversus* (O)	532	54·1
	Chaetozone nr. setosa (P)	372	62·8	*Maldane sarsi* (P)	255	62·2	*Chaetozone nr. setosa* (P)	524	61·8
	Leucon magnadentata (C)	364	70·4	*Chaetozone nr. setosa* (P)	170	66·4	*Cossura rostrata* (P)	228	65·1
	Cadulus californicus (S)	200	74·6	*Eudorella* sp. 1 (C)	87	68·6	*Huxleyia munita* (B)	227	68·4
	Eudorella pacifica (C)	106	76·8	*Leucon magnadentata* (C)	84	70·7	*Maldane sarsi* (P)	205	71·4
	Pseudharpinia excavata (A)	104	79·0	*Levinsenia gracilis* (P)	77	72·8	*Cossura candida* (P)	137	73·4
	Minuspio lighti (P)	68	80·4	*Cadulus californicus* (S)	76	74·7	*Minuspio lighti* (P)	134	75·3
	Cossura rostrata (P)	58	81·6	*Minuspio* sp. A (P)	73	76·5	*Cossura pygodactylata* (P)	100	76·7
	All Fauna (161 species)[b]	4 796	100·0	All Fauna (149 species)[c]	4 016	100·0	All Fauna (204 species)[a]	6 916	100·0
				Station R-7					
565 m Station:				*Harpiniopsis epistomata* (A)	1 458	51·4			
				Nephtys cornuta (P)	222	59·2			
				Maldane sarsi (P)	201	66·3			
				Minuspio sp. A (P)	177	72·5			
				Araphura sp. B (T)	166	78·3			
				Limnodriloides sp. 1 (O)	97	81·7			
				Cadulus californicus (S)	60	83·8			
				Chloeia pinnata (P)	50	85·6			
				Saturnia nr. ritteri (B)	48	87·3			
				Isocirrus sp. A (P)	34	88·5			
				All Fauna (111 species)[c]	2 839	100·0			

A = Amphipoda, B = Bivalvia, C = Cumacea, I = Isopoda, O = Ophiuroidea, Ost = Ostracoda, P = Polychaeta, S = Scaphopoda, T = Tanaidacea. Densities are averaged over all sampling periods.

[a] Total of 21 0·1-M^2 samples (3 replicates in 7 cruises: Oct 86, Jan 87, May 87, Oct 87, Jan 88, May 88, Oct 88).

[b] Total of 20 0·1-M^2 samples (2 replicates on May 88 cruises, plus 3 replicates on remaining 6 cruises).

[c] Total of 18 0·1-M^2 samples (3 replicates on 6 cruises: R8 and R9 not sampled in Oct 86; R7 not sampled in May 88).

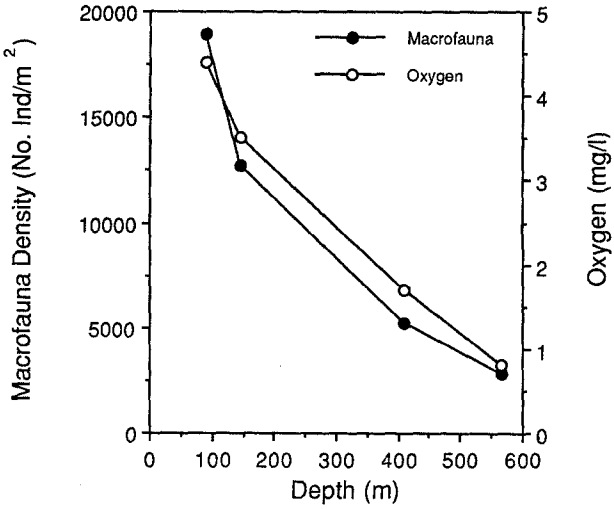

Fig. 9. Comparison of depth-related patterns in macroinfaunal densities and dissolved oxygen concentrations (bottom water) averaged over all sampling periods between October 1986 and October 1988.

study (e.g. differences in the intensity of biological interactions such as predation and competition) might also be important in controlling these patterns.

Cluster analysis (performed with group-average sorting as the clustering method and normalized expected species shared as the resemblance measure) shows that regional stations form three major groups reflecting depth-related differences in relative species abundances. These groups consist of all outer-shelf to upper-slope stations (R-1, R-2, R-8, PJ-1, R-4, and R-5; 90–161 m), all mid-slope stations (R-3, R-9, and R-6; 409–410 m) and the deep-slope Station R-7 (565 m). The outer-shelf to upper-slope stations show additional depth-related subdivisions. These results indicate that macroinfaunal assemblages occurring at different stations of approximately the same depth usually have similar faunal compositions. The relative constancy of community structure at a given depth is important with respect to monitoring-program objectives because it allows comparisons of potential impacts over broad regional areas and in relation to anticipated patterns of along-shelf current flows and sediment transport.

Although overall community structure and composition are relatively uniform among stations of similar depth (based on cluster analysis), there is a general trend of increasing species abundances and numbers of species from the northern to southern transects (Table 4). The cause of

these patterns is unknown, leaving an interesting ecological question to consider.

Among shelf and upper-slope stations, the most persistent and strongly ranked dominants (based on abundances averaged over all sampling occasions) are the two polychaetes *Mediomastus ambiseta* and *Chloeia pinnata*. Other important dominants are the polychaetes *Minuspio lighti, Levinsenia gracilis,* and *Pholoe glabra*. Ophiuroids (*Amphiodia urtica*) are also characteristic of the shallowest stations (90–92 m) and several species of crustacea (three amphipods of the genus *Photis* and the tanaid *Typhlotanais* sp. A) are increasingly important among the southern stations within this depth range. At the deeper mid-slope stations (409–410 m), *Mediomastus ambiseta* drops out as a dominant, and the polychaetes *Nephtys cornuta* and *Chloeia pinnata* become the two most persistent and strongly ranked dominants. These deeper stations are also characterized by increasing abundances of oligochaetes (*Tectidrilus diversus*), crustaceans (including the cumaceans *Leucon magnadentata, Eudorella pacifica,* and *Eudorella* sp. 1; and the amphipod *Pseudharpinia excavata*), and the polychaetes *Maldane sarsi* and *Chaetozone nr. setosa.* The scaphopod *Cadulus californicus* and the polychaete *Minuspio* sp. A also appear as dominants for the first time at this depth. The deepest slope station (R-7) is characterized foremost by the amphipod *Harpiniopsis epistomata,* which represents over 50% of total faunal abundance. While *Nephtys cornuta* remains relatively abundant at this station, *Chloeia pinnata* shows an obvious decline. Several other species appear as dominants for the first time at this depth: the tanaid *Araphura* sp. B, the oligochaete *Limnodriloides* sp. 1, the polychaete *Isocirrus* sp. A, and the bivalve *Saturnia nr. ritteri.*

The strength of dominance appears to increase with increasing water depth. Among the 90–161 m stations, 50% cumulative abundance is reached with seven to nine species; among the 409–410 m stations, 50% cumulative abundance is reached with only three species; and at the deepest Station R-7, *Harpiniopsis epistomata* alone accounts for more than 50% of the total faunal abundance. Thus, in deeper areas, it is possible that adverse effects of drilling on one or a few species might also represent an impact on the majority of the community. As described above, the transport of fine-grained sediment and associated drilling components across the outer shelf to deeper sites of accumulation on the slope is also possible due to the substantial leftward Ekman turning that occurs in the bottom boundary layer of the low-frequency poleward mean current. It is recommended that *Harpiniopsis epistomata* be studied in further detail because of its dominance in deeper sediments, where

drilling components may accumulate, and because of the known sensitivity of amphipod crustaceans to oil toxicity (Cabioch *et al.*, 1978; Sanders *et al.*, 1980). A detailed study of the life-history properties of this species is underway; additional laboratory toxicity studies are also suggested.

Data from seven different sampling occasions (Oct. 86, Jan. 87, May 87, Oct. 87, Jan. 88, May 88, and Oct. 88) provide evidence of temporal variation, including significant changes (based on ANOVA at alpha of 0·05) in total faunal abundance of all species combined, average numbers of species per sample, and dominant species abundances. Within-year variations do not appear to follow the same pattern from one year to the next. Nevertheless, these results demonstrate the importance of conducting repeated sampling before and after initiation of drilling activities, to provide a basis for differentiating between natural temporal variations in benthic community parameters and impacts due to drilling and production activities.

Cluster analysis of macroinfaunal samples also indicates a high degree of faunal homogeneity among stations within the Platform Julius site-specific array. With one major exception (the deepest station, PJ-9) site-specific samples cluster at levels of similarity that are greater than the highest similarity between different regional stations. Thus, these data indicate that the Platform Julius site-specific array appears to be located in an appropriate region for monitoring and depicting the spatial extent of potential nearfield impacts associated with a production platform in an unconsolidated sediment regime.

As described above, Pb-210 profiles indicate substantial vertical mixing of bottom sediments to depths of about 8–10 cm. These data are consistent with results of sediment-core radiography, which reveal signs of strong sediment reworking caused by the activities of deep-burrowing macroinfauna (particularly ophiuroids, echiurans, molluscs, and some larger polychaetes). These combined data support the hypothesis that drilling-associated contaminants that settle to the bottom may become mixed with subsurface sediments as a result of extensive bioturbation.

Soft-bottom meiofaunal assemblages

The structure and distribution of meiofaunal assemblages were examined based on samples collected at regional stations and the Platform Julius site-specific array on all cruises between October 1986 and October 1988. The meiofauna are regarded here, operationally, as organisms that pass through a 0·5-mm sieve and are retained on a 0·063-mm sieve (as defined by Coull & Bell, 1979). Both metazoans and protozoans are included;

however, data for the two groups are treated separately to provide a basis for comparison with other meiofaunal studies which often deal only with the metazoans. Organisms were identified to the taxonomic levels presented in Table 5. Harpacticiod copepods were identified to the species level (Table 6).

The vertical distribution of meiofauna within the sediment was studied from a subset of 14 stations (PJ-1, PJ-7, PJ-9, PJ-10, PJ-11, PJ-20, PJ-21, R-1, R-2, R-3, R-4, R-5, R-6 and R-7) sampled on the first, October 1986, cruise. Samples were taken every 2 cm to a depth of 10 cm. Results show that 56% of the meiofauna are found within the upper 2 cm and that 87% are found within the upper 4 cm. Similarly, Coull *et al.* (1977) report that meiofauna off the coast of North Carolina are concentrated in the upper 3 cm of sediment. Patterns of distribution in relation to sediment depth are similar among stations; however, different taxa display different sediment distribution patterns. For example, harpacticoids are found almost exclusively within the upper 2 cm, while most other groups exhibit a log-linear relationship between abundance and depth.

Two taxonomic groups, Nematoda and Harpacticoida, comprise 89·2% of all metazoan fauna (Table 5). The remaining 10·8% of these fauna are comprised of twenty different taxa (including many juvenile representatives of species that normally become members of the macrofauna as adults): Amphipoda, Acarina, Asteroidea, Bivalvia, Cumacea, Cnidaria, Gastropoda, Gastrotricha, Gnathostomulida, Isopoda, Kinoryncha, Nemertea, Oligochaeta, Ophiuroidea, Ostracoda, Polychaeta, Scaphopoda, Tanaidacea, Turbellaria, and various non-copepod nauplii.

The mean density of metazoans for all stations combined (upper 4 cm) is $1755 \times 10\ cm^{-2}$ and the mean density of protozoans is $942 \times 10\ cm^{-2}$ (Table 5). ANOVA indicates a significant interaction between stations and sampling times for all taxa. This is due primarily to unusually high abundances on the second cruise (January 1987) at Station R-9. The mean metazoan density for this station and sampling period is $5775 \times 10\ cm^{-2}$ and the mean protozoan density is $2538 \times 10\ cm^{-2}$, both of which exceed values for all other stations by more than a factor of two. When the anomalous January 1987 data for Station R-9 are excluded, the remaining time-series data show no significant seasonal differences in meiofaunal populations, at an alpha level of 0·05. Nematode densities, which drive overall meiofaunal patterns, are more temporally variable in comparison to the other meiofauna taxa, however these temporal differences are also insignificant.

Meiofaunal abundances at most stations in the Santa Maria Basin appear to be much higher than those reported for other continental shelf

TABLE 5

Mean Meiofauna Density (n Individuals × 10 cm^{-2}) and Percent Composition to a Sediment Depth of 4 cm for all Cruises Between October 1986 and October 1988

Taxa	*Northern transect*			*Central transect*			*Southern transect*		
	n	%[a]	%[b]	*n*	%[a]	%[b]	*n*	%[a]	%[b]
	Station R-1			*Station R-8*			*Station R-4*		
NEM	1 789	80·5	51·0	1 570	80·4	61·9	1 645	73·8	53·5
HAR	137	6·2	3·9	145	7·4	5·7	338	15·2	11·0
OTH	296	13·3	8·4	237	12·1	9·3	245	11·0	8·0
MTOT	2 222	100·0	—	1 952	100·0	—	2 228	100·0	—
FOR	922	71·9	26·3	272	46·4	10·7	639	75·6	20·8
PRO	361	28·1	10·3	314	53·6	12·4	206	24·4	6·7
PTOT	1 283	100·0	—	586	100·0	—	845	100·0	—
TOT	3 505	—	100·0	2 538	—	100·0	3 073	—	100·0
	Station R-2			*Station PJ-1*			*Station R-5*		
NEM	1 554	80·9	50·4	1 314	75·6	50·0	1 083	79·7	39·7
HAR	125	6·5	4·1	180	10·4	6·8	147	10·8	5·4
OTH	242	12·6	7·8	243	14·0	9·2	129	9·5	4·7
MTOT	1 921	100·0	—	1 737	100·0	—	1 359	100·0	—
FOR	836	71·8	27·1	642	72·0	24·4	1 230	89·7	45·1
PRO	328	28·2	10·6	250	28·0	9·5	141	10·3	5·1
PTOT	1 164	100·0	—	892	100·0	—	1 371	100·0	—
TOT	3 085	—	100·0	2 629	—	100·0	2 730	—	100·0
	Station R-3			*Station R-9*			*Station R-6*		
NEM	1 748	90·2	72·7	1 962	88·1	55·8	1 335	87·3	56·4
HAR	77	4·0	3·2	63	2·8	1·8	85	5·6	3·6
OTH	113	5·8	4·7	201	9·0	5·7	110	7·2	4·6
MTOT	1 938	100·0	—	2 226	100·0	—	1 530	100·0	—
FOR	316	67·5	13·1	1 086	84·3	30·9	693	82·6	29·3
PRO	152	32·5	6·3	202	15·7	5·7	146	17·4	6·1
PTOT	468	100·0	—	1 288	100·0	—	839	100·0	—
TOT	2 406	—	100·0	3 514	—	100·0	2 369	—	100·0
				Station R-7					
NEM				140	71·1	16·8			
HAR				15	7·6	1·8			
OTH				42	21·3	5·0			
TOT				197	100·0	—			
FOR				573	89·8	68·6			
PRO				65	10·2	7·8			
PTOT				638	100·0	—			
TOT				835	—	100·0			

NEM = Nematoda, HAR = Harpacticoida (Copepodites + Nauplii), OTH = Other Metazoa[c], MTOT = Total Metazoa, FOR = Foraminiferida, PRO = Other Protozoa (Ciliata and Flagellata), PTOT = Total Protozoa, TOT = Total (Metazoa + Protozoa)

[a]Per cent composition relative to corresponding metazoan or protozoan total.

[b]Per cent composition of the total community (metazoans and protozoans combined).

[c]Twenty taxa including many juvenile macrofauna (see text for listing).

sediments of a similar depth range (90–565 m). Coull *et al.* (1982), for example, report a mean of only 360 × 10 cm^{-2} metazoan meiofauna for the southeastern continental shelf of the United States (11–500 m). Coull *et al.* (1977) report 670 × 10 cm^{-2} meiofauna (including foraminiferans) for deeper portions (>400 m) of the southeastern shelf. McIntyre (1964; 1978) reports a mean of 1500 × 10 cm^{-2} meiofauna (including foraminiferans) for the North Sea Shelf, and Thiel (1978) reports 1000 × 10 cm^{-2} meiofauna from upwelling regions off the west coast of Africa.

The highest abundances of meiofauna in the present study generally occur at the shallowest depths. For example, the mean density of metazoans from Stations R-1, R-8, and R-4 (90–92 m) is 2134 × 10 cm^{-2}. The deepest station, R-7 (565 m) has the lowest abundances (197 × 10 cm^{-2} for metazoan meiofauna and 638 × 10 cm^{-2} for protozoans). These values are about an order of magnitude lower than values for all other Santa Maria Basin stations (Table 5), but are within the range of those that Coull *et al.* (1977, 1982) report for their deeper sediments. If the anomalous January 1987 data for Station R-9 are not considered, there is a general pattern of decreasing meiofaunal abundance (for metazoa and protozoa combined) with increasing water depth, similar to the pattern observed for macroinfauna. Harpacticoids, other meiofauna (excluding nematodes), and protozoans other than foraminifera show clear patterns of decreasing density with increasing depth (Table 5); densities are significantly different between each increment of depth.

There is also an apparent trend of decreasing abundances from northern to southern transects. Average densities of metazoans for the northern, central (excluding Station R-7) and southern transects, for example, are 2027 × 10 cm^{-2}, 1972 × 10 cm^{-2}, and 1706 × 10 cm^{-2}, respectively. These values are not significantly different from one another. However, if the anomalous January 1987 data for Station R-9 are deleted, the average density for the central transect drops to 1735 × 10 cm^{-2} and the trend becomes significant. This trend of decreasing density from north to south is strongest among nematodes, other meiofauna, and protozoans. In contrast, harpacticoid densities tend to increase from north to south.

The average density of Harpacticoida is 131 × 10 cm^{-2} (Table 5). If station R-7 is excluded, the value increases to 144 × 10 cm^{-2}. This value is two times higher than the average density (69 × 10 cm^{-2}) reported by Coull *et al.* (1982) for the southeastern continental shelf of the United States. There is a strong correlation between water depth and harpacticoid densities; as noted above, densities generally decrease with depth. Numbers of species also tend to decrease with depth at least with respect to comparisons between stations shallower than 161 m and those that are deeper. R-7, the deepest station, has an average density of only

TABLE 6

Harpacticoida (Copepodites and Adults only) Species Data for all Cruises Between October 1986 and October 1988

	Northern transect			*Central transect*			*Southern transect*		
	Species	*Mean*	*Cum. %*	*Species*	*Mean*	*Cum. %*	*Species*	*Mean*	*Cum. %*
	Station R-1			*Station R-8*			*Station R-4*		
	Cletodes smirnov	13·49	17·0	*Stenhalia* sp. J	6·72	10·0	*Cletodes* sp. B	22·92	13·0
	Amphiascus sp. A	7·82	27·0	*Cletodes smirnov*	5·88	18·0	*Cletodes smirnov*	15·43	21·0
	Zosime sp. A	3·83	32·0	Ectinosomatidae sp. I	4·03	24·0	Ectinosomatidae sp. C	12·20	28·0
	Stenhelia sp. E	3·53	37·0	*Bradya cladiofera*	4·03	30·0	Species I	12·20	35·0
90–92 m	Species I	3·07	41·0	Ectinosomatidae sp. SM	3·86	36·0	*Typhlamphiascus pectinifer*	11·46	41·0
Stations:	*Cletodes* sp. B	3·07	45·0	*Halectinosoma kunzi*	3·02	40·0	*Halectinosoma kunzi*	7·20	46·0
	Bradya cladiofera	2·76	48·0	*Stenhelia* sp. E	2·69	44·0	*Bradya cladifora*	6·61	49·0
	Ectinosomatidae sp. SM	2·76	52·0	*Amphiascus* sp. A	2·18	47·0	*Stenhelia* sp. J	5·88	53·0
	52 Others	37·72	100·0	49 Others	36·44	100·0	60 Others	84·94	100·0
	Total	78·05		Total	68·86		Total	178·84	
	Station R-2			*Station PJ-1*			*Station R-5*		
	Danielssenia sp. A	6·91	9·0	*Cletodes smirnov*	11·39	13·0	Ectinosomatidae sp. C	8·18	11·0
	Zosime sp. A	6·32	18·0	*Zosime* sp. A	11·39	26·0	*Zosime* sp. A	6·07	19·0
	Species I	4·26	24·0	*Cletodes* sp. B	10·44	38·0	Species I	5·08	25·0
	Amphiascus sp. A	3·67	28·0	Ectinosomatidae sp. C	4·61	44·0	*Stenhelia* sp. J	3·81	30·0
145–161 m	*Tachidiella* sp. A	3·53	33·0	*Cletodes* sp. D	4·34	49·0	*Cletodes smirnov*	3·67	35·0
Stations:	*Halectinosoma kunzi*	3·09	37·0	*Amjphiascus* sp. A	4·07	53·0	*Stenhelia* sp. E	3·67	40·0
	Ectinosomatidae sp. SM	2·94	41·0	*Danielssenia* sp. A	3·39	57·0	Species C	2·54	43·0
	Species C	2·79	45·0	*Bradya cladiofera*	2·58	60·0	Ectinosomatidae sp. I	2·54	47·0
	58 Others	40·85	100·0	54 Others	34·32	100·0	59 Others	40·77	100·0
	Total	74·36		Total	86·54		Total	76·32	

	Station R-3			Station R-9			Station R-6		
409–410 m Stations:	*Halectinosoma kunzi*	11·65	22·0	*Tachidiella* sp. B	5·81	14·0	*Stenhelia* sp. D	8·59	17·0
	Tachidiella sp. B	6·13	33·0	Cerviniidae sp. A	5·19	27·0	*Halectinosoma kunzi*	8·13	33·0
	Cerviniidae sp. A	5·67	44·0	Cletodidae sp. P	4·15	38·0	Cerviniidae sp. A	3·68	40·0
	Stenhalia sp. C	4·91	53·0	*Halectinosoma kunzi*	3·94	47·0	Ectinosomatidae sp. ME	3·37	47·0
	Stenhelia sp. D	4·60	61·0	Ectinosomatidae sp. M	2·28	53·0	*Zosime* sp. A	2·61	52·0
	Ectinosomatidae sp. I	3·07	67·0	Species AA	1·87	58·0	*Tachidiella* sp. A	2·15	57·0
	Species AA	2·61	72·0	*Stenhelia* sp. D	1·87	62·0	Ectinosomatidae sp. LA	1·23	59·0
	Species R	2·45	76·0	Species V	1·24	65·0	Ectinosomatidae sp. SM	1·07	61·0
	35 Others	12·73	100·0	30 Others	13·90	100·0	52 Others	19·63	100·0
	Total	53·82		Total	40·25		Total	50·45	
				Station R-7					
565 m Station:				*Halectinosoma kunzi*	3·88	26·0			
				Ectinosomatidae sp. I	2·12	40·0			
				Cerviniidae sp. A	1·76	51·0			
				Tachidiella sp. A	1·41	60·0			
				Species AA	1·06	67·0			
				Species NN	1·06	74·0			
				Ectinosomatidae sp. K	0·71	79·0			
				Cletodidae sp. X	0·35	81·0			
				8 Others	2·82	100·0			
				Total	15·17				

Mean density (n individuals $\times$ 10 cm^{-2}) to a sediment depth of 4 cm and cumulative percent composition listed in order of dominance.

$15 \times 10\ cm^{-2}$ and only 16 species that have been encountered (Table 5).

The composition of the harpacticoid fauna of the Santa Maria Basin is very complex. One hundred and fifteen species have been identified among 216 samples. Because this region has never before been the subject of a systematic study of meiofauna, there are many undescribed species (Table 6). The four overall dominant species in rank order are *Cletodes smirnov, Halectinosoma kunzi, Cletodes* sp. B, and *Zosime* sp. A. The dominant families are Cletodidae and Ectinosomatidae. Results of a cluster analysis of the harpacticoid species data (performed with the single-linkage clustering method and the Pearson product-moment correlation coefficient as the resemblance measure) indicate that stations of approximately the same depth have similar species compositions. Mid to deep-slope stations (>400 m) are clearly different from the shallower outer-shelf to upper-slope stations (90–161 m). The outer-shelf stations (90–92 m), however, show close similarities to the upper-slope stations (145–161 m). Stations within the Platform Julius site-specific array are very homogeneous.

Meiofaunal populations provide an excellent tool for monitoring potential long-term impacts of oil and gas development and production in the Santa Maria Basin. First, the meiofauna are known to serve important functional roles in the ecosystem (see reviews by Coull & Bell, 1979; Coull & Palmer, 1984). Second, they are concentrated within the top 4 cm of the sediment surface, where potential effects resulting from the sedimentation of drilling fluids are most likely to occur. Third, they are unusually abundant in the Santa Maria Basin in comparison to other localities; thus numbers are sufficiently large to detect natural spatial and temporal patterns. Lastly, because of a high degree of homogeneity among stations within the Platform Julius site-specific array, spatial patterns of change that are attributable to drilling discharges should be detectable within reasonable statistical confidence limits.

Hard-bottom assemblages

Photographic samples of hard-bottom assemblages have been analyzed from three sampling periods: October 1986, July 1987 and November 1987. Photographic analysis consists of estimation of species percent cover based upon random-point contact methods, enumeration of all specimens for species occurring as discrete individuals, and noting the presence of all remaining species not contacted by a random point or counted. All estimates of percent cover and densities are normalized to the visible amount of rock in each photograph.

Most of the rock surfaces were covered by a turf characterized as a Komokoaicea-Hydroida mat. This assemblage averages over 70% cover

across all stations. Rock samples collected from the study area indicate that this mat consists almost exclusively of komokoaicean foraminiferans, although photographs have shown that some assemblages may also contain a hydroid component.

With the exception of the Komokoaicea-Hydroida mat, no taxon truly dominates the study area. The photographs analyzed thus far reveal a diverse fauna consisting of more than 200 taxa, many of which are present at all stations. In fact, 17 of the 25 most abundant taxa are present at all stations.

The 25 most abundant taxa in the samples consist mostly of suspension feeders. Eight of the 25 most abundant taxa are anthozoans. The next most diverse group is poriferans, represented by four taxa. These groups are followed by three polychaete taxa, two ophiuroid taxa, two urochordate taxa, and one taxon each of Foraminiferida, Crinoidea, Decapoda, Brachiopoda, Ectoprocta, and eggs of the elasmobranch group Scyliorhinidae. Many of these taxa have been reported as dominants in prior surveys of the region (Nekton, 1981; Dames & Moore, 1982, 1983; and SAIC, 1986).

Despite the broad distribution of many of the 25 most abundant taxa, the data show that their abundances vary substantially among stations. Only six taxa are among the five most abundant at more than one station. The importance of anthozoans in these assemblages is further supported by the fact that they represent the majority of the five most abundant taxa at each station.

The data reveal that abundances of many of the taxa vary with station depth. Percent cover of the anthozoans *Amphianthus californicus, Desmophyllum crista-galli* and *Stomphia didemon* are positively correlated with station depth, as are galatheid decapods, sabellid polychaetes and two descriptive taxa consisting of shelf sponges and tan encrusting sponges. In contrast, the abundances of the anthozoans *Caryophyllia* spp. and *Paracyathus stearnsii* are negatively correlated with station depth.

Cluster analysis (performed with group-average sorting as the clustering method and the Bray-Curtis index as the resemblance measure) also suggests depth-related differences among stations and that these patterns are highly persistent with time. The clusters from each of the sampling periods form two main groups consisting of the shallowest (PH-E, PH-F, PH-I, PH-J and PH-U) and deepest (PH-R and PH-W) stations, respectively. The intermediate low-relief Station PH-N clusters with both shallower and deeper stations, depending on the sampling period. The intermediate high-relief Station PH-K clusters with the deeper stations in every sampling period.

The persistent depth-related patterns suggest temporally stable, but

spatially variable, hard-bottom assemblages. These characteristics are clearly evident for two species of anthozoan cup corals, *Desmophyllum crista-galli* and *Paracyathus stearnsii* (Figs 10 and 11). Although the percent cover of *D. crista-galli* and *P. stearnsii* display opposite relationships with depth, their spatial patterns are persistent over the one-year period examined thus far.

The abundances of hard-bottom species, especially sessile suspension feeders, appear to be related to both station depth and height of substrate relief. The five shallowest low-relief stations differ in depth by only 14 m and have very similar percent cover of sessile suspension feeders, whereas the three deepest low-relief stations have substantially greater cover of suspension feeders (Fig. 12). However, at similar depths high-relief stations have greater cover of suspension feeders than low-relief stations. High-relief stations also show a trend of increasing cover of suspension feeders with increasing station depth, as do the low-relief stations. Increased abundances of suspension feeders on high-relief rock features have also been reported by Pequegnat (1964) and by Genin *et al.* (1986). Although Genin *et al.* (1986) suggest accelerated currents as a cause for the greater occurrence of corals on topographic highs, other factors may explain the present results.

We suggest that suspended sediment plays a major role in controlling the depth and substrate-related distributions of suspension feeders. In a previous section, we described the negative correlation between station

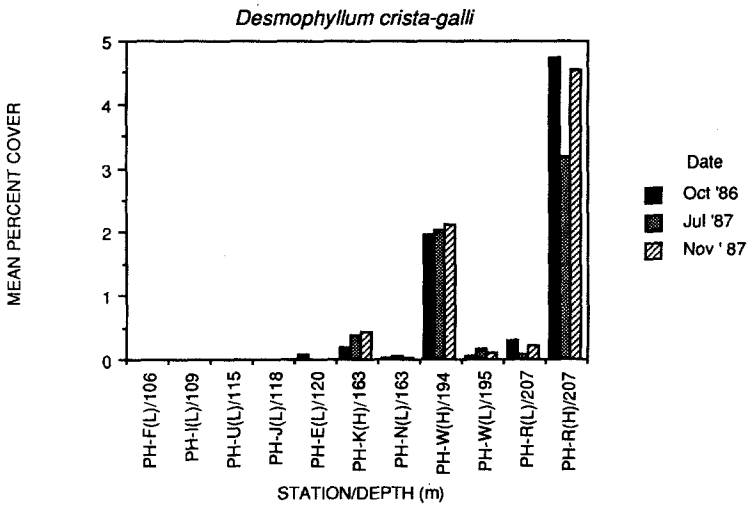

Fig. 10. Mean percent cover for *Desmophyllum crista-galli* at eight low-relief (L) stations and three high-relief (H) stations over three sampling periods near Platform Hidalgo.

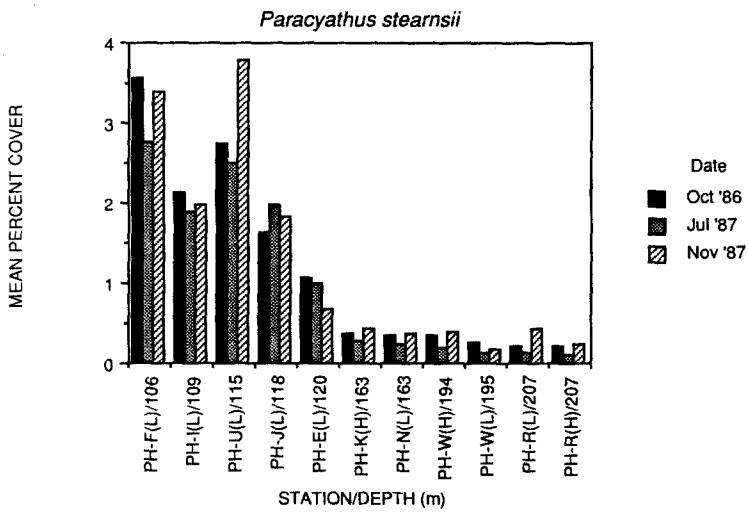

Fig. 11. Mean percent cover for *Paracyathus stearnsii* at eight low-relief (L) stations and three high-relief (H) stations over three sampling periods near Platform Hidalgo.

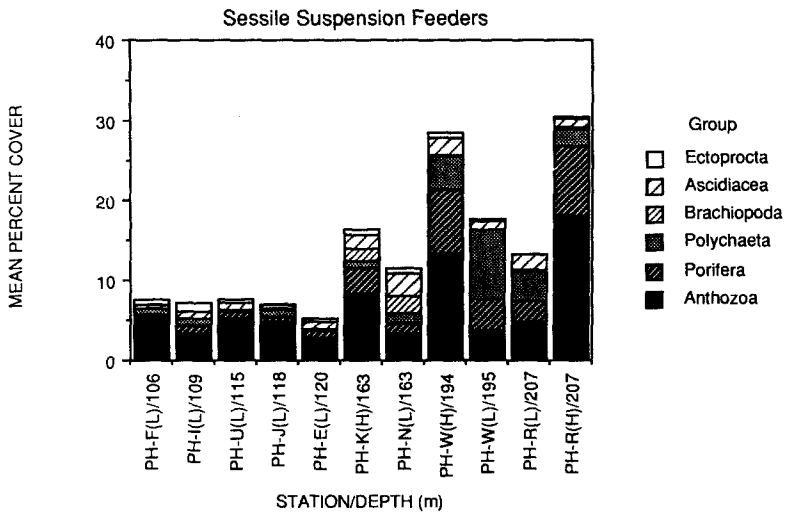

Fig. 12. Mean percent cover for six groups of sessile suspension feeders at eight low-relief (L) stations and three high-relief (H) stations over three sampling periods near Platform Hidalgo.

depth and sediment flux; similarly, there is a negative correlation between sediment flux and the percent cover of suspension feeders at low-relief stations ($r^2 = 0{\cdot}765$). Thus suspension feeders at deeper low-relief stations may be found at higher densities than those appearing at shallower low-relief sites because they are exposed to smaller inputs of

suspended sediment. Furthermore, the common appearance of a nepheloid layer, which diminishes with distance above the seabed, suggests that organisms on high-relief rocks probably experience a lower concentration of suspended sediment than organisms on low-relief rocks. This reduced exposure would also explain the greater percent cover of suspension feeders on high-relief rocks.

The temporal stability and possible sensitivity to suspended sediments displayed by suspension feeders suggest that organisms with this mode of feeding may be good indicators of the effects of particulate discharges from drilling activities. This would be particularly true for those taxa whose abundances increase with depth or height above the seabed and thus are less accustomed to dealing with large inputs of such materials.

ACKNOWLEDGMENTS

This study is funded by the US Department of Interior/Minerals Management Service (Pacific OCS Office, Los Angeles, California 90017) under Contract No. 14-12-0001-30262 to Battelle Ocean Sciences. The work is being performed by a team of scientists and advisors from Battelle; Kinnetic Laboratories, Inc.; University of California, Santa Barbara; University of Texas; Woods Hole Oceanographic Institution; US Geological Survey; University of Maine; Lawrence Livermore National Laboratories; Louisiana State University; Louisiana Universities Marine Consortium; Oregon State University; University of Western Ontario; and Sea Space, Inc. Several independent consultants are also involved. Many people representing these various entities have contributed their knowledge and skills to performing this ambitious, multidisciplinary program. The authors of this paper wish to acknowledge the importance of the contributions and sacrifices that each of these individuals has made throughout the various phases of study. We also extend our special appreciation to Dr Gary Brewer, the MMS Project Technical Officer, who has provided much encouragement and technical guidance throughout the course of study. Lastly, we thank Donna Good Higbee for typing the manuscript.

CONCLUSIONS

Results obtained thus far (representing the first two years of sampling) provide a basis for beginning to understand environmental processes and relations that will be important in detecting and interpreting any

subsequent impacts caused by oil and gas development and production activities in this region of the California OCS. Much of the predrilling chemical, physical, and biological data generated to date in this program demonstrate that impacts of discharges from oil and gas operations should be detectable, if they occur, and should be distinguishable from natural environmental variability.

Concentrations of hydrocarbons and trace metals in sediments are, for the most part, uniformly low throughout the region, and are characteristic of uncontaminated fine-grained sediments. However, increases in the concentrations of barium (a major constituent of drilling fluids) and inputs of petroleum-derived hydrocarbons in suspended matter have been detected in sediment traps deployed at some of the stations near Platform Hidalgo, during a period when drilling fluids were being discharged from this particular platform. Barium and polynuclear aromatic hydrocarbons have also been detected in bottom sediments at sites near Platform Hidalgo, but during the pre-drilling phase; thus these results indicate additional inputs originating from other neighbouring platforms (e.g. Platforms Irene, Harvest, and Hermosa). None of these inputs have been linked to adverse impacts on hard-bottom or soft-bottom assemblages in the area. However, preliminary screening of photoquadrats from one Platform Hidalgo site sampled in October, 1988, revealed a high frequency of whitish bacterial aggregations, which appear similar to the *Beggiatoa* mats associated with petroleum seeps (Spies & Davis, 1979) and may or may not be associated with the drilling activities.

Results of this study are available for use in various decision-making steps of the California OCS Federal leasing program. Also, these results expand existing knowledge of basic oceanographic processes and ecological conditions of the southern California OCS and should provide information to help interpret results of future offshore monitoring programs conducted in other planning areas.

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