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FINAL TECHNICAL REPORT TO THE CALIFORNIA COASTAL COMMISSION

B. Anomalous Sediments in the San Onofre Kelp Forest

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SUMMARY

The characteristics of anomalous sediments, first observed in the San Onofre Kelp Forest (SOK) in October, 1985, are described and hypotheses regarding their origin and deposition are discussed and evaluated. The possible biological impacts of the anomalous sediments in SOK are also discussed briefly.

The anomalous sediments are remarkable for the bulk properties of high penetrability and cohesiveness. They also are finer than the sediments normally found in the San Onofre kelp forest and have a higher organic content. The anomalous sediments are generally characterized by a percentage of silts and clays of about 57 percent, a total organic carbon (TOC) of about 0.35 percent and an organic nitrogen of about 0.03 percent. The bulk, grain size and organic characteristics of the anomalous sediments are similar to those found in sediments at depths of 30 meters.

Having established that the cohesive sediments are indeed different from the normal sediments in the area, the remainder of the report erects hypotheses with and without the effects of SONGS to answer the following questions: 1) What accounts for the anomalous properties of the sediments? 2) Why did they first appear in October, 1985 about 2 years after the onset of commercial operation of SONGS Units 2 and 3? 3) Why have they only been found in the San Onofre kelp forest? 4) Why have they persisted or recurred from 1985 to the present?

Hypotheses not involving the operation of SONGS can explain the presence of fine deposits in the vicinity of SOK after about 1980. However, there is no presently documented natural mechanism which also explains the unusual bulk properties and high percent TOC and percent organic nitrogen of the anomalous sediments and the delay of their appearance in SOK until 1985. We conclude that, at present, the most parsimonious explanation for local distribution, recency, and the physical and chemical properties of the anomalous sediments involves the

operation of SONGS. The plume of SONGS Units 2 and 3 creates stagnation points in longshore current flow by itself and in conjunction with trapping by kelp in SOK. There is well-documented evidence that the cooling system from SONGS increases seston flux in the upcoast portion of SOK by about 50 percent. Finally, the cooling system ingests, kills and discharges 900 metric tons of zooplankton per year and an undetermined amount of phytoplankton that is no doubt several times higher. This organic matter is a likely source of the higher percentage of TOC and organic nitrogen in the anomalous sediments, and may serve as a source of cohesion. Conditions associated with the El Nino of 1982-1984 provide the most likely explanations for the delay of the appearance of anomalous sediments until 2 years after the onset of the full operation of SONGS. During the El Nino, the planktonic supply of organic material and clay particles was an order of magnitude lower than in 1985.

Evidence is presented indicating that the anomalous sediments have reduced the abundances of a number of kelp forest invertebrates and the coverage of turf algae in the upcoast portion of SOK.

This draft report does not address two important questions 1) How has the distribution and abundance of the anomalous sediments changed since July, 1988? ; and 2) Do the plumes of SONGS Units 2 and 3 cause the formation of significant amounts of macro-flocs that may contribute to the formation of the anomalous sediments? These questions are being addressed by on going work.

1.0 INTRODUCTION

When divers began the quarterly survey of benthic invertebrates in October, 1985, they were struck by the presence of fine, very penetrable sediments at study sites in the San Onofre Kelp Forest (SOK; see Bence and Schroeter, 1989). The sediments immediately attracted attention because they covered many of the fixed quadrats that had been sampled for years. However, the San Onofre kelp forest is a relatively sandy location, and it would not have been unusual if one or two quadrats had been mostly covered by a shift in the coarse sands that were typically found among the cobbles. A large-scale influx of the finer sands that surrounded the boulder field would have been more surprising, but only because it had not previously occurred during the study. The presence of the new sediment at the sampling stations was puzzling because it was a discrete deposit which had no obvious nearby source, it accumulated in a relatively short time (< 3 months) and its appearance was unlike local sediments. Compared to other unconsolidated materials in the boulder field, the new sediments were very fine, very easily penetrated, and could be squeezed into a ball that held its shape. Interest intensified when, instead of being transported to deeper water as expected, the sediments increased in abundance at the monitoring station in the upcoast, offshore quadrant of SOK.

Beginning in 1986, an attempt was made to estimate the abundance of the anomalous sediments throughout SOK. Between March, 1986 and July, 1988, the estimated area of rocky substrate partially or completely covered by the deposits increased and the deposits were generally most abundant along the upcoast and offshore margins of SOK.

Any substantial increase in the abundance of fine sediments in the cobble field will have adverse effects on the populations of animals and plants which live on hard substrates (see Appendix B; Bence and Schroeter, 1989; Bence, *et al*, 1989) for a discussion of some ecological effects of the anomalous sediments in SOK). Therefore, an understanding of the distribution, abundance, origin, and mode of deposition of the anomalous sediments is important.

Before the fall of 1986, these sediments were studied as part of investigations designed to gather biological data. The sites at which substrate measurements were made was dictated by the design of the ecological sampling programs and were confined to areas predominated by cobbles and boulders. Useful estimates of the abundance of the anomalous sediments were made periodically at all the biological stations, and beginning in the fall of both 1986 and 1987, substrate characteristics were described and cores of sediment were also collected at about 65 sites in a 1200 hectare area surrounding the diffusers for SONGS Units 2 and 3. Grain size and Total Organic Carbon were measured for many of the samples, and several were subjected to mineralogical analyses. In 1989 an intensive field and laboratory study was undertaken to characterize the sediments in SOK which were thought to be anomalous and compare them to samples of normal sediments from surrounding areas, to analyze water samples from the turbid plume created by the cooling system for Units 2 and 3, and to analyze existing oceanographic and hydrological data pertinent to questions of origin and deposition.

The purpose of this report is to present the results of the various studies that have been undertaken and to provide a basis for judging the likelihood that SONGS' operation is a substantial contributing cause of the deposition of anomalous sediments in SOK. The various methods employed in these studies are discussed as the need arises, but briefly. A detailed presentation of the field and laboratory methods is contained in Appendix A. We have also included a listing of all the grain size and chemical data (Appendix C) for the benefit of the critical reader.

Section 2 of this report is a review of the evidence that there is, indeed, something that needs to be explained. We conclude that there is: the sediments in question, although variable, are distinctive and anomalous and their deposition is almost entirely restricted to the neighborhood of SOK and the period after July 1985.

Section 3 is a discussion of the potential sources and mechanisms which are the elements of any hypothesized explanations of a localized deposition of anomalous sediments during a particular time. A useful hypothesis must provide answers to several questions: What are the likely sources of the bulk material? How was it transported to the site? Why was it deposited in a restricted area? How did it persist or recur in the face of wave-erosion?

Section 4 of the report is a discussion of background data which are pertinent to all hypotheses concerning the origin and deposition of sediments in SOK. Whereas the previous section is a listing of possible mechanisms and their combinations, this section is a physical discussion of the mechanisms and a review of the evidence that bears on their relative likelihood.

Section 5 is an evaluation of several alternative hypotheses erected to explain the appearance and persistence of anomalous sediment deposits in SOK. Both the origin of the deposits and the mechanism of deposition are considered.

2.0 DESCRIPTION OF ANOMALOUS DEPOSITS AND OTHER SEDIMENTS NEAR SONGS

2.1 Character of the Sediments

The anomalous characteristics of the sediments which were first seen in 1985 at the benthic monitoring stations were their fineness and unusual bulk characteristics. They were very soft and penetrable and were cohesive. Throughout this report when we use the term "cohesive," we use it in the everyday sense of "sticking together tightly." When a handful of the anomalous sediments was squeezed into a ball it held its shape, and when one pressed the sediments the resultant handprint remained for many minutes. The consistency of the sediments was also unusual for the area. It was much like that of pudding. The surface had a somewhat gelatinous "crust" which, when struck, vibrated 30 or 40 cm away. Although the deposit was more than 50 cm deep in places, divers could easily thrust their arms through it and feel the cobbles and boulders beneath. Such penetrability is unusual and suggests high water content.

The cohesive sediments at the benthic monitoring station in upcoast SOK (SOKU45=F1 in Figure 6) compacted with time. After about 10 months they were much firmer, but it was still possible to work one's fingers into the sediment or force a ruler through it. From 1986 to 1989 there was little additional change in the characteristics of that deposit. However, with time the surface took on a coarser look and often bore ripples, and the deposit appeared less homogeneous. In 1989, the bottom 10 centimeters or so of material was darker, seemed finer, and appeared to have higher water content than the overlying sediments. Although this deposit of anomalous sediments has been present since fall, 1985, the shape has varied and the constituent grains of sand and silt making up the deposit may well have been replaced several times over. We have no data on the turn-over rate of the sediments, but it is clear that the deposits we have observed were not static bodies.

The anomalous sediments at the downcoast monitoring station were present until July, 1988. Since 1985 we have also observed anomalous sediments at many other stations in the San Onofre Kelp Forest. Some formed thick, discrete patches as at SOKU45 (=F1), others occurred as a thin (2-3 cm) deposit overlying moderately coarse sands or covering the surface of boulders and cobbles.

We collected samples of the new sediments at the upcoast benthic station (SOKU45 (=F1)) when it first appeared. In May 1986 we resampled that deposit and also collected cores at three other stations in the kelp forest and at a station directly offshore in 30 m of water (Figure 1). In fall, 1986 we visited 67 sites in a 1200 hectare area that included the San Onofre Kelp Forest (Figure 2). The intent of the survey was to document the distribution of anomalous sediments and to compare the grain size distribution and total organic carbon content of anomalous and other sediments. In 1987 a second, similar survey was conducted and most of the sites visited in 1986 were again sampled (Figure 2).

A fourth major collection of sediments was made in early 1989. Samples were taken at stations at three water depths (10m, 20m, & 30 m) near the San Mateo, San Onofre and Barn Kelp Forests and at a few stations at kelp bed depths (Figure 3). During the 1989 survey, cores of sediment were brought to the surface, kept awash in water and tested with a penetrometer and vane-shear in the field before being sent to laboratories for assessments of grain size distribution, TOC, and N. A penetrometer measures the force required to drive a probe of a given diameter a fixed distance into the sediment. A vane-shear measures the torque required to cause failure, or slippage within a sediment sample. The vanes are forced into the sediment and torque applied until the vanes rotate (Appendix A). Samples from eight stations were also tested with a "shaker" analysis which estimates the resistance of a sediment to suspension. A perforated disk is moved up and down over sediment in a large core for a fixed time and seston concentration is measured (Appendix A).

When first observed, the anomalous sediments were qualitatively different from the coarser sands at our study sites and readily distinguished. However, during the fall, 1986 survey it became apparent that the new sediments, when compacted, were at one end of a continuum of grain size, cohesiveness, and penetrability. We erected the following tests for anomalous sediments:

1. Is the consistency pudding-like?
2. When pressed, will it hold a hand print?
3. When squeezed, does it hold its shape?
4. When shaken into the water, does it form a cloud of turbidity rather than sink?
5. Is it talc-like or sticky?

The answer to each of these questions was "yes" for the anomalous sediments collected earlier at the benthic monitoring station and for the sediments at the 30-m station further offshore. In practice, tests 4 and 5 were widely ignored because they were difficult to apply in a consistent manner and many of the divers didn't think they were good discriminants. In this and all later surveys, unconsolidated materials were considered to possess anomalous properties (were called "ooze" in field notes) if the answer to question one **or** question two **or** question three was "yes." During the 1986 and 1987 surveys the divers applied the tests and recorded their judgement. During the 1989 survey the tests for anomalous characteristics were expressed in a slightly different fashion and formalized in a data sheet (Appendix A: Figure A1). Divers recorded the results of the tests and the assessment of sediment type was made later based on the test results and field notes.

There were, of course, occasions when the tests of penetrability and cohesiveness were not definitive and the answer to each question was closer to an uncertain "maybe" than a definite "yes." When the field notes indicated uncertainty or two observers disagreed in their assessment, the sample was classified as "intermediate." There was no protocol or other attempt at standardization for describing other sediments. However, all the investigators involved in these surveys had years of experience diving in southern California's coastal waters and tended to use similar suites of descriptors. Where field notes indicated that sand was overlain by anomalous sediments the sample was termed "mixed".

The results of all three surveys were similar (Table 1). On average, the rankings of sands and silts into categories of increasing grain size by divers in the field corresponded reasonably well with rankings based on the percentage of silts and clays (phi >4). Since there was no attempt at standardization in categorizing sands and silts, different observers used somewhat different descriptions and when all the data were combined it was apparent that several of the categories were not different (Table 2). Although it is reassuring that observers can distinguish coarse from fine sands in the field, the important result is that they can distinguish sediments with anomalous characteristics from all others. Sediments which were judged anomalous in the field were significantly different from other unconsolidated materials in percent of silts and clays, percent of clay (phi >8), total organic carbon, and total organic nitrogen (Tables 2 & 3). Furthermore, although the percent TOC in the sediments was directly related to the percent of silts and clays present, total organic carbon was still significantly higher in anomalous sediments when the percent of materials finer than phi 4 was held constant in the analysis (Table 3). The percentage of silts and the percentage of clays also tend to vary together, but when the percentage of silts is used as a covariate in the analysis, the anomalous sediments still have a higher clay content than the other sediments (Table 3). The

1989 measurements with penetrometer and vane-shear corroborate the divers' *in situ* assessments. Samples which were judged to be anomalous proved to be more penetrable and more easily sheared than the other sands and silts (Table 4).

What all this means is that investigators are able to distinguish very fine grained sediments from coarser sands in the field, and they are able to distinguish fine sands and coarse silts that are highly penetrable and cohesive *in situ* from fine sediments that do not possess those characteristics. The former sediments were called "ooze" in the field notes. Although the term may be objectionable on several counts, it is worth retaining as a convenient shorthand for the moment. The results of the various analyses allow us to define "ooze" as unconsolidated sediments which are very penetrable and cohesive *in situ*, are composed, on average, of about 57 percent silts and clays, 3.0 percent clays and 0.35 percent total organic carbon (Table 2). The point we wish to make here is that the compacted "ooze" found in the kelp forest and the sediments located 200 m to 600 m farther offshore at 20 and 30 m depths are indistinguishable by divers in the field and were all designated "ooze". Laboratory analysis of grain size and organic carbon also show that these sediments are significantly different from "Other Sediments". In a search for more acceptable term we have adopted the relatively neutral "anomalous" to describe the characteristics of "ooze". However, the characteristics of the sediments described as "ooze" are anomalous only in relation to the coarse sands normally found in the kelp forest and the sands and coarse silts upcoast and downcoast at the same and shallower depths. There is no reason to believe that the characteristics are anomalous relative to the normal sediments found in deeper water.

The mineralogy of the anomalous sediments in the San Onofre Kelp Forest appears unremarkable. A preliminary investigation of the mineralogy of the anomalous sediments by Pierce (1986) indicated that the sands and silts were composed of quartz, feldspar, mica, and other aluminosilicate minerals. Shell fragments, diatoms, and foraminifera were also present. These mineral species are normal constituents of sediments for this section of coast (Gayman, 1986). X-ray diffraction analysis indicated that the anomalous sediments did not stand out from the other sediments in the area with regard to the mix of clay minerals (Table 5).

What do the various characteristics which are statistically associated with "ooze" tell us about these materials? These distinctive sediments have been called "cohesive" because a handful will stick together in a ball. The property of cohesion by itself, though, is not fully separable from effects of high water content on both the field identifications and strength measurements, which is one of the reasons we have generally adopted the more neutral name "anomalous sediment." Non-cohesive grains will initially settle from suspension in a more or less loose packing, with excess water between grains. Then they will gradually shake down into closer packing, expelling the excess water upward through the channels between grains. These channels are narrower for finer grains, so the rate of compaction falls off steeply with grain size. Rapidly deposited and thick accumulations of the finest silts can retain excess water for many days. For example, after slumping, the firm sands and silts (median phi 5-6) near the head of Scripps Canyon were sufficiently liquified that a diver could force his arm nearly a meter into the bottom (Marshall, 1978). Within about a month the sediment was noticeably more compact, but it took about six months to return to its original state.

If a sediment is cohesive because it contains some soft sticky grains or because the grains have a sticky coating, it is all the more likely to retain excess water longer, for several reasons. The cohesion retards relative motions of grains toward closer packing, and the cohesive component may obstruct the channels between grains. If cohesion has aggregated grains into irregular flocs before they settled, the initial packing may be very loose, giving a high initial water content.

The properties of cohesion and high water content are likely to be associated, then, but they have opposite effects on shear strength. With or without cohesion between grains, sediments will show some shear strength due to interlocking or friction between grains. This kind of shear strength is very sensitive to loading: it increases greatly if the grains are forced together by an applied pressure. On the other hand, it will decrease greatly if the grains are kept apart by excess water, as in the extreme case of a quicksand.

With these things in mind, we can consider the meaning of the various tests applied to anomalous and normal sediments. The anomalous properties of retaining a ball-shape or a handprint against gravity definitely show that the anomalous sediments have perceptible shear strength under the lightest loading, while normal sediments do not. These are the tests that let us describe the anomalous sediments as cohesive.

The tests of penetrability and vane-shear strength measure shear strength under various conditions of considerable loading due to the test itself. The stress under a penetrometer foot, for instance, varies from uniaxial compression at the middle to pure shear at the edge, equivalent to a varying mix of shear and pressure. Under these tests with loading, the anomalous sediments generally show lower shear strength than normal sediments. This can be ascribed to high water content: the reduction of frictional shear strength more than offsets the strength due to cohesion. These measures of loaded shear strength may best be taken as measures of excess water. The quaking test (or earlier designation as "pudding-like") is probably also a measure of water content: frictional losses in a well-compacted sediment will prevent the visible propagation of waves, but excess water will reduce these losses so that a wave can travel a few feet before it damps out. In short, the ball and print tests indicate unloaded shear strength due to cohesion between grains. The penetrometer, vane-shear, and quaking tests indicate excess water content, probably, but not necessarily, associated with cohesion.

The results of shaker measurements on eight samples from San Onofre are shown in Figure 4. All the samples showed about the same suspension threshold, at a frequency somewhere between 5 and 8 cycles/sec , and about the same increase of suspension with frequency above threshold. The differences among samples at the frequencies of 5 and 6 cycles/sec were 20% of the mean or less, and were not systematically related to grain size or anomalous character in the samples.

Shaker results on a variety of sediments have shown a reproducible relation to suspension measurements in a unidirectional flume, but they have not yet been correlated with observations of net suspension or erosion by ocean waves of period 6 to 20 seconds. The conditions of loading, and probably also the seston profiles near the bottom, are very different for the three cases of the shaker, the one-directional flume, and the sea-bottom under wave, and the correspondence between shaker and flume may not extend to net suspension by waves. These caveats aside, the shaker results suggest that if there are real differences in resistance to wave erosion by waves among the San Onofre samples, they are probably not large.

In summary, the distinctive sediments that have appeared on hard substrates in the San Onofre kelp forest are not unusual in mineral composition and are what one would expect based on a knowledge of terrestrial sources. Their anomalous characteristics are that they are cohesive *in situ*, appear to have a high water content, have a higher proportion of silts and clays than is usually found in shallow water, have a higher content of both total organic carbon and total organic nitrogen than normally found in local sands, are rapidly deposited in relatively large quantities, were not seen prior to 1985, and have persisted or increased over a period of several years.

2.2 Spatial and Temporal Distributions

2.2.1 Observations at Sites with Fixed Quadrats

Two stations in the San Onofre Kelp Forest, one in the San Mateo Kelp Forest and one in the Barn Kelp Forest have 40 fixed quadrats marked with steel stakes (Figure 6 and Bence, et al, 1989). The anomalous sediments were first observed at the stations in SOK and were still present at the upcoast station in 1989. These stations are of particular interest because the history of the deposits there are so well-known.

The patch of anomalous sediments at the array of fixed quadrats at SOKU45 (=F1) was first observed in October, 1985. The anomalous sediments were not observed on the previous visit which was in July 1985. This station was visited four to six times a year for surveys or maintenance. Visibility was generally 2 m to 5 m, but was occasionally greater than 20 m. As a result, we can state categorically that the anomalous sediments were not present at any of the stations prior to 1985.

The deposit at SOKU45 (=F1) increased in size over the next 14 months. In December, 1986, anomalous deposits were present in nearly 90 percent of the quadrats (Figure 5). In April 1989 the deposit covered about 1300 m^2 and two similar deposits of roughly the same size and character were found nearby. This temporal pattern indicates accretion of a relatively stable deposit.

At SOKD45 (=F2) the new deposits were first observed in March, 1986. Abundance was highest in September, 1986, and declined by December, 1986, when the deposits were present in only 3 percent of the quadrats (Figure 5). In January 1989, two patches of the anomalous sediments were observed at SOKD45 (=F2). The sediments were very fine and very easily penetrated. They overlaid patches of coarser sand in the cobble bed and covered about 40 m^2. They disappeared during a period of large swells in February, 1989. Anomalous deposits were never observed in fixed quadrats at SMK45 (=F3, Figure 5) or BK

2.2.2 Observations in Random Quadrats in SOK and SMK

Other biological monitoring programs made use of a large number of stations arrayed in uniform grids overlying the San Onofre and San Mateo Kelp Forests. At each of these fixed stations, 3 to 5 random quadrats were examined on each survey (Figure 6 and Bence, et al, 1989).

Systematic searches for the anomalous deposits throughout SOK and SMK were begun in March, 1986. At this time, such deposits were observed at three stations very close to the array of fixed quadrats at station SOKU45 (=F1; Table 6; station locations are in Figure 6). The frequency of occurrence and depth of the deposits increased in SOK through July, 1988 (Table 6; Figures 7 - 9). The increase was greatest in the upcoast, offshore portion of SOK, where the anomalous deposits occurred at 7 out of 10 stations. In general, the deposits tended to be most abundant along the upcoast and offshore margins of the kelp forest in SOK (Figures 7 - 9). The frequency of occurrence generally increased in the offshore portion of SOK, whereas it was generally lower, not as deep, and fluctuated more in SOKN and the inshore quadrants of SOK.

Deposits of fine sands were found at one station on the downcoast, offshore margin of SMK and were identified in the field as anomalous on two occasions. They differed from those in SOK by having lower percentages of TOC and of silts and clays.

2.2.3 Sediment Samples from the SONGS Area

Analysis of sediment samples taken in October, 1986 indicated relatively high percentages of silts and clays along the upcoast margin and about 200 meters offshore of the offshore margin of the San Onofre Kelp Bed (Figure 10). The percent of silts and clays at these sites was similar to that found at depths of 30 meters (mean = 64.8).

Many more samples were available from the margin of the kelp bed in July, 1987. As in the October, 1986 sample, percentages of silt plus clay were high along the upcoast margin of the bed and 200 meters offshore (Figure 10). Sediments with high silts and clays were also found along the inshore and downcoast margins and upcoast and offshore of the Unit 2 diffuser.

In summary, anomalous deposits with high percentages of silts and clays were first observed near the upcoast, offshore margin of SOK in October, 1985. Their distribution and abundance increased during the following 14 months, primarily along the offshore and upcoast margins of SOK. Deposits with similar high values of silts and clays have been seen near SOKU45 (=F1) in the past. These deposits differ from the anomalous sediments in two ways. First, the percentage of TOC was 1/3 to 1/2 of that in the anomalous sediments (Table 9). Second, they were much less persistent. Whereas the anomalous sediments have persisted for at least four years after they were first sited, the fine sediments observed before 1985 lasted no longer than three months (Figure 11). Fine sediments were observed along the offshore downcoast margin of SMK. They differed from the anomalous sediments in SOK by having a lower percentage of silts and clays and lower TOC.

The last large-scale, systematic survey of anomalous sediments was conducted in July 1988. We do not know how the distribution and abundance of such sediments has changed since then, but a 1989 survey is scheduled.

3.0 POTENTIAL SOURCES AND MECHANISMS

A number of hypotheses are on the table, each seeking to explain the occurrence of anomalous sediments in a region virtually confined to the neighborhood of SOK, beginning in fall, 1985 and persisting or recurring from then to the present. Each hypothesis describes a compound event, involving a source of the deposited material, a mechanism for its transport to SOK, and a mechanism for its deposition and persistence or recurrence. To make a fair and systematic comparison of these compound hypotheses, it will be useful to break them down into their parts and give specific attention to plausible potential sources, transport mechanisms, and mechanisms for recurring deposition or persistence. This section gives a logical framework for assessing compound hypotheses in terms of their parts, and brings out a set of specific questions that are crucial for comparing compound hypotheses that do or do not involve the operation of SONGS. The sources and mechanisms considered are described and discussed as necessary in the following Section 4 . Here they are simply identified and listed, as follows, with labels to use when the discussion becomes dense.

<u>Sources of bulk material:</u>

S1: Normal sources of the local shelf sediments: seston derived from stream discharges and coastal erosion over an unspecified length of coastline around San Onofre.

S2: The deposits of fine sediments laid down on the shelf in the neighborhood of San Onofre in particular following the very high runoffs of 1978-80 and 1982-3 (see 4.1.2 below).

S3: The sand-release at San Onofre of January 1985 (see 4.1.3 below).

Mechanisms of Transport to SOK:

T1: Normal processes of sediment transport on the inner shelf: suspension by waves and advection and dispersion by currents, including wave-induced currents nearshore.

T2: SONGS-induced transport: seaward transport by ingestion, discharge,and entrainment; shoreward and lateral transport by the make-up flow toward the diffusers.

Mechanisms of recurring deposition or persistence at SOK:

D1: Normal balance of deposition and erosion by waves.

D2: Hydrodynamic trapping of sediment due to slowing of currents or reduction of wave-height by kelp or some other natural cause.

D3: Hydrodynamic trapping of sediment due to slowing of currents by SONGS.

D4: Resistance of sediments to wave-erosion due to some natural constituent or texture.

D5: Resistance of sediments to wave-erosion due to some constituent or texture supplied by SONGS.

D6: Increased settlement rate of fine particles due to increased flocculation by SONGS

This list is confined to potential sources and mechanisms that are generally accepted in principle and have at least some basis in local observations. All the hypotheses put forth so far can be assembled from the elements in this list. The list is comprehensive in that sense, though it cannot be expected to comprise all the elements of any compound hypothesis that might be proposed in future.

It is important to note that no source or mechanism on this list excludes any other. In each of the categories, it is likely enough that more than one element is actually at work. Proper comparisons may entail quantitative assessment of the relative importance of different sources and mechanisms, rather than choosing one and dismissing another. This is particularly the case for transport mechanisms, since both natural and SONGS-induced transports are undeniably present and are of comparable magnitude near SOK. It may also be so for physical trapping of sediments by slowing of currents due to kelp and SONGS.

The "normal" sources and mechanisms (S1, T1, & D1) represent the ordinary regime of sediment supply, transport, and deposition on the inner shelf. This natural regime, especially the supply of sediments from streams, can be highly variable on a scale of years as well as seasons, and a compound hypothesis might invoke variations in any or all of the natural sources and mechanisms for transport and deposition to help explain the anomalous sediments. The compound hypothesis S1-T1-D1, for example, asserts that the anomalous sediments are an occurrence within the normal range of the natural regime, though perhaps close to an extreme of that range.

Any complete hypothesis must explain the following observations:

1. The sediments in question possess anomalous characteristics.

2. The anomalous sediments are local. They are confined to the general neighborhood of San Onofre, and are non-randomly distributed around and in the San Onofre Kelp Forest;

3. The anomalous sediments are a recent occurrence, not present before around July 1985;

4. The anomalous sediments have persisted or recurred from fall, 1985 to the present;

The general requirement for a full explanation is that each of these four observations must be accounted for by at least one element in a compound hypothesis. In particular, we note that the anomalous sediment character is not incidental, since it defines the distribution of the deposits in question. A hypothesis that does not explain the anomalous character of the sediments in question, or explains it as a pure coincidence, cannot be taken as satisfactory. Section 4 below is devoted to providing the data by which one can evaluate the various elements of any general hypothesis.

The hypotheses of SONGS transport (T2), hydrodynamic trapping by SONGS (D3), SONGS-induced cohesion (D5), and SONGS-induced-flocculation (D6) and the hypothesis (S2) that the silt deposits of 1983 are the bulk source, all provide for the absence of anomalous sediments before 1983, but do not account for their absence from 1983 when Units 2 and 3 began operating to latter 1985. To maintain any of these hypotheses, some co-factor is required to account for the two-year delay in anomalous deposition (the most obvious candidate is the extreme El Nino event of 1982-4, as discussed in 4.5 below). To simplify the logical shorthand, we will denote any of these sources or mechanisms combined with the required co-factor by an asterisk, that is: T2*, D3*, D5*, D6* and S3*.

The "normal" compound hypothesis (S1 and T1 and D1) is tenable in principle but so far is only documented by some citations of penetrable fine deposits at other times and places which do not have the same anomalous character and persistence as the post-1985 deposits in SOK (Carter, 1986; North, 1986). The most general compound hypothesis that does not involve the operation of SONGS and does not invoke undocumented variations in S1, T1, or D1 has the form:

(S2* and/or **S3)** and **(T1)** and **(D2** and/or **D4).**

The sources S2* or S3 provide recency to 1985 and localization to San Onofre, while the mechanisms D2 and possibly D4 provide localization to kelp beds, so a combination of these can account for deposition starting in 1985 at SOK but not at

SMK. S2* and, possibly, S3 provide a persistent source. Any of S2*, S3, and D4 is a possible, though undocumented, source of the anomalous sediment character.

To provide a documented full explanation without SONGS in this form, we must show all of the following:

1. A delaying co-factor exists for the 1983 deposits S2 and/or the sand-release S3 provides a persistent source; and,

2. A natural source of cohesion D4 exists and/or the sources S2* or S3 can account for the anomalous sediment character. If we do not invoke hydrodynamic trapping by kelp D2, we must also find a natural source of cohesion that is localized to kelp beds.

The first is necessary to explain the full localization, recency and persistence; the second to explain anomalous character. As a matter of physical argument rather than pure logic, we must go further to eliminate SONGS by showing also that:

3. SONGS-induced transport (T2) is relatively unimportant compared to the natural transport (T1); and

4. Hydrodynamic trapping by SONGS (D3) is relatively unimportant compared to trapping by kelp (D2).

The forms considered so far do not exhaust all the hypotheses without SONGS that can be formed from these elements, which would have the general form:

(**S1** and/or **S2*** and/or **S3**) and (**T1**) and (**D1** and/or **D2** and/or **D4**).

There is, for instance, some evidence that natural trapping could provide localization to San Onofre as well as to kelp beds (see 4.3 below), so the hypothesis S1 and T1 and D2 could be maintained if the characters of recency, persistence, and anomalous sediment character could be found between S1 and T1. An exhaustive table of the requirements to maintain any hypothesis of the general form would be very long and not very helpful, so it is omitted, but there is no intention to take other hypotheses out of consideration *a priori.*

Any full explanation that does involve SONGS operation must include the following:

T2* and/or **D3*** and/or **D5*** and/or **D6***

To document any such explanation, we must show the following:

(A natural source of anomalous character exists)

and

((A co-factor exists for transport or trapping by SONGS)

and/or

(A co-factor exists to cause a lag in SONGS-induced cohesion or flocculation))

This section can be recapitulated as a list of specific questions important for judging and comparing compound hypotheses:

General "Normal" Hypotheses:

1. Is there evidence of localization of natural sediment supply near San Onofre?
2. Is there evidence of convergence of natural sediment transport on the neighborhood of SOK?
3. Is there evidence of a step-change in 1985 of natural sediment supply, or natural transport, or the natural deposition-erosion balance?
4. Can normal, natural sources and processes account for the anomalous sediment character?

Specific Hypotheses not involving SONGS Operation:

5. Does an adequate co-factor exist for the 1983 sediments, accounting for the delay of anomalous deposition from this source until 1985?

6. Does the sand-release provide an adequate source for deposition in SOK persisting or recurring from 1985 to the present?

7. Can any properties of the 1983 sediments or the sand-release material S3 account for the anomalous sediment character?

8. Is there an actual natural source of wave-resistance? If so, is it localized to kelp beds?

9. How do natural and SONGS-induced transports compare quantitatively?

10. How do physical trapping of sediments by kelp and by SONGS compare quantitatively?

Hypotheses involving SONGS Operation:

11. Do adequate co-factors exist for SONGS-induced transport, hydrodynamic sediment trapping by SONGS, or SONGS-induced wave-resistance, accounting for the delay from 1983 to 1985 of anomalous deposition due to any of these causes?

4.0 BACKGROUND DATA

4.1 Bulk Sources of Sediment

4.1.1 Shoreline Sources

Gayman (1986) has made a comprehensive review of the supply of fine sediments to the sea from sources between Dana Point and Oceanside over the years 1974 - 1984. Table 7 is a summary of the estimated supply, showing that watersheds upcoast from San Onofre supplied about 2 million tons of silt and clay over the eleven years, the two rivers downcoast from San Onofre supplied about 4 million tons, while coastal erosion supplied about half a million tons. The comparison of daily and annual maxima with the eleven-year totals shows the highly episodic character both of runoff and coastal erosion.

The most accurate data are from San Juan Creek where the discharge records are most nearly continuous over the years, and where the total sediment load is monitored regularly. The comparative runoff data in Table 7 are mainly derived by extrapolation of yields per unit area from San Juan Creek to other watersheds. For comparison of sediment yields between years, the total sediment yields from San Juan Creek, shown in Table 8, are the index with least uncertainty. The years 1978 - 1980 and 1982 - 1983 were extreme runoff periods. No comparable runoff has happened since the latter 1960's. Sediment yields in the years 1984 through 1988 are two orders of magnitude below the extreme years.

Sediment supply from erosion of bluffs and gullies is generally smaller than the supply from runoff, and even harder to measure with any accuracy. For our purposes, the most useful thing available is a calendar of the major potential events of coastal erosion, which is given by the history of weekly maximum wave-heights in Figure 15.

4.1.2 Deposits of Silt off San Onofre, 1980 and 1983

From January 1978 through February 1980, something on the order of 1,500,000 m^3 of silt and clay were carried into the sea by local streams (Eco-M, 1987c). Most of the runoff was concentrated during February, March and April of each year. Added to this, were fine materials from the dredging activities associated with the construction of the cooling systems for Units 2 and 3. Construction of the intake and discharge structures took place from April, 1977 to January, 1980. Trenches were dug in the sea bottom to accommodate the intake and discharge pipes (3 - 5.5 m internal diameter). On the order of 300,000 m^3 of sediment from dredging was deposited on the beach at San Onofre. In addition, an unknown quantity was left for backfill. During the course of these operations a portion of the finer fraction of the dredged materials were no doubt transported and dispersed some distance from the dredge site. We cannot separate the results of runoff and dredging, and simply note that changes attributed to runoff include an undetermined contribution from construction activities.

Where they are deposited, the fine materials added by runoff will tend to make the sea-bottom finer and less well-sorted. However, the storm waves associated with the runoff will tend to suspend fines on the bottom, so the bottom may actually become coarser and better-sorted out to some distance from shore.

The variate of interest in the present context is the percent silt and clay (materials smaller than 0.062 mm). Figures 12 and 13 present the history of the percentage of silts and clays at various distances downcoast from the diffusers along the 7.6 (25 ft) and 18.3 m (60 ft) depth contours. On the inshore (7.6-m) line, the percentage of silts and clays was reduced to below 10% at all the stations during 1978 and 1979 and into 1980 at the downcoast stations (Figure 12). This was probably a result of the severe storms during the winters of those years. In 1980 and 1981 the percentage of silts and clays rose to above 30% at the station at x= +1900 m. Since sorting processes do not act to preferentially remove coarse particles, this change can be interpreted as in influx of fine materials. At the deeper, offshore stations (Figure 13), there was a general increase in the percentage of silts and clays at the stations near San Onofre from 1977 through 1979. Whereas the increase in fine materials near San Onofre on the shallow transect was ephemeral, the increased silts and clays in deeper water persisted (Figure 12).

Along the offshore transect, during the years 1980 - 1982, the percentage silts and clays remained above 60% near San Onofre and rose from around 30% to about 50% at the downcoast stations (Figure 13). After the high runoff during the winter of 1982-1983, the percentage rose above 80% near x= +1900 m and above 50% nearly everywhere else, and stayed high through 1984. We interpret the general trend of increasing percentages of silts and clays from 1976 through 1984 as the accumulation fine sediments which were introduced by streams during a series of stormy winters beginning in 1977. These years included the 1982-1984 El Nino, which brought extreme waves and high runoff in the winter of 1982-83 and largely suppressed organic productivity of the local waters through 1983 and 1984. They also saw the transition of SONGS Units 2 and 3 from occasional testing to normal full operation. June 1, 1983 is taken as the nominal midpoint of this transition (Kastendiek and Parker, 1988).

It is also instructive to examine the history of sediments at stations various distances offshore from the San Onofre Kelp Forest. The stations listed in Tables 9 and 10 are roughly on lines extending seaward through the upcoast end of SOK, and are listed from left to right in order of increasing distance from shore (Figure 14).

The station at X= +400, Y=-1700 in Table 10 lies just upcoast from the kelp as of 1985, and after, between the kelp and the outer end of the outer diffuser (Unit 2). The station at X= +800, Y=-1700 (Table 9) is within 100 m of the array of fixed quadrats in SOKU45 (=F1). Stations at Y=-2400 or -2500 are 300-400 m offshore from the kelp, close to the 18.3 m isobath for which the history further downcoast is plotted in Figure 13.

The first thing to note in Table 10 is that the percentage of silt-clay has a maximum at Y=-2400, from which it decreases both shoreward and seaward. This maximum became evident in 1980, and is almost certainly associated with the longshore maximum at X= +1900. It should not be taken as representative of a long stretch of the shelf or a long stretch of years. The maximum in percentage of silts and clays at Y=-2400 is obvious in a graphical presentation of the same data in Figure 12. The contours were done by hand. It appears that the fine materials which were introduced by runoff and bluff erosion during stormy winters from 1977 to 1983 stalled along the 20-m isobath near San Onofre. It is also interesting that the percentage of silts and clays at the station near the kelp forest (y=-1700) waxed and waned irregularly from less than 30% to greater than 60% as fine materials were periodically deposited and removed (Figure 13).

From Table 9 we can see that the particulate organic carbon generally increased with distance offshore at stations near San Onofre from June, 1981 through March, 1985, and that it was not very different near the kelp bed (Y=-1700) than it was a few hundred meters offshore (Y=-2500). It is also interesting that four out of five of the maxima at different stations occurred in September, 1981 (the SOK station is the exception), while all of the minima occurred between September, 1982 and December, 1983, during the El Nino period.

4.1.3 Sand-release

In December, 1984 and January, 1985, Southern California Edison removed the retaining walls projecting across the beach in front of SONGS that confined the laydown pad (Eco-M, 1987c). This freed about 170,000 m^3 of unconsolidated material held behind the walls which was bulldozed into the surf-zone. About 10,000 m^3 of the laydown pad was very fine sand (.125 - 0.62 mm diameter grains) and about 20,000 m^3 was silt and clay ($d < 0.62$ mm; Table 11). Removal of the walls also released about 500,000 m^3 of beach sand which had accumulated above the original beach profile upcoast of the walls. These sands contained less than 2% of grains finer than .125 mm. Based on aerial photographs, it was estimated that about 80% of the laydown pad material was washed away by waves before January 27, 1985 (Eco-M, 1987c).

Although the sand would be expected to be carried downcoast without dispersing more than about 800 m or so seaward, the 30,000 m^3 of very fine sand and silt could certainly be winnowed out in the surf-zone and dispersed well offshore by currents whenever it was resuspended above the bottom by waves. The material behind the walls was originally excavated from the bluffs and was not substantially different in character from the normal sources of local bottom sediment derived from streams and from erosion of cliffs and gullies. The amount of sediment released was comparable to the amount that would be discharged by local streams in a winter of high but not extreme runoff.

It appears from the temporal changes in the distribution of grain sizes at stations near San Onofre that the fine sands and silts from the laydown pad moved across the shelf relatively rapidly. On the offshore transect (Figure 13) the percentage of silts and clays decreased markedly in April 1985 and returned nearly to its former values by December, 1985. The minimum value of 25% had not been seen anywhere on the offshore line since 1980, and this sudden local decrease certainly exceeds the natural fluctuations of the previous few years. This is probably the best evidence we have of a physical change beyond the nearshore zone attributable to the release of the laydown pad, since it is an extreme event localized near SONGS and occurring after a reasonable time-lag of about three months. Some other cause acting at the same time and place cannot be firmly ruled out, but it remains to be identified. The pattern of this change points to a transport of fine sand into a region where the bottom had been mainly composed of silt over the previous five years, followed by dispersion of this sand over a larger area. The consistently low values of grain-size dispersion throughout the region and period seem to indicate that the fine sand arrived as a well-sorted body overlying the local silts (Eco-M, 1987c).

4.2 Mechanisms of Natural Seston Transport

In water depths greater than 10 m or so, outside the zone where waves become steep and break, the normal sediments are largely fine sand and silt, and the main mechanism of seston transport is initial re-suspension by waves, dispersion upward into the water column by turbulence due to current, and transport by the mean current. Inshore from 10 m depth, nonlinearities in the steep and breaking waves cause varying net transport onshore and offshore, made visible in rip currents on a short time scale, and in the seasonal erosion and accretion of beaches on a longer time scale. Waves approaching a beach obliquely and breaking cause nearshore currents that transport sand along the beach, leading to erosion or deposition of sand where the currents diverge or converge.

4.2.1 Transport in water depths greater than 10 m

The amount of seston per unit area that can be held and carried in suspension in a water column of given depth increases steeply with either of two factors: the height of the waves, and the velocity of the current. The effects of waves and currents are fairly well separable off San Onofre. The oscillating wave-orbital motions are fairly laminar and uniform with depth near the bottom, except for the concentrated shear and turbulence in a bottom boundary layer of thickness measured in centimeters. The shear and turbulence in currents is spread over several meters or more of the lower water column, so save motions produce much higher shear stress on the bottom than currents of comparable velocity. Waves are principally responsible for the primary resuspension of sediment into the lowest 20 or 30 cm of the water column, but their oscillating motions do jot produce net transport. The turbulence due to current is mainly responsible for dispersion of seston further upward into the water column, where the mean current that produces net transport is stronger than it is close to the bottom.

To look for events in the history of seston transport, we will refer first to Tables 12 and 13, which give monthly mean longshore and cross shelf currents from 1977 through 1986. These are composite means from a set of stations that varied over the years; all stations were inshore of the 18-m isobath, and all were within 2700 m alongshore on either side of SONGS (Eco-M, 1987d, 3.4, p.228 and Tables 3-4-1 and 2; see Eco-M, 1988b for station locations and recording periods).

Longshore Transport by Currents

The prevailing downcoast drift is well shown by the monthly means in Table 12. Only 20 out of 100 monthly means are upcoast, and the largest of these is 4.2 cm/sec; the longest run of consecutive upcoast means is three months in the ten years of data. The long-term average of the downcoast drift is close to 3 cm/sec. This persistent downcoast flow makes the shoreline sources of seston upcoast from San Onofre more important for our concerns than the larger downcoast sources such as the Santa Margarita and San Luis Rey Rivers. Seston from upcoast sources will sooner or later pass by off San Onofre, but seston from far enough downcoast may never do so.

The major events of longshore transport were all before 1983: May, 1978, June, 1980, July through October, 1981 (clearly the greatest), and May through September, 1982. The years 1984 and 1985 show no remarkable variations in longshore transport or differences from each other.

Cross-shelf Transport by Currents

By continuity, a local convergence of longshore current near a coast must be associated with an offshore current increasing with distance seaward from the coast, where its value is zero. The history of cross shelf velocity in Table 13 also gives a qualitative history of divergence and convergence in the longshore transport of water and seston at San Onofre.

As regards SONGS effects on this estimate of regional cross shelf velocity, the "Before" mean of the monthly means from February, 1977 through April, 1983 is 0.2 cm/sec seaward, while the corresponding "After" mean from June, 1983 through December, 1986 is 0.4 cm/sec seaward. The difference might have a marginal statistical significance in terms of the standard errors of these means, but it is not physically significant in comparison with the instrumental uncertainties.

There is a distinct change midway through the "After" period, however. The mean from June, 1983 through March, 1985 is 2.0 cm/sec seaward, while the mean from April, 1985 through December, 1986 is 1.2 cm/sec shoreward. This large change could be partly due to changes in the stations that made up the composite, but it is likely that it shows a real change in the local transport regime. This change is not accounted for by variations in SONGS pumping, and it is probably a natural event.

At face value, Table 13 shows the strongest episodes of offshore transport in the summer of 1980 and in the spring and fall of 1984, with somewhat weaker episodes of onshore transport in summer 1983, late spring 1985, and in summer and fall of 1986. The net offshore transport in 1984, in particular, results mainly from a skewness of the velocity distribution, with a longer tail of offshore velocities extending to 20 cm/sec (Eco-M, 1987d, Figs. 3-4-73 & 74). The skewness is unlikely to be an instrumental artifact, and shows that instantaneous offshore velocities high enough to transport sediment actually did occur.

Remembering that seston transport also requires waves high enough to suspend sediments, we can compare Tables 12 and 13 with the calendar of weekly maximum wave heights in Figure 15. Throughout 1984 and 1985 there were no high waves comparable to those of 1982 and 1983 before or February 1986 afterward. This quiet time for re-suspension leaves the offshore transport of 1984 as the only notable event in the history of sediment transport that might bear on the origin of the anomalous sediments.

4.2.2 Wave-Induced Nearshore Transport

The main effect of wave-induced longshore currents is to carry sand along the beach and in the surf zone. Very fine sand and silt entering the sea in runoff and eroding from the coastline has to spend some time in crossing this zone, though, and will be moved alongshore while in transit across. A persistent convergence of wave-induced longshore transport that led to local beach accretion would also be associated qualitatively with some local offshore transport of silt.

Figure 16 is a history of the longshore transport of sand past Oceanside, San Onofre, and San Clemente, estimated from the relation:

$$T = k\,(EC \sin a \cos a)$$

where, EC is the flux of wave energy onto the beach, a is the angle of wave incidence (zero for normal incidence) and k is an empirical factor (Seymour and Higgins, 1978). The seasonal regularity of the transport, upcoast in summer and downcoast in winter, is remarkable. At all times when the Oceanside curve is below the San Clemente curve, the transport is divergent, and beach erosion and shoreward transport of seston is to be expected. There were several brief episodes of divergence during the period 1983 through 1985, and no convergences of comparable magnitude, which argues strongly against wave-induced transport as a source of silt for the anomalous deposits. The variations in the San Onofre curve often bring it above or below both Oceanside and San Clemente, implying a very localized cell in the nearshore sand movement. We have no explanation for this.

Figure 17 is a history of beach changes following the sand release that took place from December, 1984 through January, 1985 (R. Flick, unpublished data). The overall picture is one of stability through 1985, and moderate net erosion downcoast from SONGS through 1986 into 1987. The interpretation of the beach bulges as relicts of the sand pad and trapped beach seems problematical to us, and any suggestion that these bulges represent an appreciable source of silt continuing into 1987 seems a very unlikely hypothesis, unsupported as it is by any evidence of silt persisting in the bulges themselves.

4.3 Natural and SONGS-Induced Transport and Sediment Trapping

SONGS induces a volume flow of 100 m^3/sec toward the intakes (800 m offshore), and a further volume flow of about 1000 m^3/sec toward the diffuser lines

(1000-2500 m offshore) to supply the water that is entrained close to the diffusers and carried seaward and downcurrent in the plume. The natural transport by a longshore current through the cross section of about 20,000 m^2 from the shore to 2500 m out is about 2000 m^3/sec for a current velocity of 10 cm/sec and proportionately larger or smaller for faster or slower currents. The natural and SONGS induced transports in the neighborhood of SOK are generally comparable. The complicated patterns of flow that result from the interactions of ambient currents with the discharge and make up flow of SONGS, further modified by the kelp beds, was documented by Eco-M (1987a, 1987e, 1988b).

The natural transport of seston in the region of SOK since 1983 is not generally separable from the transport due to SONGS, since both kinds of transport are undoubtedly taking place with comparable magnitudes. The largest transport episode that can be reasonably singled out as natural is the seaward transport in 1984, in contrast to shoreward transport in 1985-6, as noted in 4.2 above.

Transport carries seston to and through a region, but does not by itself cause net deposition of the seston as sediment. Some mechanism for trapping the seston supplied by the transport is also needed. The most likely candidates are hydrodynamic trapping due to damping of waves or slowing of currents, which we discuss here, or the local addition of some cohesive component, discussed in 4.4 below.

At any place where either the wave motion or the current velocity is less than it is in the surroundings, seston will tend to settle out of the water column to the bottom and form a deposit of sediment. The textbook example of the effect of waves is the tendency of waves to straighten a sandy coastline. Refraction makes waves higher around headlands and the headlands are worn away, while it makes the waves lower in coves and the coves are filled in. The effect of currents is most clearly seen in the deposits of silt at the concave side of river bends where the velocity is lowest. Here we consider the separate mechanisms of seston trapping as a result of regional variations in wave climate and wave damping by kelp, and trapping by slowing of currents by SONGS or by kelp beds.

4.3.1 Trapping of Seston by Waves

Regional Variations of Wave Climate

Regressions of daily mean significant wave height between Oceanside (OC), San Clemente (SC), and San Onofre (SO) show that Oceanside and San Clemente, respectively downcoast and upcoast from San Onofre, have nearly identical wave climates, but that the heights of the highest waves are considerably reduced at San Onofre relative to the station on either side. The regression lines for the period when appropriate data were available are:

OC = .07m + .96xSC, r^2=.80, N=1638, 1983-88;

SO = .46m + .64xOC, r^2=.48, N=451, 1981-83;

SO = .22m + .66xOC, r^2=.70, N=525, 1985-86;

SO = .23m + .67xSC, r^2=.71, N=532, 1985-86.

It can be seen from the regression lines and from Figures 18, 19, and 20 that, with the exception of three extreme events (Figure 18), ordinary waves in the range 0.5 m to 1 m height generally have about the same heights at San Onofre as they do to either side, while waves higher than about 1.5 m at Oceanside and San Clemente are consistently lower by as much as one-third at San Onofre. The reduction is about the same in 1985-6 as it was in 1981-2, and may be taken as a persistent characteristic of San Onofre which is probably due to a difference in sheltering by offshore islands (Figure 21).

Since bottom stress due to waves varies approximately as the square of wave height or orbital velocity, the resuspension rate at San Onofre during storms could be as low as one half of what it is to either side. Sediment resuspended and carried along the coast during storms can settle out in the milder storm wave climate around San Onofre and remain after the storm. This is probably an important mechanism for trapping sediment, and is a good candidate for explaining why the fine sediments from the high runoffs of 1978-80 and 1982-3 settled preferentially in the neighborhood of San Onofre. These deposits appear to be centered in a region about 1.5 km downcoast from SONGS, and may indicate the place where storm wave heights are at a minimum for this stretch of coast.

Wave Damping by Kelp

It is commonly observed that waves are damped by dense stands of kelp, though there are no wave records to document the amount of damping. Damping of waves by kelp could be responsible for part of the reduction of high wave heights at San Onofre, though island sheltering from storm waves is probably more important. It provides a possible mechanism for sediment trapping localized to kelp beds, rather than to the general neighborhood of San Onofre. At the side of a dense kelp bed on which the waves are incident, some increase of wave height due to partial reflection is likely. Deposition due to wave trapping would be expected inside the bed but not outside on the incident side, but might extend beyond the kelp on the opposite side.

4.3.2 Trapping of Seston by Currents

SONGS-Induced Trapping

A longshore current of 12 cm/sec, say, will increase to about 15 cm/sec as it approaches the SONGS diffusers, and decrease to about 9 cm/sec as it crosses the diffusers (Eco-M, 1987b). In general the reduction in velocity of water that crosses the diffusers will be about 6 cm/sec, due to the entrainment and removal of about 1000 m^3/sec of water from a cross section of about 18,000 m^2 (1500 m diffuser length x 12 m average depth).

The seston in water that is entrained will be carried off in the plume, while some of the seston in water that gets across the diffusers will settle out because of the reduction in velocity. When the current next changes direction, some of this may be resuspended and carried back to the diffusers, where part will go off in the plume and some will settle again on the other side. The whole process will trap seston that settles either alongside the diffusers or where it falls out of the slowing plume.

The make-up flow that supplies water for entrainment is directed more or less radially inward from all directions toward the diffusers, while the plume flows out from the diffusers, more strongly but in a narrow range of directions that depends on the ambient current velocity. The plume velocity falls off at the sides and bottom of the plume, and there can be places where the plume velocity at the margins and the opposite velocity of the make-up flow add up to zero.

One such stagnation point for velocity at the surface was observed directly in a dye study (4/7/87, Eco-M, 1987e). A dye patch (patch 16 in Figure 22) was set at the point X = 550m, Y = -1550m, about halfway between the outer diffuser and the upcoast edge of SOK, and downcurrent from the diffusers, in an ambient current of about 10 cm/sec. This patch did not move appreciably over the next three hours, but slowly dispersed in place until it was no longer visible. Meanwhile, a number of other patches on the same side of the diffusers moved about a kilometer on various offshore and downcoast trajectories through or around the kelp, while some patches set on the upcurrent side of the diffusers moved inshore and downcoast toward the diffusers, showing the shoreward component of the make-up flow. The stationary patch lay between visible separate plumes from the diffusers of Units 2 and 3, where presumably the shoreward and upcoast velocity of the make-up flow was just balanced by the seaward and downcoast velocity imparted by the two plumes to the water in between.

This observation definitely shows that stagnation points can actually exist in the total flow due to SONGS and currents together, and are not just a theoretical construct. We do not have the data for a good estimate of the spatial and temporal distribution of stagnation points in the actual current regime. It is suggestive, though not definitive, that this particular instance of stagnation occurred close to the place where the new cohesive deposits are most prevalent and persistent.

Trapping by Currents in Kelp Beds

The kelp plants in a dense stand of adults exert an appreciable drag force on moving water, which produces a pressure field that diverts some of the flow around a kelp bed, reducing the velocity within the bed (Jackson and Winant, 1983). It is useful, though not physically exact, to think of part of the flow as unaffected by the kelp while the remainder is redirected as if by a solid obstacle. The redirected fraction of the flow will have a stagnation point at the upcurrent end where it impinges on the kelp bed, zero velocity within the bed but increased velocity along the sides just outside the bed, and a second stagnation point at the down current end where the flow rejoins. Superposing this flow on the uniform velocity of the fraction of flow unaffected by kelp gives points of reduced, rather than zero, velocity at the ends of the bed, higher than ambient velocity along the sides just outside, and lower than ambient velocity within the bed.

The complications of flow as a current impinges on an irregularly shaped bed are not closely calculable, but we have excellent examples of actual retardation and diversion of flow by kelp from the same dye study referred to above. Figure 22 (from Eco-M, 1987e) shows the trajectories of a number of dye patches with positions along each track marked by a dot every half-hour. Patches 2 and 3 were set within the kelp and moved slowly until they escaped. Patch 9 was set just upstream of the kelp, and patch 15 at a greater distance upstream 24 minutes later. Patch 9 was evidently set close to a point of near stagnation. It moved slowly along the edge of the kelp while patch 15 quickly overtook it, and then moved quickly through a channel in the kelp. Patch 15 slowed and turned aside when it reached the original site of 9, and then followed the course of 9.

These examples show that the flow of plume and current together can actually be much diverted and retarded by the denser parts of the San Onofre kelp, and give a measure of the velocity changes to be seen in a region where the plume will often impinge on the kelp.[†] The whole array of patches, including the stationary patch 16, makes the point that the ambient currents, the SONGS discharge, and the configuration of the kelp beds are all significant partners in determining the local patterns of seston transport and the sites of seston trapping due to slowing of current.

4.3.3 BACIP Result from Seston Traps

Differences of seston concentration near the bottom are the combined results of differences in supply, transport, and physical trapping, all acting together. The accumulation rate of seston in open tube traps is roughly one or two times the product of volume concentration and settling rate (Eco-M, 1987h), so differences in accumulation rate will roughly correspond to differences in seston concentration if the grain-size distributions are about the same. An analysis using the Before-After-Control-Impact-Pairs (BACIP; Stewart-Oaten, et al, 1984) has found a large and significant local effect of SONGS on seston accumulation rate near the bottom, which can be taken as a measure of the importance of SONGS, relative to natural processes, in the combined process of supply, transport, and physical trapping.

The BACIP analyses compared accumulation rates in traps close to the bottom at station SOKU45 (=F1; 400 m downcoast from the diffusers) and station SOKD45 (=F2, 1400 m downcoast from the diffusers), before and after SONGS reached a state of normal operation in 1983. The traps were set out to collect continuously and were changed every week or two. The mean accumulation rate over a deployment was recorded as the height of the deposit in the tube divided by the time elapsed. The mean accumulation rates, in millimeters per day, are shown below:

	SOKU45	**SOKD45**
Before (N=31)	7.7	7.6
After (N=21)	11.2	7.5

The full statistical analyses, allowing for autocorrelation in the data, gave the effect of SONGS as an absolute increase of 3.6 mm/day or a relative increase of 48%, at significance levels close to p = .001, and with high probability that the "Before" differences were additive for the analyses of both absolute and relative change.

BACIP analyses of SOKU45 (=F1) and SOKD45 (=F2) with SMK45 (=F3) as control did not show clearly additive "Before" differences and did not give statistically significant results, probably because "Before" data from SMK45 (=F3) were sparse. In any case, a BACIP result on trap collections at SOK relative to SMK would be subject to a large confounding effect from the deposition in 1983 of fine sediments a few hundred meters offshore from SOK, centered on the interval X = 1000 to 2000m at Y near -2400m. The nearness of these sediments could increase seston concentration at SOK relative to SMK after mid-1983, but the sediments are a little closer to SOKD45 (=F2) than to SOKU45 (=F1), if anything, and would not by themselves produce a large increase at SOKU45 (=F1) but none at SOKD45 (=F2).

The increase of 48% after 1983 at SOKU45 (=F1) but not at SOKD45 (=F2) is a strong, significant, and reliable result which indicates that SONGS is responsible for about one-third of the accumulation rate at the upcoast end of SOK, and, by inference, for a substantial fraction of the transport and trapping of seston in this region. This result gives the most direct observational answer to questions 9 and 10 (3.0, above) taken together: transport and trapping by SONGS is indeed comparable to natural transport and trapping around SOK, and makes up an important part of the total.

4.4 Natural and SONGS-Induced Cohesion

Clay minerals and organic matter are the ordinary sources of cohesion in sediments. Total organic carbon (TOC) and percentage of clay sizes (particles finer than .004mm) both average about twice as high in all the samples classified as anomalous (showing cohesion under light loading and/or high water content) as in all normal samples, as shown in the table below:

	Anomalous	**Normal**
Mean % silt-clay	57.0	25.0
Mean % clay	3.0	1.7
Mean % TOC	0.35	0.18

These differences are all related, since clay and TOC both generally increase with percentage of silts and clays, but part of the differences in TOC and clay are independent of the difference in fineness. An analysis of variance that controls for percentage of silt and clay shows highly significant differences in TOC due to sediment type alone (Table 3). A similar analysis with percent silt as the covariate shows significant differences in the percentage of clay due to sediment type (Table 3).

The content of organic matter, as indicated by TOC (and total organic nitrogen in 1989 samples), is the one chemical tracer that is generally associated with cohesion and has a reliable statistical relation to the properties of cohesion and high water content that distinguish the anomalous and normal sediments found in and around SOK. This does not exclude clay as a source of cohesion in the anomalous sediments, but it does suggest that organic matter, alone or interacting with clay, may be more important or critical than clay alone.

4.4.1 Natural Cohesion

The ordinary processes of supply, transport and deposition do not produce cohesive sediments on the exposed inner shelf under normal or mean conditions, but they might do so now and then, and here or there, as extreme vagaries. An extreme vagary is in fact documented by the extreme runoffs of 1978-80 and 1982-3, the El Nino storms of 1982-3, and the localized deposition of silts around San Onofre in 1980 and 1983. We will consider this observed vagary rather than hypothetical vagaries, and ask if the 1980 or 1983 sediments are a potential source of cohesion as well as of bulk silt. First, though, we should note some citations of soft fine sediments on the Southern California shelf before 1983 or a long distance from SONGS (Marshall 1978, Carter 1986, North 1986). The cited deposits are fine and highly penetrable, but there is no direct report of cohesiveness *per se*, and all properties can be accounted for by high water content due to rapid deposition. These deposits are also much smaller and more ephemeral than the anomalous deposits around SOK.

The 1980 and 1983 Deposits Offshore from SOK

TOC was generally higher than 0.3 at the Y=-3700 and Y=-3000 stations offshore from SOK in 1980 and 1981, less than 0.3 in 1982 and 1983, rising again at the end of 1983. At the three stations at Y=-2400 where the new silt deposits were centered, TOC was between 0.2 and 0.3 in 1982-3 and generally below 0.2 afterward. At Y=-1700, just upcoast of SOK, TOC was generally between 0.1 and 0.2 in 1980-84 (MEC, 1986). After early 1982, then, there is no evidence of local sediments with higher TOC than the anomalous sediments that first appeared in 1985. Any local source for the bulk of the anomalous sediments has either had TOC added, or has been somehow high-graded (sorted in favor of TOC) on the way to redeposition. The fact that a TOC anomaly exists independent of grain-size suggests that the latter is unlikely.

The 1980 sediments at y=-2400 had TOC about the same as the anomalous deposits up into 1982, and probably dispersed to the station upcoast of SOK intermittently in 1981-83 (see Figure 13). If this TOC was a sufficient source of cohesion, and if it could have produced anomalous deposits without the aid of SONGS-induced transport and trapping, it did not take the opportunity to do so between 1980 and 1983. The 1983 sediments, with less TOC, are that much less likely to provide sufficient cohesion by themselves.

Material from the Sand-Release

TOC was not measured in the samples from the laydown pad and trapped beach treated in Table 11, but there is no reason to think it would be higher than that in normal nearshore shelf sediments. The size-fraction smaller than .008 mm (phi=7) was 1.4% for the sand-pad material and 0.5% for the beach; the fractions of clay size (<.004 mm or phi < 8) are most unlikely to be greater than half of these, so we may expect the clay in the sand-pad to be less than 0.7% or 1200 m^3, and that in the trapped beach to be less than 0.3% or 1500 m^3. This clay fraction might avoid dispersing much faster than the silt by flocculating in the surf-zone as the released material was winnowed (see 4.4.2 below), but in any case it is lower than the clay fractions of both the normal and anomalous sediments. Like the silt fraction, it represents a limited amount of material which cannot supply cohesion to all the anomalous deposits of 1985 through 1989 except through some remarkable but unknown process of recycling in place.

4.4.2 SONGS-Induced Cohesion

There are two evident mechanisms by which SONGS could induce cohesion in nearby sediments. One is by supplying dead organic matter to the seston. SONGS takes in and discharges about 3 x 109 m^3/year of water (3 km^3/year) and one gram/m^3 or mg/liter of any particulate matter in the water taken in amounts to 3000 tons per year leaving the discharge. The average supply of organic seston from zooplankton larger than .02 mm killed in SONGS is estimated as about 1000 tons/year dry weight (Plankton Report), and the supply from phytoplankton, further down the food web, is likely to be several times larger. The other mechanism is flocculation in the turbulence of the discharge, which could aggregate fine clay particles and light organic particles, making them settle in the vicinity instead of remaining in suspension and dispersing far away. The two processes may obviously interact: SONGS could both supply organic matter from the discharge and flocculate it along with entrained ambient seston.

Supply of Organic Seston

SONGS undoubtedly does discharge an amount of dead organic matter on the order of one or a few thousand tons per year. The bioassays by BACIP studies on fauna that live in, on, and just above the bottom confirm that extra detrital food is incorporated into the sediments near SONGS as well as into the seston near the bottom (Kastendiek, et al, 1989). The addition of one or two parts per thousand of TOC to superficial sediments near SONGS is not a quantitative surprise; it might well be a good deal more if there were no actively-feeding organisms in the sediment.

As noted above, there is a reliable statistical relation between TOC and the cohesion of anomalous sediments seen by divers in the field. What has not been demonstrated is that this cohesion can make enough difference in resistance to erosion by waves to account for the persistence of the anomalous sediments. The limited shaker tests described in 2.1 do not settle the matter one way or the other, though they suggest that the difference in response of anomalous and normal sediments to the actual waves off San Onofre is likely to be subtle.

Flocculation

Flocculation is a normal part of deposition in shelf waters, because ordinary grains often acquire organic coatings in the sea, and aggregates form when large grains overtake small grains in settling. Flocs may also form in particular situations when turbulence produces a high rate of collisions between particles, as in the surf-zone, and perhaps around the discharge-jets of SONGS. Turbulence also sets a limit to floc size by breaking up flocs.

Since settling flocs sweep up all particles smaller than themselves, floc-settling produces a different size-distribution in sediments than does single-grain settling, and the relative importance of floc- and grain-settling may be estimated from the shape of the fine tail of the size-distribution (Kranck and Milligan, 1985). Estimates of this kind made by Kranck on eight samples from San Onofre did not distinguish between anomalous and normal sediments in general, but did show a notably greater influence of flocculation (and notably greater organic content) on the especially cohesive sediments found draped over cobbles in July of 1987 (Table 14). These results establish that flocculation is an actual rather than hypothetical mechanism for the anomalous deposition, but they also show it is not universal or dominant.

4.5 Co-Factors

4.5.1 El Nino

During the extreme El Nino event which arrived at San Onofre in September 1982 and remained, with brief remissions, through October 1984, the normal coastal waters were largely displaced by oceanic surface waters with much lower contents of dissolved nutrients and plankton. The mean concentration of chlorophyll plus phaeophytin measured in the region was 2.7 mg/m^3 in 1976-1982, 0.8 mg/m^3 in 1983-1984, and 9.5 mg/m^3 in 1985-1986. That is, the density of phytoplankton, and the corresponding rate at which SONGS produced organic seston from killed plankton, increased by an order of magnitude in the summer of 1985 over what it had been since SONGS began full operation during 1983, from hundreds of tons per year to thousands. The observed depletion of plankton by El Nino provides a co-factor that can account for the delayed appearance of any cohesion in sediments due to organic matter from SONGS.

The ocean surface water of the El Nino years also lacked a few tenths of a gm/m^3 of clay particles which are perennially suspended in normal coastal waters and account for a few hundredths m^{-1} of extinction. If flocculation of clay minerals by SONGS is a significant source of cohesion, depletion of the normal suspended clay during El Nino is a possible co-factor. A difference of 0.1 gm/m^3 clay particles in the water taken in by SONGS amounts to a difference of 300 tons/year of clay passed through SONGS and exposed to flocculation.

The extent and density of kelp in SOK were much reduced during 1983-4 by El Nino, falling to minimum values in the survey of October 1984, but recovering strongly by April 1985. Hydrodynamic trapping of seston by kelp certainly depends strongly on kelp density, and El Nino is a possible co-factor for seston trapping by kelp, reasonable but of unknown magnitude.

4.5.2 Offshore Transport by Currents

The sediments deposited off San Onofre after the high runoffs and storms of winter 1982-3 were in place by June of 1983. A single wave-episode in December, 1983 dispersed or mixed them a little, but the wave history after that is unusually calm until February, 1986. The year 1984 showed unusual offshore flow of currents in the region of San Onofre, with monthly mean velocities greater than 4 cm/sec for three successive months in spring and again in fall. This offshore transport, which is unlikely to be related to SONGS operation, is a possible co-factor delaying the dispersion of the 1983 fine sediments shoreward into SOK.

5.0 CONCLUSIONS

We conclude by first setting out what seems to us the most comprehensive and parsimonious explanation. There are four main elements to this hypothesis - Source, Transport, Depositional Mechanism, and Co-factors.

Source: The most likely main bulk source of the anomalous sediments is the deposit of silt laid down just offshore from SOK following the extreme runoffs of 1978 - 1980 and 1982 - 1983. The reduced height of storm waves at San Onofre relative to places upcoast and downcoast is an adequate and likely explanation of why these silts settled and remained in the neighborhood of San Onofre. Material from the release of the laydown pad perhaps contributed a good deal also in 1985-1986, but less since 1986.

Transport Mechanism: We think that silt from the deposit offshore was carried to SOK principally by the ordinary processes of suspension by waves and dispersion by currents, which will move silt in all directions from a concentrated deposit, even against a moderate mean drift.

Depositional Mechanism: Silt that dispersed to SOK was retained for a time by hydrodynamic trapping in the kelp beds, which was supplemented after mid-1983 by hydrodynamic trapping due to SONGS. At the sampling station X=400, Y=-1700, just upcoast from SOK, the silt-clay percentage ranged from 37% to 70% swung from well-below to well-above 50% nine times in the three years from mid-1981 to mid-1984, in contrast to much greater stability at all other stations; this history shows the specific swings in the balance of natural dispersion of silt from the offshore deposit into SOK and its removal by waves and currents. The increase of 48% in the collection-rate of seston traps in upcoast SOK after 1983 indicates that SONGS has played a significant part in the whole process of transport and hydrodynamic trapping since 1983.

Co-Factors: SONGS did not kill many plankton during 1983 and 1984 because population densities in the water drawn in were very low in the El Nino years. In 1985, phytoplankton densities increased by an order of magnitude and so did the output of dead organic matter from SONGS. This addition of organic matter to the seston around SONGS probably added some cohesion to silts dispersing into SOK. This may have contributed to an increased rate of flocculation of fine particles and an increased settlement rate, and may have increased their wave resistance and mean residence time in SOK. We suggest that this may have tipped the balance between supply and removal enough to make the silts remain longer in SOK, and to accumulate in the places where trapping was most effective.

The evidence for the crucial parts of this hypothesis is mixed. The observed cohesiveness of the new sediments is definitely and significantly associated with high content of organic matter relative to normal sediments. However, the amount of added wave-resistance conferred by the cohesiveness is not documented, but the limited shaker results suggest that it is not large (although the relevance of the shaker results is still uncertain). Two of the samples of anomalous sediments had a large proportion of flocculated particles and four anomalus and two normal sediments did not.

This explanation accounts for the character of the anomalous sediments and their distribution in space and time without calling on any coincidence or wholly undocumented hypothesis. Its weakest link is the failure of the shaker to demonstrate any clear differences in resistance to suspension among four anomalous and four non-anomalous samples.

The involvement of SONGS in this explanation consists of SONGS' contribution to transport and trapping, and the cohesion added by SONGS' increased supply of dead organic matter after 1984. Transport and trapping by

SONGS certainly takes place and most probably is a substantial fraction of the total, and it helps explain the specific pattern of anomalous deposition. It would still be possible to say, though, that SONGS adds something to the volume of anomalous deposits and affects where they settle, but is not a major contributing reason for their existence.

The cohesion supplied by SONGS, with El Nino as a delaying factor, is harder to replace by an equivalent that does not involve SONGS. Nonetheless, we will set out what appears to us as the most parsimonious hypothesis which is based only on natural events. As in the hypothesis presented above, this one has four main elements - Source, Transport, Depositional Mechanism, and Co-Factors.

<u>Source</u>: The most likely bulk source of anomalous deposits, regardless of the involvement of SONGS, is the deposit of silt laid down offshore of SOK, which is discussed above.

<u>Transport</u>: The historical record of grain sizes from the station nearest SOK shows repeated influxes of silt from 1981 - 1984, demonstrating that it is possible for fine materials to reach the kelp bed in the absence of SONGS. The presence of stands of giant kelp would tend to retain for a time materials which naturally dispersed to SOK.

<u>Deposition</u>: No special mechanisms were are work. There was simply the normal balance of deposition and erosion, coupled with trapping by giant kelp.

<u>Co-Factor</u>: The clay minerals in the sand-release were a new source of cohesion that appeared in 1985, whether or not the released silt is regarded as an important bulk source. In addition, the unusual offshore current in 1984 delayed the natural dispersion of the 1983 fine sediments into SOK.

The problem with this and other "natural" hypotheses is that they do not provide for the persistence and recurrence of the anomalous sediments. A single event is not sufficient.

Another explanation of cohesion without SONGS invokes deposits of clay or mud buried under the sand and silt of the shelf until 1985, and then exposed by wave-erosion to supply clay or organic binder to silts dispersing into SOK. This would be serious contender if suitable exposures at suitable times and places were actually demonstrated. As it is, it is very much an *ad hoc* hypothesis with no basis in observation of which we are aware.

One other hypothesis that is independent of SONGS' Operation should probably be addressed. This hypothesis states that there is no pattern to be explained. Sediments such as those observed at SOKU45 have always been present in the San Onofre Kelp Forest and environs and were simply overlooked or not recognized until some of them were deposited right on top of fixed, marked quadrats where they could not be ignored. The grain size and chemical characteristics were always present and the bulk characteristics simply reflect recent, rapid deposition. This would be the most parsimonious hypothesis if it accounted for all the observations, but it does not do so. Compacted, anomalous sediments would not have been noted as unusual if they were viewed from a distance in any of the surveys, before or after 1985. However, if the meter-tape used to position the random quadrats crossed over anomalous sediments, the sediments would have been noticed and noted. Therefore, the results of the random surveys make the "search image" and "accident of sampling" elements of the hypothesis very improbable. Secondly, the anomalous character of the deposits is still a problem. The new question is, Why do some "natural" sediments in SOK have anomalous characteristics whereas other "natural sediments" do not. And, one still must find a persistent source of high TOC for those that do. Nonetheless, hypotheses based on existential statements (e.g., anomalous sediments have always existed at SOK) and coincidence can not be falsified. On the other hand, because they are not falsifiable, they are not at all compelling.

Based on the available evidence, the most tenable hypothesis seems to us to involve an interaction between SONGS and natural processes. Hence, we predict that the effects of SONGS on the deposition of anomalous sediments in SOK will vary depending upon the availability of terrestrial inputs of fine materials, and of organics in the form of planktonic organisms. However, on average we expect the San Onofre Kelp Forest will be subject to a higher flux of anomalous sediments than before Units 2 and 3 began operating.

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7.0 TABLES

Table 1. Some grain size, chemical characteristics, and field descriptions of various sediments found in the region near SONGS on four surveys from spring, 1986 through winter, 1989. Means are tabulated.

Survey 1: May, 1986

Sediment Description	N	% Silt/clay	% Clay	% TOC	% Organic Nitrogen
COARSE SAND	2	12.46	3.25	0.21	.
ANOMALOUS	6	43.38	4.12	0.52	.

Survey 2: October, 1986

Sediment Description	N	% Silt/clay	% Clay	% TOC	% Organic Nitrogen
SAND	4	7.12	1.83	0.28	.
FINE SAND	3	23.91	3.66	0.11	.
VERY FINE SAND	6	31.03	2.64	0.11	.
ANOMALOUS	9	52.71	5.90	0.42	.

Survey 3: July - October, 1987

Sediment Description	N	% Silt/clay	% Clay	% TOC	% Organic Nitrogen
COARSE SAND	1	0.15	.	0.17	.
MEDIUM SAND	6	5.78	.	0.13	.
SAND	4	6.64	.	0.06	.
FINE SAND	9	12.46	0.08	0.17	.
SILT	2	25.55	0.00	0.06	.
FINE SILT	5	28.61	0.05	0.17	.
ANOMALOUS	23	55.14	2.19	0.25	.

Survey 4: March, 1989

Sediment Description	N	% Silt/clay	% Clay	% TOC	% Organic Nitrogen
SAND	3	39.46	0.96	0.24	0.01
FINE SAND	18	23.89	0.57	0.15	0.01
VERY FINE SAND	6	44.76	1.19	0.16	0.01
ANOMALOUS	27	63.76	2.31	0.36	0.03

Table 2. Some grain size and chemical characteristics of various types of sediments found in the region near SONGS. Data are sorted by increasing percentage of silt-clays. Means are tabulated. Means of percent Silt and clays that do not differ significantly are grouped with vertical lines.

Sediment Description	N	% Silt/clay	% Clay	% TOC	% Organic Nitrogen
MEDIUM SAND	6	5.78	0.13	.	
COARSE SAND	3	8.35	3.25	0.20	.
SAND	11	15.77	1.46	0.19	0.01
FINE SAND	32	20.46	0.84	0.15	0.01
SILT	2	25.55	0.00	0.06	.
FINE SILT	5	28.61	0.05	0.17	.
VERY FINE SAND	12	37.90	0.91	0.14	0.01
ANOMALOUS	49	57.42	3.00	0.35	0.03

Table 3. Comparisons of percent TOC, percent organic nitrogen, and percent clay between anomalous and other sediments. Percent silts and clay was used as a covariate for analysis of percent TOC and percent organic nitrogen. percent silt was used as a covariate for analysis of percent clay. Data were collected from 1985 - 1989; years were lumped. P-value is for difference between means of sediment categories (corrected for covariate for all variables but percent silt/clay).

Dependent Variable	Sediment Type	Mean	P_value
% TOC	ANOMALOUS	0.35	0.0001
	OTHER	0.18	
% Organic Nitrogen	ANOMALOUS	0.03	0.011
	OTHER	0.01	
% Clay	ANOMALOUS	3.0	0.00001
	OTHER	1.7	
% Silt/clay	ANOMALOUS	57.4	0.0001
	OTHER	25.1	

Table 4. Comparisons of penetration and vane shear forces (kg/cm^2) between anomalous and normal sediments. Data were collected in fall and winter 1989. P-value is for t-test of differences between sediment types.

Dependent Variable	Sediment Type	Mean (kg/cm^2)	P_value
Penetration Force	ANOMALOUS	0.067	0.0001
	OTHER	0.144	
Vane Shear Force	ANOMALOUS	0.007	0.0001
	OTHER	0.009	

Table 5. Percentages of various clay minerals in sediments collected near SONGS. **K**=kaolinite; **I**=illite; **S**=smectite; **ML**=mixed layer; **CHL**=chlorite. Cohesive sediments were collected in October 1987. Controls and samples from stagnation points were collected in August 1987. Samples from the laydown pad were collected in May 1984. Samples with the same group letters have a similar mix of clay minerals. Laydown pad samples collected from 2 sites within the construction laydown pad just seaward of Units 1, 2, and 3. Depth of samples in feet are indicated next to the site numbers. The sample from U2-30m was collected about 1 km seaward of the end of Unit 2 diffuser. * Refer to Figure 6 for location of sample. Locations of all other samples are indicated on Figure 2.

Sites with Cohesive Sediments	**K**	**I**	**S**	**ML**	**Group**	**% Clay Size**
U2-30ν	2.5	2.5	93	2	A	4.11
35*	2	2	96	0	A	7.74
B1	1.5	3.5	95	0	A	1.10
C4	1.5	3	85	10	B	0.83
D1	1	3.5	76.5	19	B	2.06
D4	1	2	91	5.5	A	--
E3	1	3	90	6	A	--
E9	4	2	66	28	B	--
Sites with Non-cohesive Sediments						
16*	5	2	91	2	A	1.00
B5	1.5	3	95.5	0	A	1.89
C10	1	3	67	29	B	0.94
D11	1	1.5	97	0	A	0.87
D11	20	3	77	0	C	0.87
Sites from the Laydown Pad						
#2 1.5'	9	10	81	0	D	1.34
#2 3.0'	7	17	76	0	D	1.90
#3 0.5'	0	10	46	19	**25 CHL**	1.5
#3 2.0'	0	5	0	95	E	0.05
#3 3.0'	10	4	9	77	E	0.09

Table 6. Mean percent cover of anomalous deposits throughout SOK and SOKN. Five randomly placed 1 m² quadrats were sampled per date at each station, except for stations F1 and F2 before July, 1987, when 40 1 m² quadrats were sampled. Station locations are indicated on Figure 6.

		MEDIAN DATE OF SAMPLE				
Kelp Area	**Station**	**28Mar86**	**28Jun86**	**13Nov86**	**14Jul87**	**22Jul88**
SOKD35	12	0.0	3.0	0.0	.	.
	13	0.0	0.0	0.0	0.0	0.0
	16	0.0	0.0	0.0	0.0	0.0
	17	0.0	0.0	0.0	39.0	0.0
SOKD45	31	0.0	0.0	0.0	0.0	0.0
	25	0.0	0.0	0.0	.	.
	33	0.0	0.0	0.0	.	.
	24	0.0	0.0	0.0	0.0	0.0
	32	0.0	3.0	0.0	4.4	0.0
	21	0.0	0.0	0.0	0.2	0.0
	23	0.0	0.0	37.0	20.0	1.3
	26	0.0	0.0	0.0	0.0	1.0
	38	0.0	0.0	0.0	0.0	54.2
	39	0.0	26.0	22.0	16.0	0.0
	40	0.0	16.0	8.0	28.0	14.0
	F2	6.8	6.8	0.2	.	0.0
SOKU35	2	0.0	0.0	4.0	.	.
	1	0.0	26.0	0.0	80.8	0.0
	6	0.0	0.0	0.0	0.0	0.0
	7	0.0	2.2	0.0	84.0	0.0
	9	0.0	0.0	0.0	0.0	1.0
	10	0.0	0.0	0.0	0.0	0.0
SOKU45	47	0.0	0.0	0.0	.	.
	29	0.0	0.0	0.0	.	.
	30	0.0	0.0	0.0	0.0	0.0
	27	56.0	38.0	11.0	4.2	6.4
	28	0.0	33.0	0.0	31.0	37.0
	18	100.0	0.0	98.0	3.0	0.0
	19	0.0	0.0	0.0	9.6	0.0
	34	0.0	82.0	1.0	18.0	52.8
	35	10.0	0.0	2.0	0.0	0.0
	36	0.0	0.0	0.0	20.2	5.0
	42	0.0	12.0	5.8	0.0	13.2
	44	0.0	0.6	13.8	43.6	18.4
	F1	29.5	30.6	44.2	.	74.0
SOKN	48	0.0	0.4	0.0	2.0	16.0
	45	0.0	6.0	0.0	0.0	57.0
	46	0.0	0.0	0.0	25.0	5.0
% of Stations with Anomalous Sediments		13.2	36.8	31.6	56.7	43.8
% Cover of Anomalous Sediments		7.1	9.0	8.6	14.3	15.2
Area of Anomalous Sediments (ha)		13.9	17.6	16.8	28.0	29.8

Table 7. Supply of fine sediments to the sea (thousands of metric tons) from 1974 to 1984.

WATERSHED	MAX. DAILY (10^3 MT)	MAX. ANNUAL (10^3 MT)	11-YEAR TOTAL (10^3 MT)
San Juan Creek and Tributaries (500 km^2)	350	850	1100
San Mateo Creek and San Onofre Creek (350 km^2)	200	200	450
Las Flores and Other Creeks (200 km^2)	100	150	300
Santa Margarita and San Luis Rey Rivers (3400 km^2)	250	900	3900
Erosion of Coastal Gullies	50	150	300
Erosion of Sea-Cliffs	50	100	200
Sewage Outfalls	0.02	5	50

Table 8. Annual sediment yields from San Juan Creek (thousands of metric tons). Water year periods are from October of the prior year through September of current year. Data from USGS.

WATER YEAR	TOTAL YIELD (10^3 MT)
1974	0.5
1975	2.4
1976	0.2
1977	0.2
1978	661.0
1979	48.0
1980	877.0
1981	0.6
1982	16.0
1983	209.0
1984	2.0
1985	6.7
1986	3.1
1987	0.3
1988	1.2

Table 9. Particulate organic carbon (Percent of dry weight) in sediments, 1981-85. X= +800, Y=-1700 is in SOK; X= +800, Y=-2500 is about 400 m offshore from SOK; s/m is ratio of standard deviation to mean.

	X= +800	+800	+800	+400	+400
Date	Y= +100	-1700	-2500	-3000	-3700
6/81	.09	.18	.22	.36	.42
9/81	.15	.17	.29	.77	.47
12/81	.12	.19	.28	.33	.40
3/82	.11	.17	.23	.27	.37
6/82	.09	.18	.14	.17	.23
9/82	.07	.12	.22	.09	.24
1/83	.08	.15	.12	.28	.34
3/83	.01	.16	.14	.24	.15
6/83	.12	.07	.14	.27	.32
9/83	.07	.13	.14	.32	.33
12/83	--	.19	.10	.27	.41
3/84	.10	.34	.23	.24	.37
mean	**.09**	**.17**	**.19**	**.30**	**.34**
s/m	**.40**	**.36**	**.33**	**.52**	**.26**
6/84	.09		.19		
9/84	.13		.20		
12/84	.11		.22		
1/85	.11		.21		
2/85	.11		.21		
3/85	.13		.16		
mean	**.11**		**.20**		
s/m	**.14**		**.11**		

Table 10. Percent silt-clay/grain-size dispersion, 1981-85. X=+400, Y=-1700 is at the upcoast edge of SOK; stations at Y=-2400 are about 300 m offshore from SOK; s/m is ratio of standard deviation to mean.

Date	X= +400 Y= +150	+400 -1700	+400 -2400	+1100 -2400	+400 -3000	+400 -3700
6/81	17	65	65	74	58	63
9/81	16	37	62	74	54	57
12/81	20	60	67	73	50	63
3/82	27	46	63	76	52	57
6/82	14	64	58	70	45	57
9/82	13	39	66	71	--	61
mean	**18**	**52**	**64**	**73**	**52**	**60**
s/m	**.26**	**.22**	**.05**	**.03**	**.08**	**.05**
1/83	13/.5	38/.5	.	75/.6	42/.6	61/.8
3/83	8/.4	68/1.3	.	91/.4	54/.7	57/.9
6/83	8/.4	62/.6	.	92/.6	57/.8	59/.9
9/83	18/.5	43/1.8	67/.6	93/.5	53/.7	58/.7
12/83	12/.4	70/.7	65/.6	66/.6	50/.7	63/.8
3/84	13/.4	49/1.1	75/.6	80/.5	53/.7	62/1.0
mean	**12**	**55**	**69**	**83**	**52**	**60**
s/m	**.28**	**.22**	**.06**	**.12**	**.09**	**.04**
6/84	13/.5	70/.6		87/.6		
9/84	25/.7	70/.6		83/.5		
12/84	22/.6	71/.6		83/.6		
1/85	25/.7	73/.6		76/.6		
2.85	19/.6	72/.6		77/.6		
3/85	25/.7	69/.6		78/.5		
4/85	24/.7	70/.6		25/.6		
7/85	13/.4	60/.6		59/.6		
9/85	39/.7	55/.6		50/.6		
12/85	26/.7	72/.6		77/.6		
mean	**23**	**68**		**69**		
s/m	**.32**	**.09**		**.28**		

Table 11. Grain-size distributions for excavated material (LAYDOWN PAD, 4 location avera beach sand (TRAPPED BEACH*, 3 location average).

			LAYDOWN PAD 170,000 m^3		TRAPPED BEACH ca. 500,000 m^3	
Diameter (mm)	Settling-rate s(cm/sec)	PHI ($-\log_2 d$)	FREQ. %	VOL. $10^3 m^3$	FREQ. %	VOL. $10^3 m^3$
<2.0	>30.0	<-1.0				
			4.9	8.3	2.0	10.0
2.0	30.0	-1.0				
			20.0	34.0	4.5	22.5
1.0	15.0	0.0				
			26.3	44.7	22.9	114.5
0.5	8.0	1.0				
			21.9	37.3	53.0	265.0
0.25	3.0	2.0				
			10.6	18.0	14.2	71.0
0.125	1.44	3.0				
			5.6	9.6	1.0	5.0
0.063	0.36	4.0				
			4.4	7.5	0.3	1.5
0.031	0.090	5.0				
			3.0	5.1	0.0	0.0
0.016	0.023	6.0				
			2.2	3.7	0.0	0.0
0.008	0.006	7.0				
			1.4	2.4	0.5	2.5
<0.008	<0.006	>7.0				

*Report of MRC grain samples from the Laydown Pad and Trapped Beach at SONGS (MEC,

Table 12. Monthly mean longshore currents. The units are cm/sec. Values not underlined are positive, directed upcoast. Underlined values are negative, directed downcoast. * indicates missing values.

Year	J	F	M	A	M	J	J	A	S	O	N	D
1977	*	0.6	0.9	0.3	2.4	3.6	*	3.8	5.9	4.7	1.5	1.0
1978	*	*	*	*	18.2	2.7	1.5	0.8	2.3	2.5	0.6	0.1
1979	0.4	1.1	1.4	3.3	0.9	0.8	0.4	0.6	2.0	6.4	4.1	1.3
1980	*	*	0.6	4.5	1.0	18.1	*	*	*	*	1.3	3.7
1981	*	*	*	*	*	0.5	10.2	13.4	36.0	14.1	1.0	*
1982	1.8	0.3	3.4	1.6	6.0	8.0	10.1	9.1	9.3	*	2.6	*
1983	*	1.0	2.5	10.4	*	2.6	3.8	*	0	0.1	8.0	2.7
1984	0.2	5.9	0.6	2.3	1.1	3.7	6.2	9.8	3.8	6.5	5.8	1.8
1985	2.8	0.7	3.2	5.9	7.4	5.0	4.2	0.7	2.7	1.9	1.7	1.2
1986	0.2	0	1.2	0.8	8.6	5.4	3.5	2.2	7.3	4.4	1.3	2.5

Table 13. Monthly mean cross-shelf currents. The units are cm/sec. Values not underlined are positive, directed shoreward. Underlined values are negative, directed seaward. * indicates missing values.

Year	J	F	M	A	M	J	J	A	S	O	N	D
1977	*	0.5	0.2	0.8	0.4	0.5	*	2.0	0.4	0.7	1.7	1.0
1978	*	*	*	*	2.4	0.5	0.8	0.7	0.1	0.3	0.3	1.2
1979	0.7	0.3	0.1	0.3	1.3	0.7	0.9	0.9	0.4	0.1	0.1	0.3
1980	*	*	0.6	0.1	2.5	5.9	*	*	*	*	0.3	0.7
1981	*	*	*	*	*	0.5	2.3	2.1	*	1.1	0	*
1982	1.1	1.2	0.6	0.7	0.7	0.3	1.6	0.9	0.7	*	0.7	*
1983	*	0.9	0	0.8	*	1.6	3.8	*	1.5	1.7	1.9	3.2
1984	0	4.6	7.0	4.6	1.7	2.5	1.5	5.1	4.6	5.7	0.8	1.7
1985	1.1	0.7	1.6	3.3	3.2	1.7	1.4	0.7	0	0.1	0.2	1.1
1986	1.0	0.6	0.4	0.2	2.5	3.3	1.4	0.8	3.7	1.6	0.1	1.5

Table 14. Ratio of floc to grain settled particles, modal size (mm) and percentage ash weight of several anomalous and normal sediments collected in the vicinity of San Onofre in the fall and winter of 1989.

Sediment Type	Floc/Grain Ratio	Modal Size (mm)	% Ash Weight
Normal	0.21	0.063	0.9
Normal	0.30	0.064	0.5
Anomalous	0.27	0.064	1.2
Anomalous	0.27	0.051	2.2
Anomalous	0.29	0.064	1.2
Anomalous	0.30	0.051	1.5
Anomalous	0.47	0.051	2.6
Anomalous	0.97	0.051	6.5

8.0 FIGURES

Figure 1. Locations of Stations Sampled for Sediments in May, 1986.

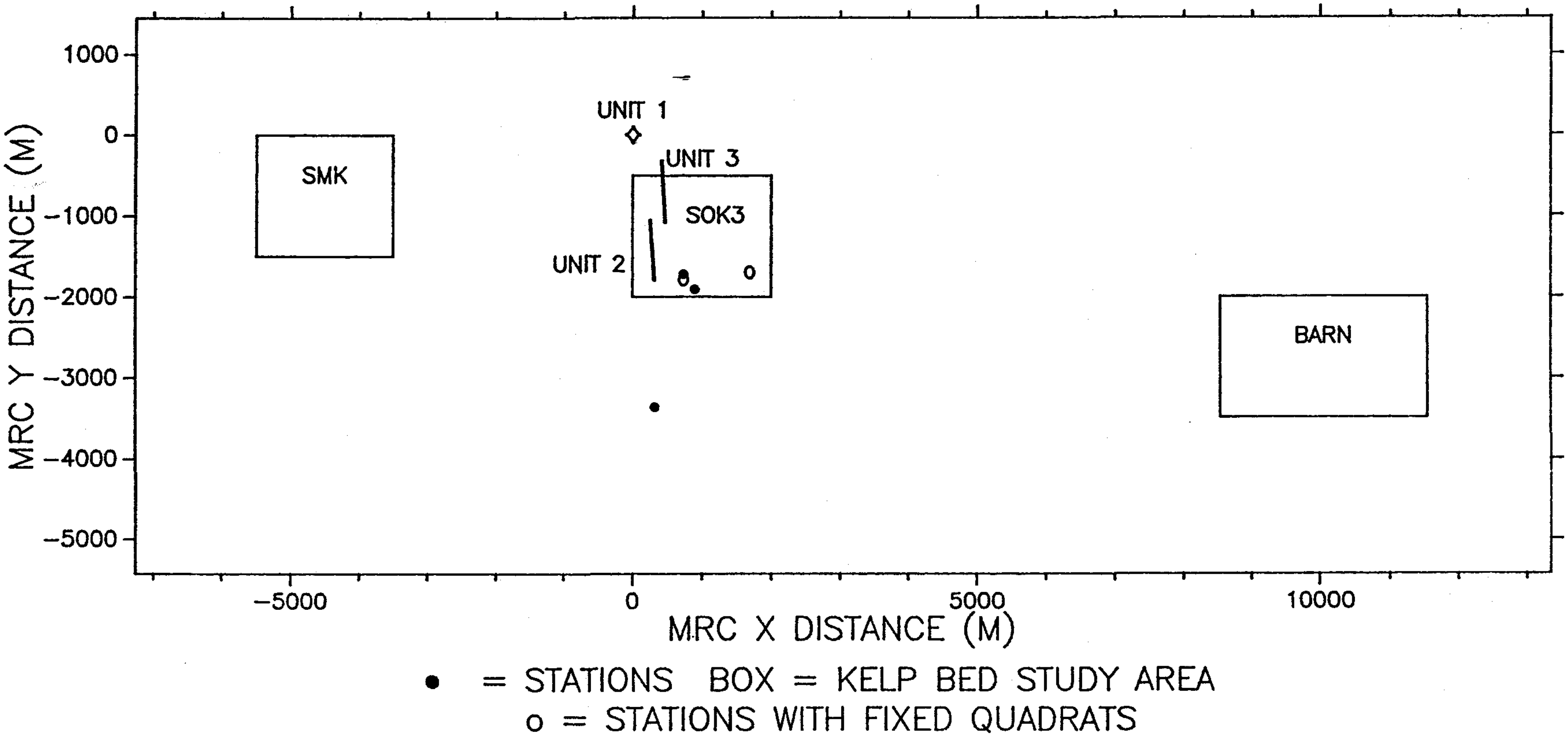


Figure 2. Map of locations for sediment samples taken in October, 1986 and July, 1987. Samples were taken at grid intersection points and at stations off the grid.

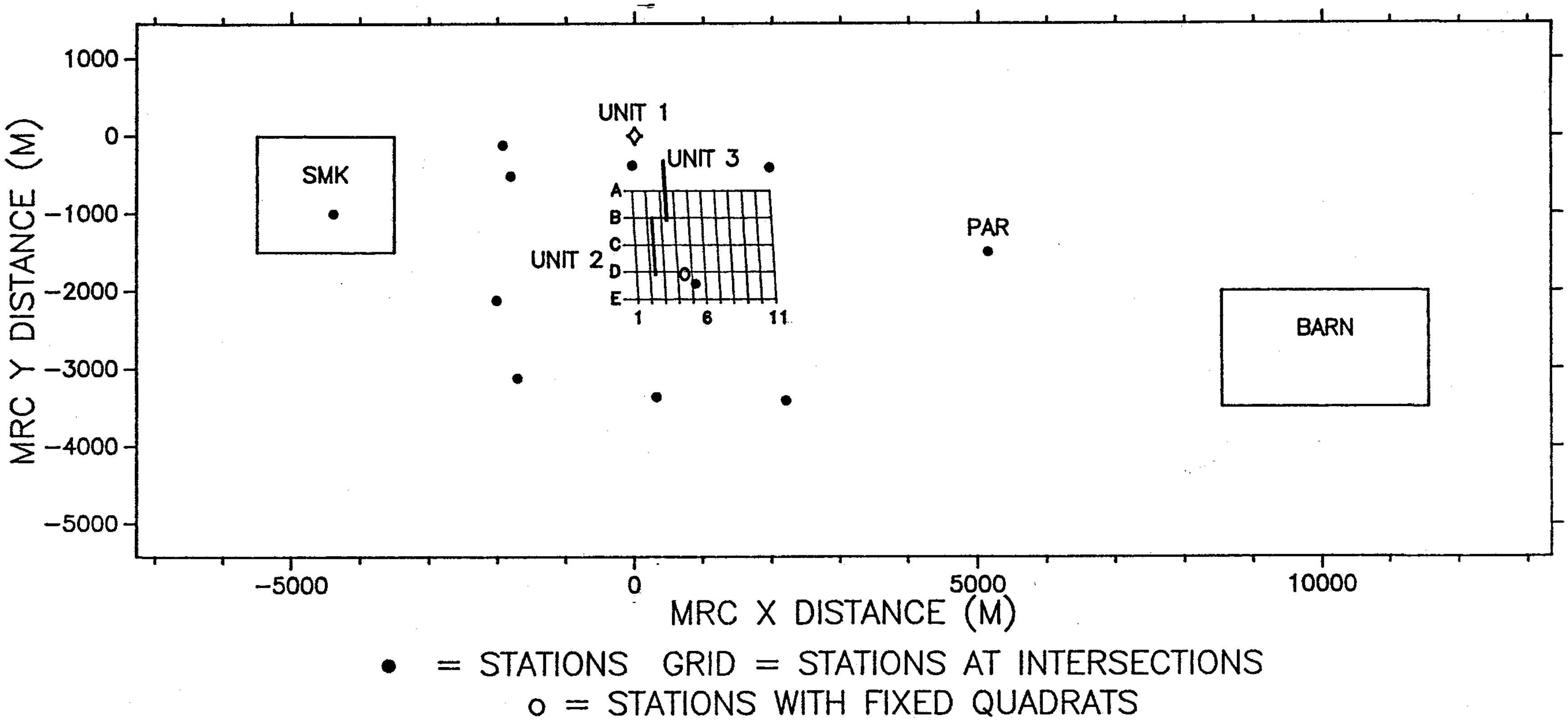


Figure 3. Locations of Stations Sampled for Sediments in 1989.

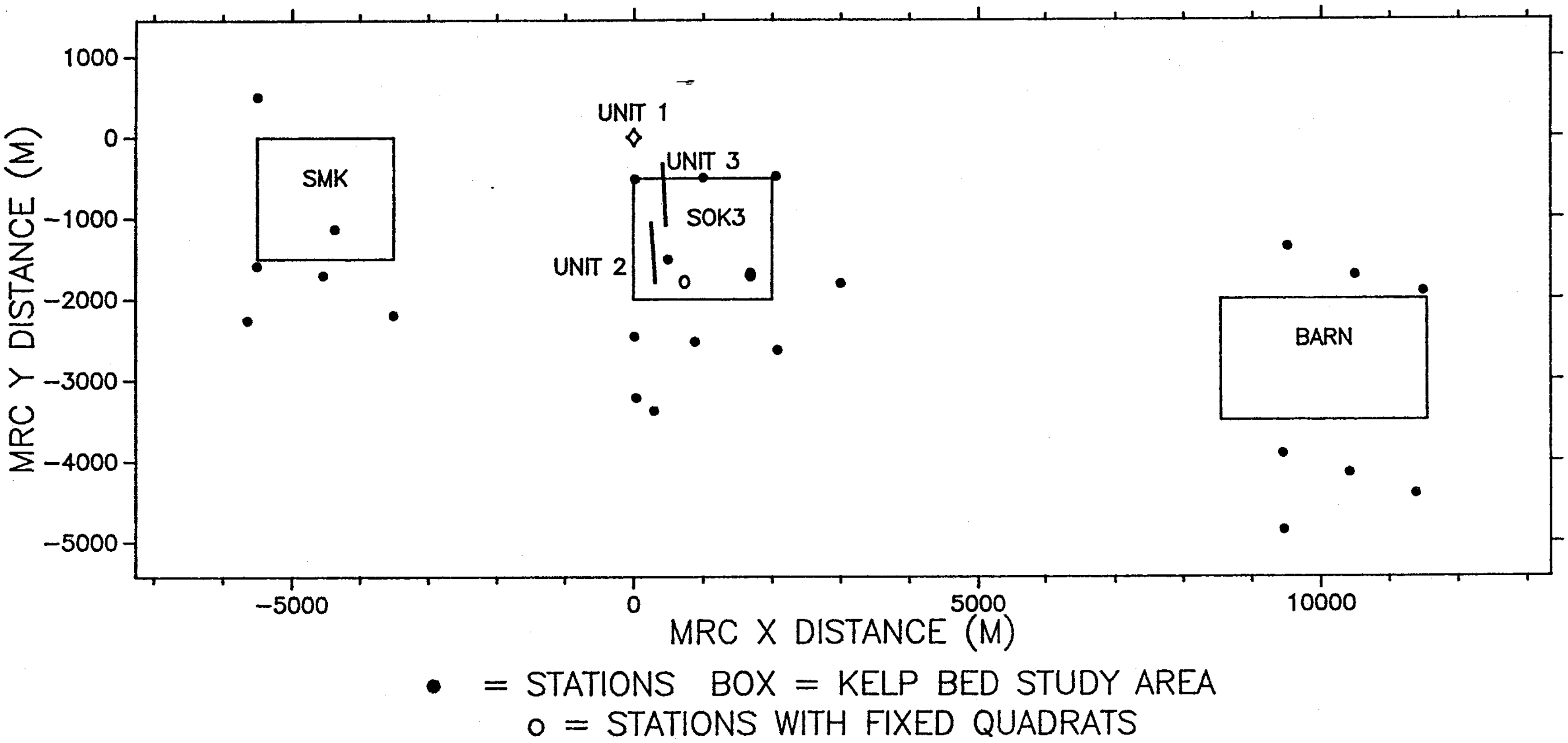
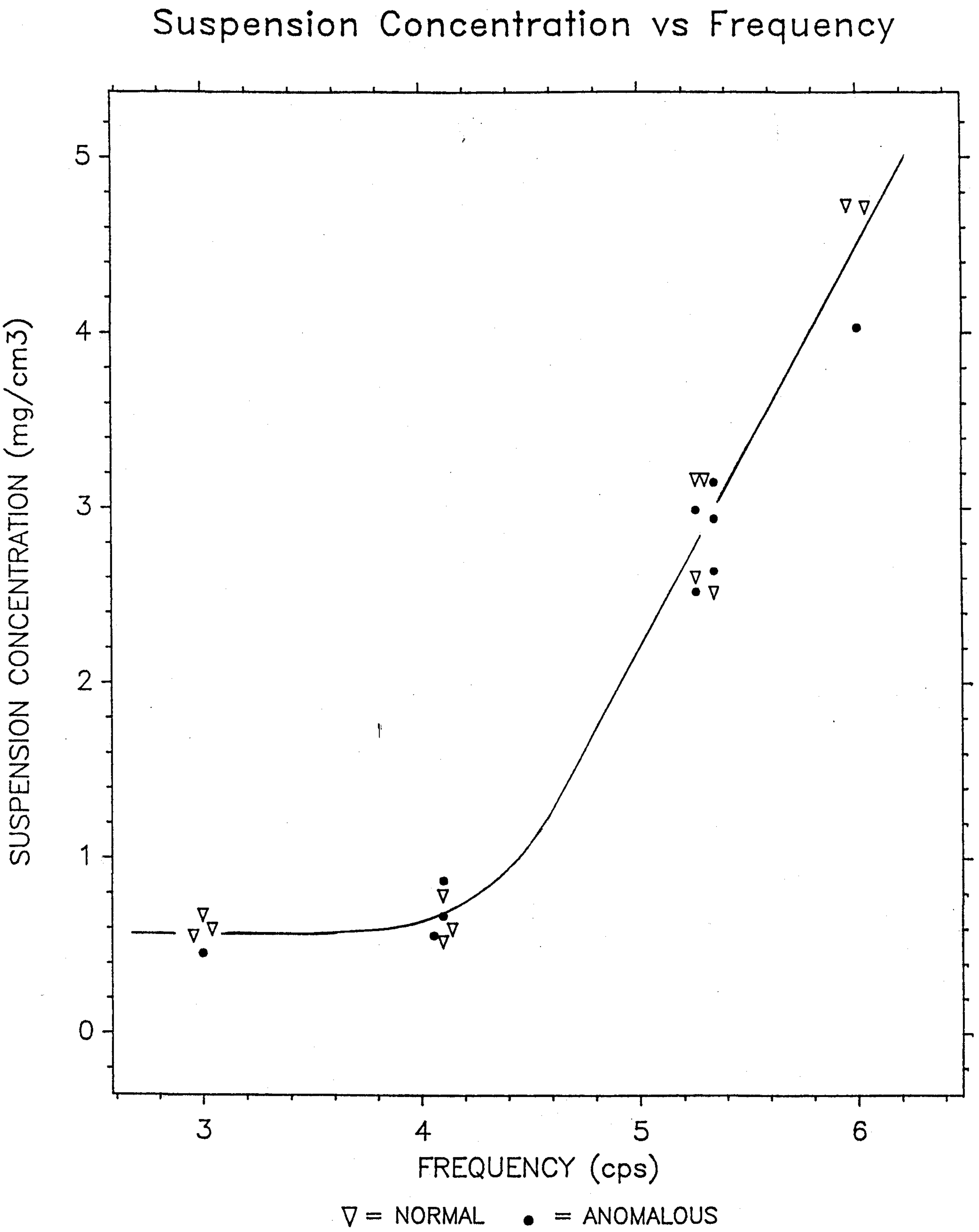


Figure 4. The relationship between the amount of sediment suspended and the frequency of ocillation (cycles per second) of the shaker.



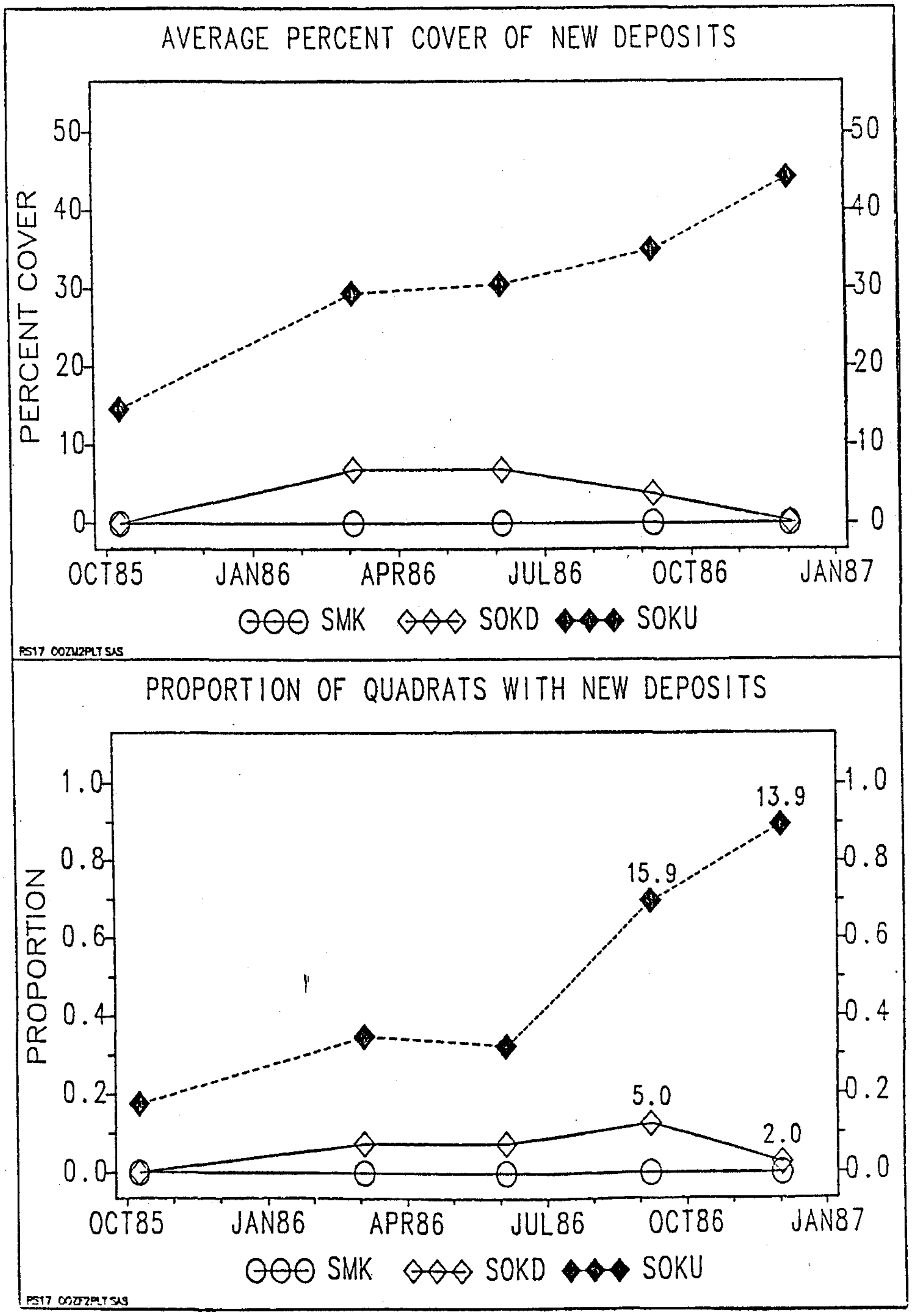


Figure 5. Percentage cover and frequency of occurence of anomalous sediments at 3 arrays of fixed quadrats: SOKU45=F1, SOKD45=F2, and SMK45=F3.

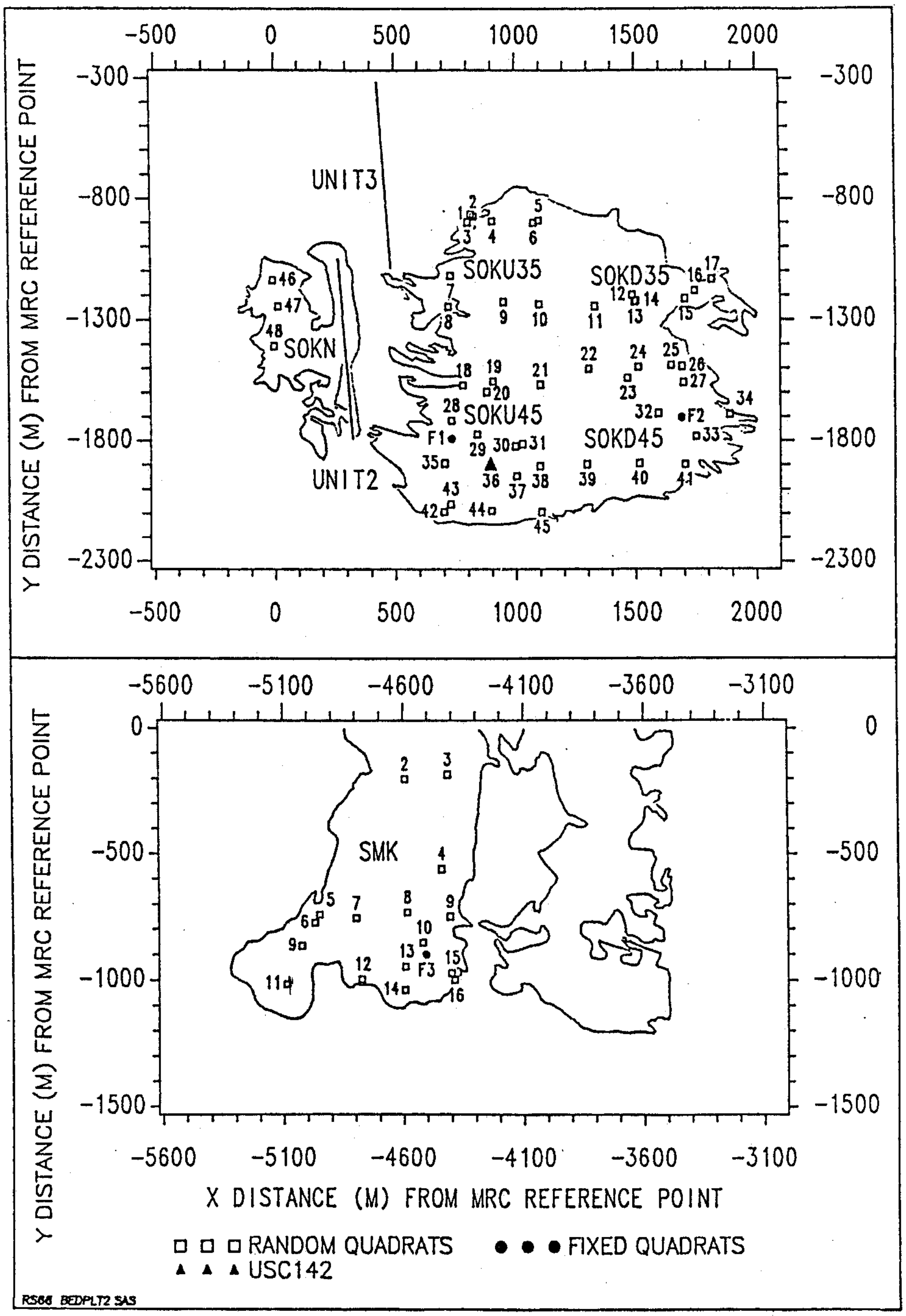


Figure 6. Map of stations with fixed and random quadrats in SOK and SMK.

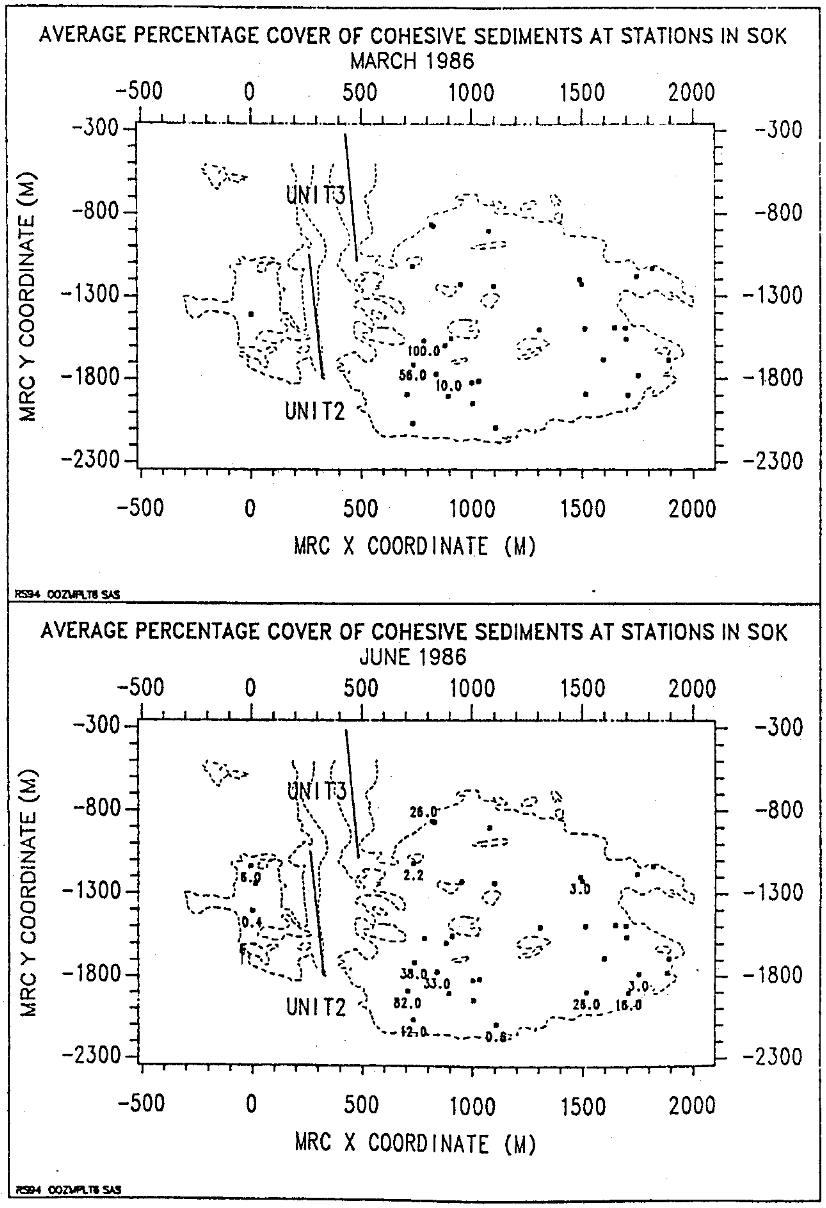
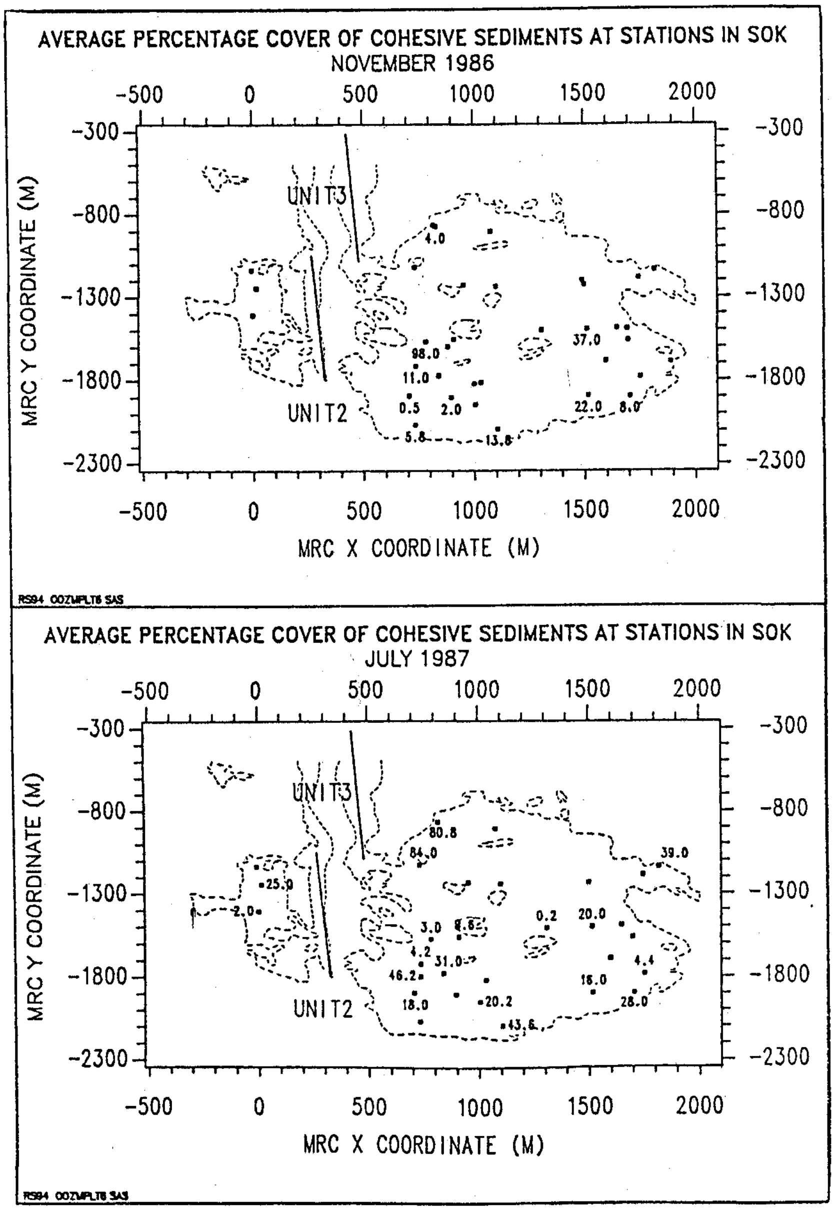


Figure 7. Average percentage cover of cohesive (anomalous) sediments in randomly placed quadrats in the San Onofre kelp forest in March and June, 1986. The percentages are indicated next to the filled square marking the stations. Coverage is zero at stations without numbers. The dashed line is the one plant per 100 m^2 isopleth for giant kelp as estimated by down-looking sonar.



AVERAGE PERCENTAGE COVER OF COHESIVE SEDIMENTS AT STATIONS IN SOK
NOVEMBER 1986

RS94 OOZMPLT8 SAS

AVERAGE PERCENTAGE COVER OF COHESIVE SEDIMENTS AT STATIONS IN SOK
JULY 1987

RS94 OOZMPLT8 SAS

Figure 8. Average percentage cover of cohesive (anomalous) sediments in randomly placed quadrats in the San Onofre kelp forest in November, 1986 and July, 1987. The percentages are indicated next to the filled squares marking the stations. Coverage is zero at stations without numbers. The dashed line is the one plant per 100 m^2 isopleth for giant kelp as estimated by down-looking sonar.

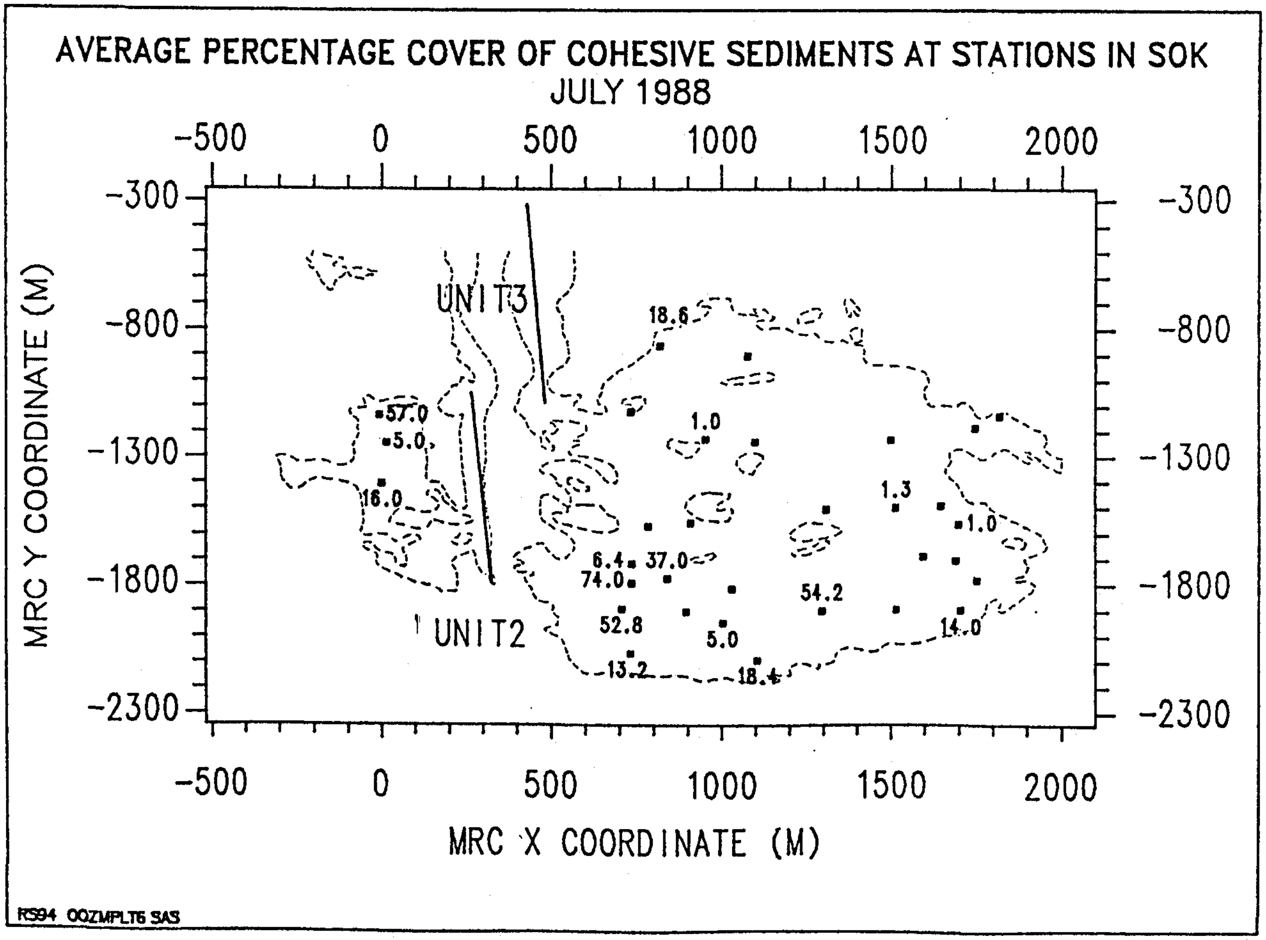
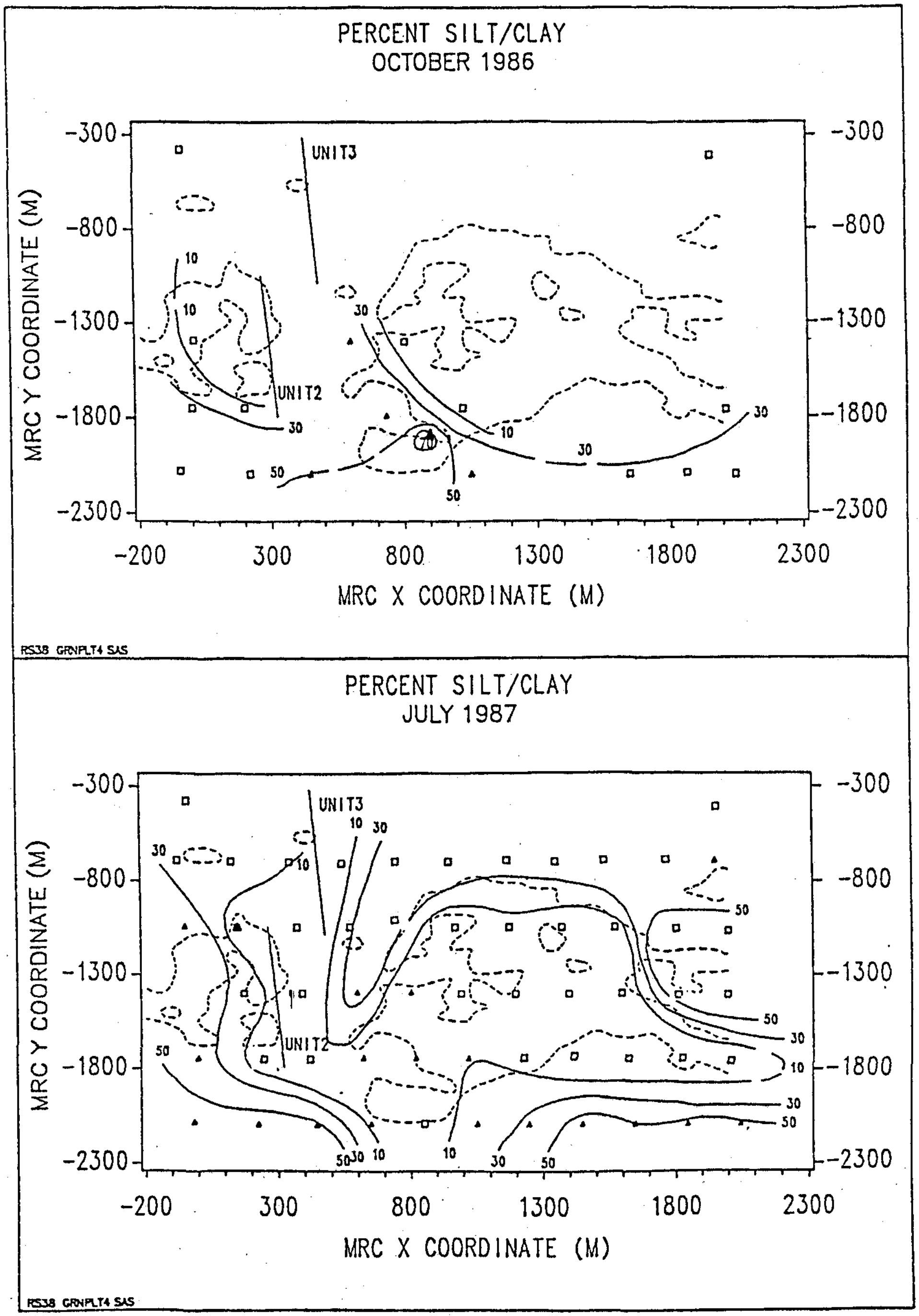


Figure 9. Average percentage cover of cohesive (anomalous) sediments in randomly placed quadrats in the San Onofre kelp forest in July, 1988. The percentages are indicated next to the filled squares marking the stations. Coverage is zero at stations without numbers. The dashed line is the one plant per 100 m^2 isopleth for giant kelp as estimated by down-looking sonar.


PERCENT SILT/CLAY
OCTOBER 1986

PERCENT SILT/CLAY
JULY 1987

Figure 10. Percentages of silt-clay (d < 0.062 mm) in sediments collected with cores in October, 1986 and July, 1987. Solid triangles indicate anomalous sediments.

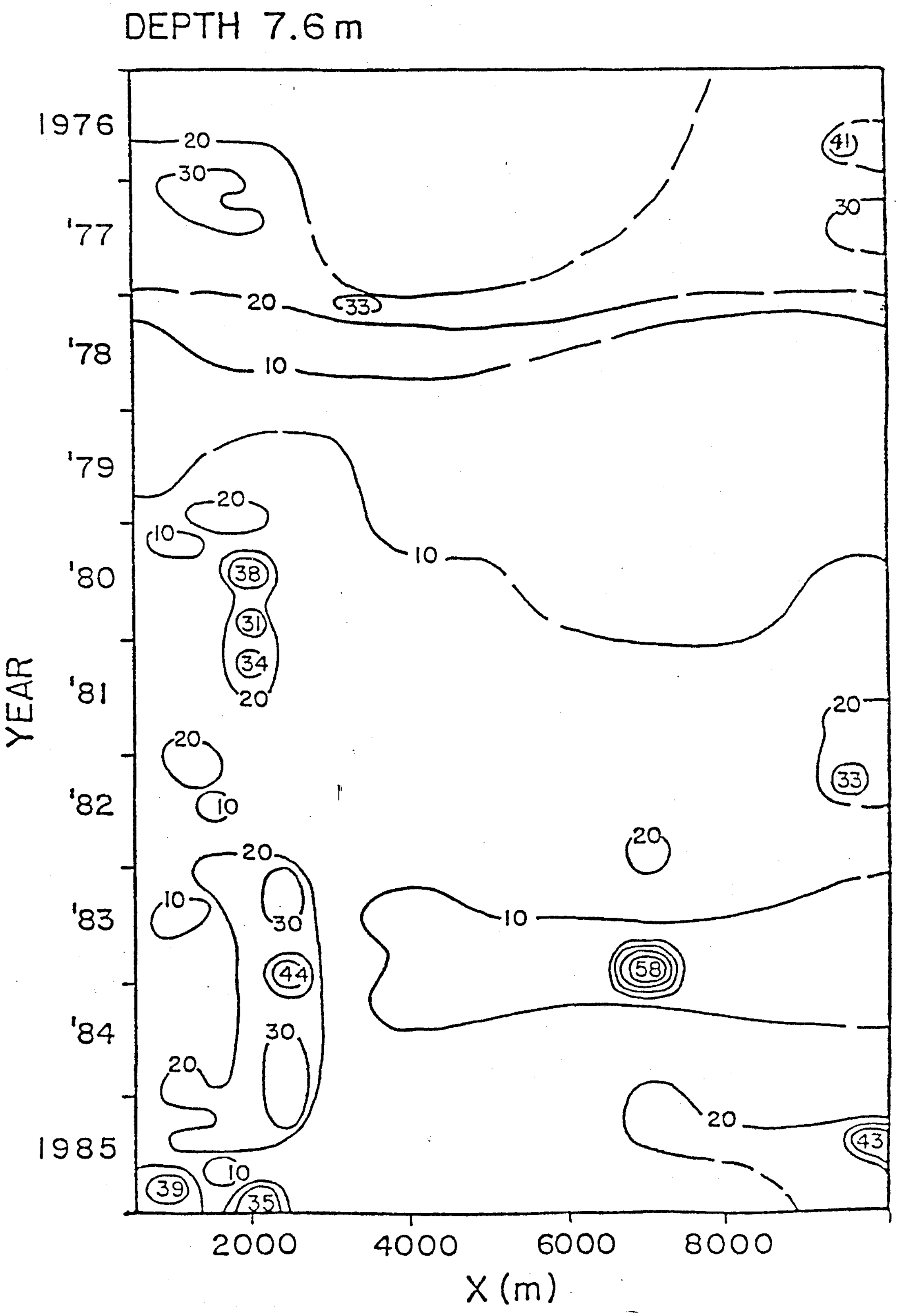


Figure 11. Percentage of silt-clay (d < 0.062 mm) at stations running downcoast from SONGS in a 7.6 m depth of water from 1976 to 1985.

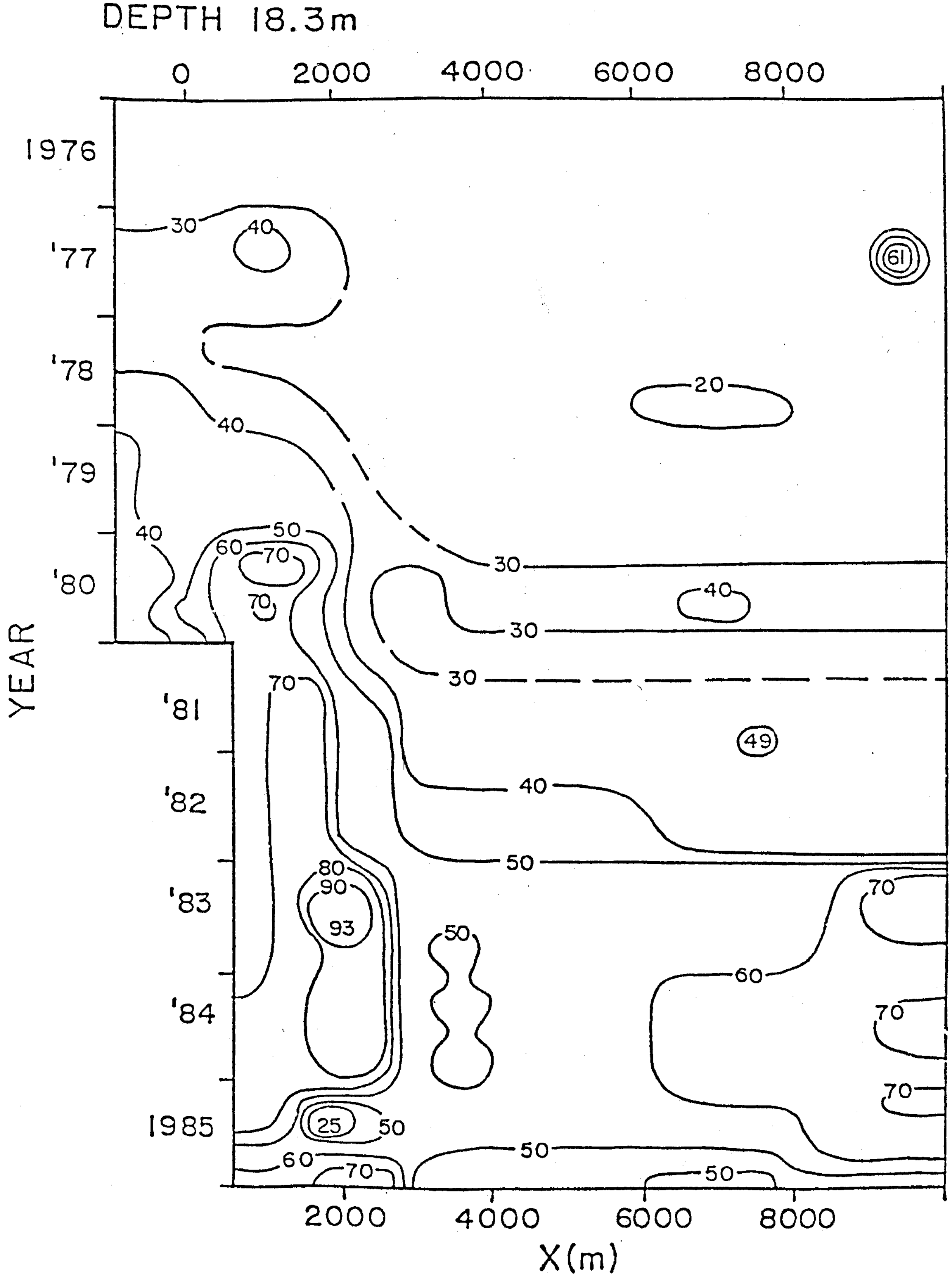


Figure 12. Percentage of silt-clay (d < 0.062 mm) at stations running downcoast from SONGS in 18.3 m depth of water from 1976 to 1985.

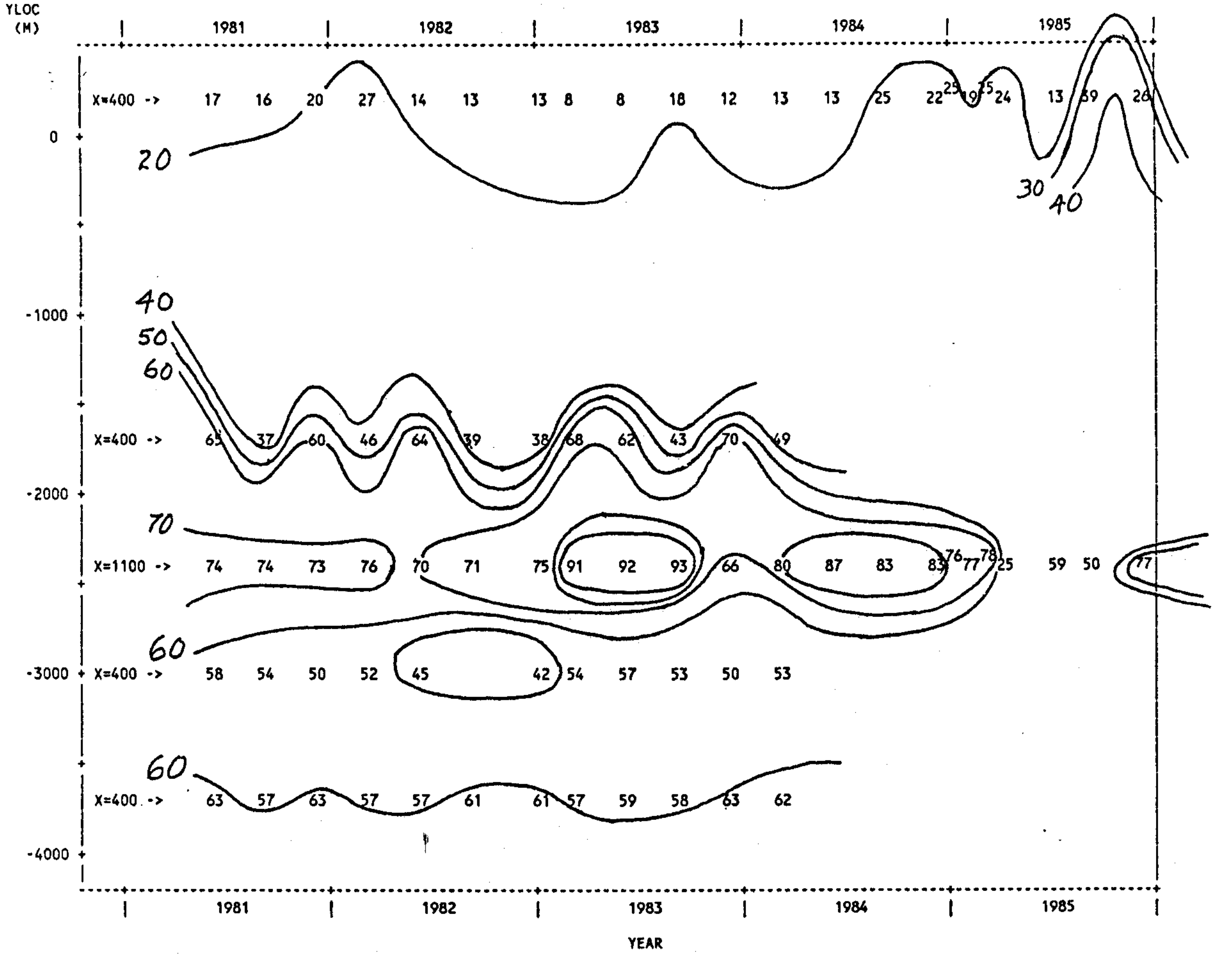


Figure 13. Variations in the percentage of silt-clay (d < 0.062 mm) at various locations near the diffusers of SONGS Units 2 and 3. X = +400, Y = -1700 is the upcoast edge of SOK. Stations at Y = -2400 are about 300 m offshore from SOK. Entries in the body of the figure are mean percentages of silt-clay.

Figure 14. Locations of stations sampled for sediments in 1981 - 1985.

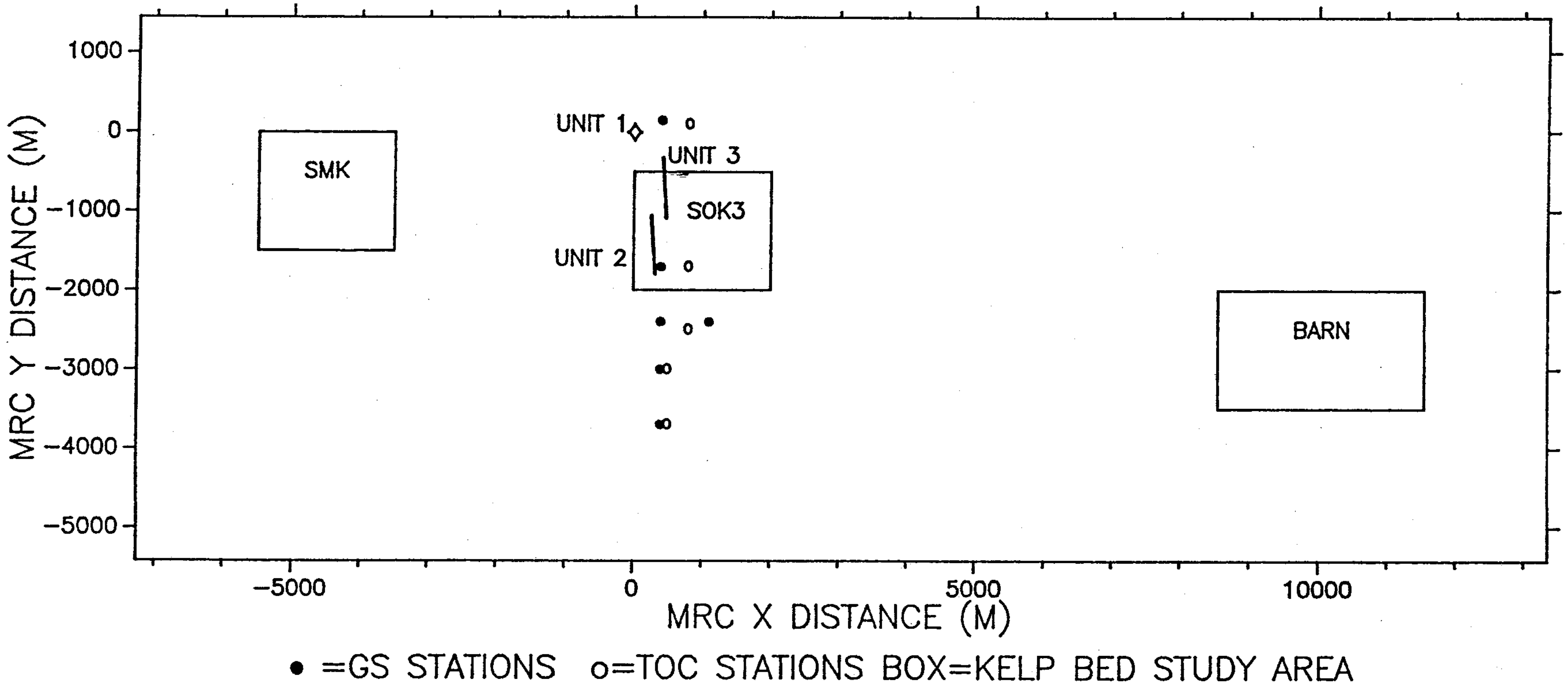


Figure 15. Weekly maximum significant wave height (m) at Oceanside, San Onofre and San Clemente from 1982 - 1988.

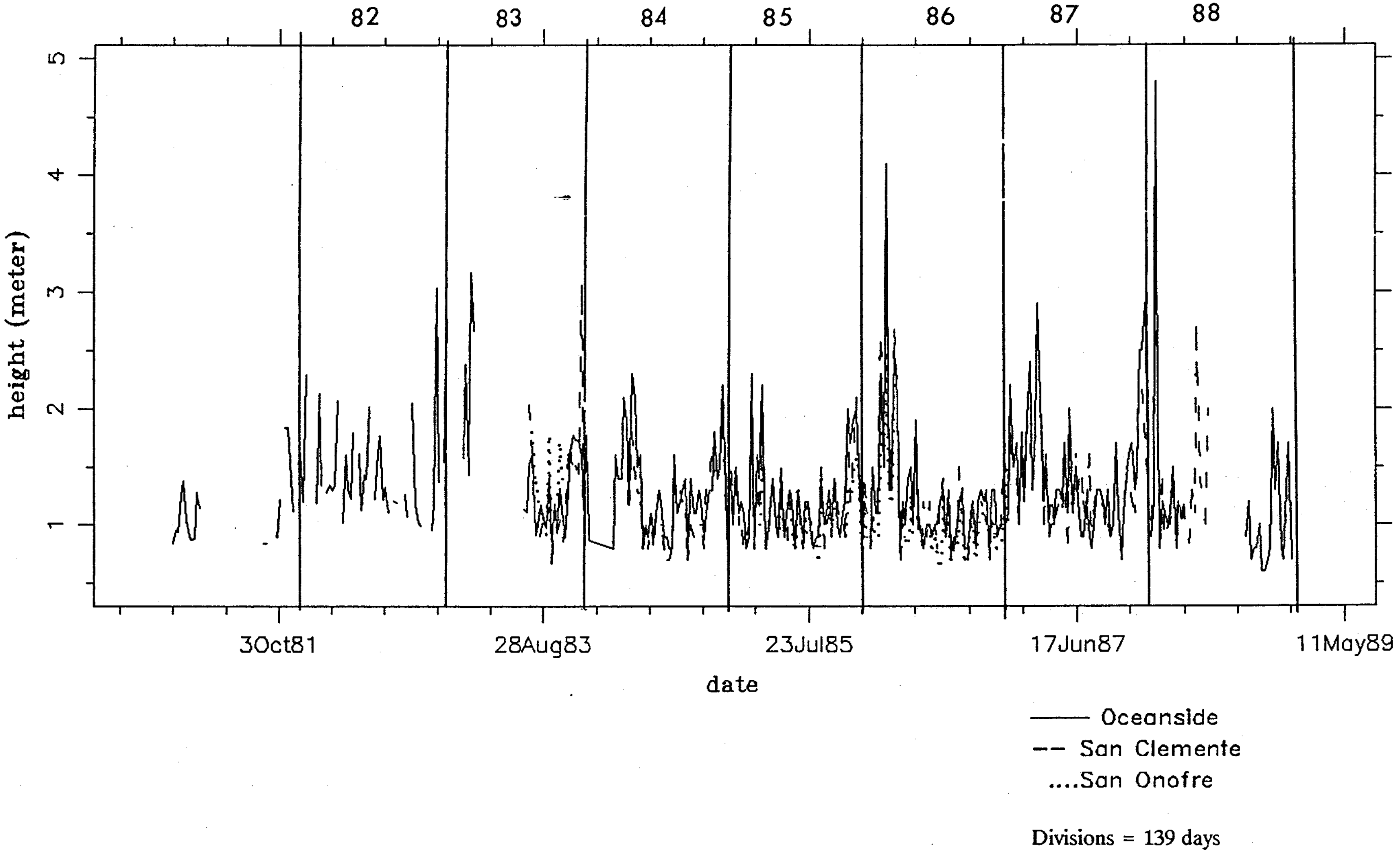
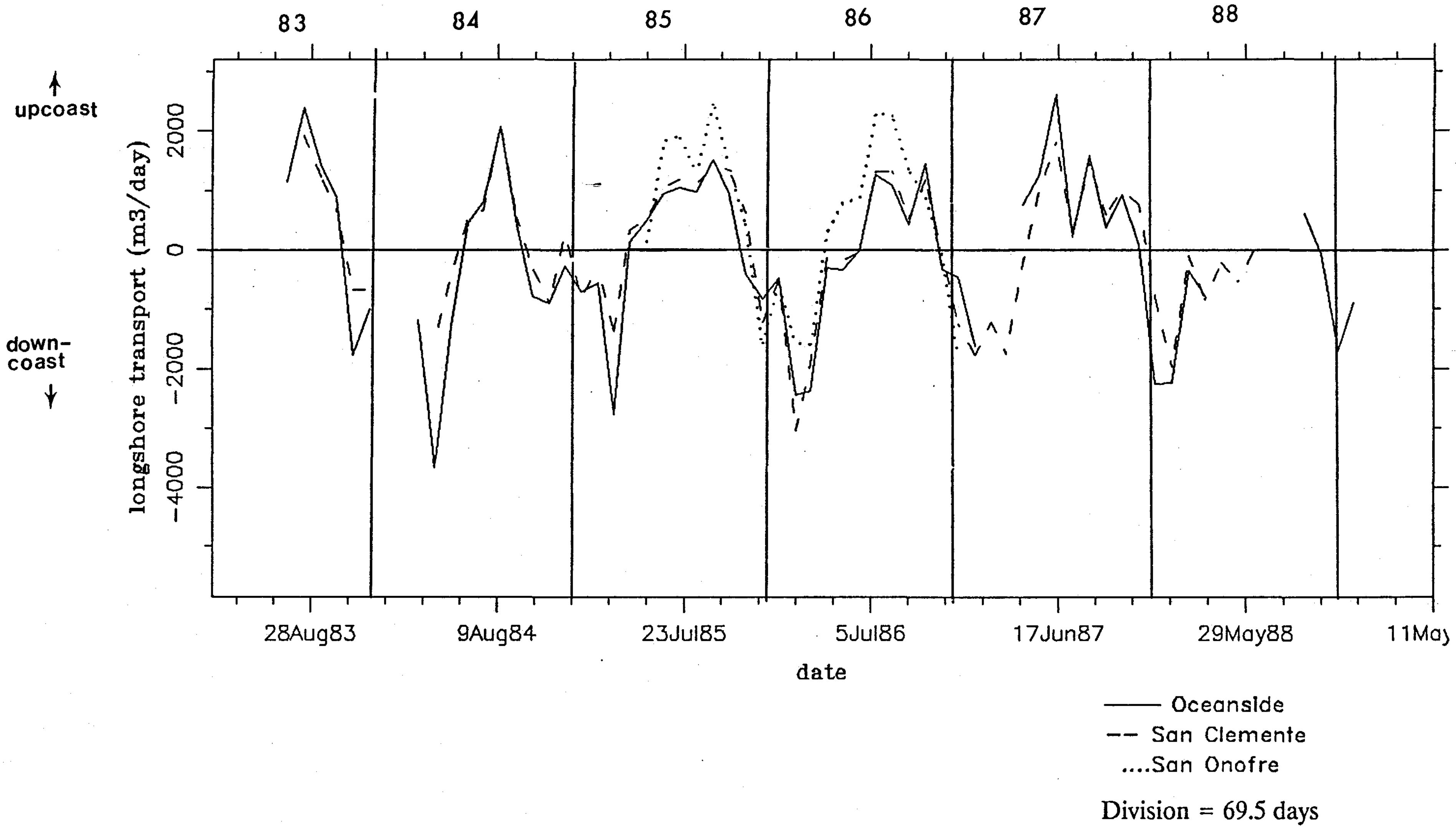


Figure 16. Daily longshore transport of beach sediments (m^3/d), 1983-89



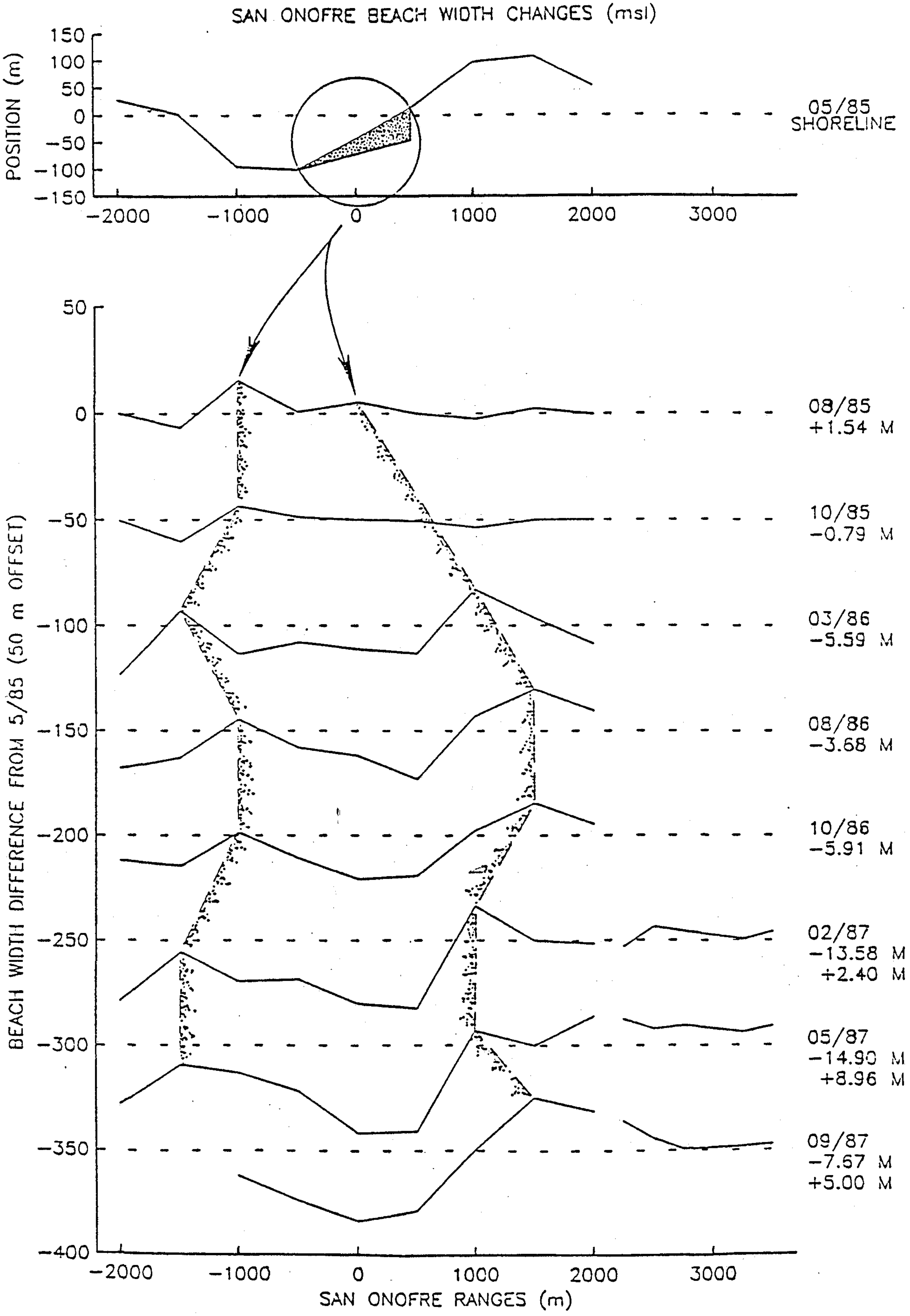
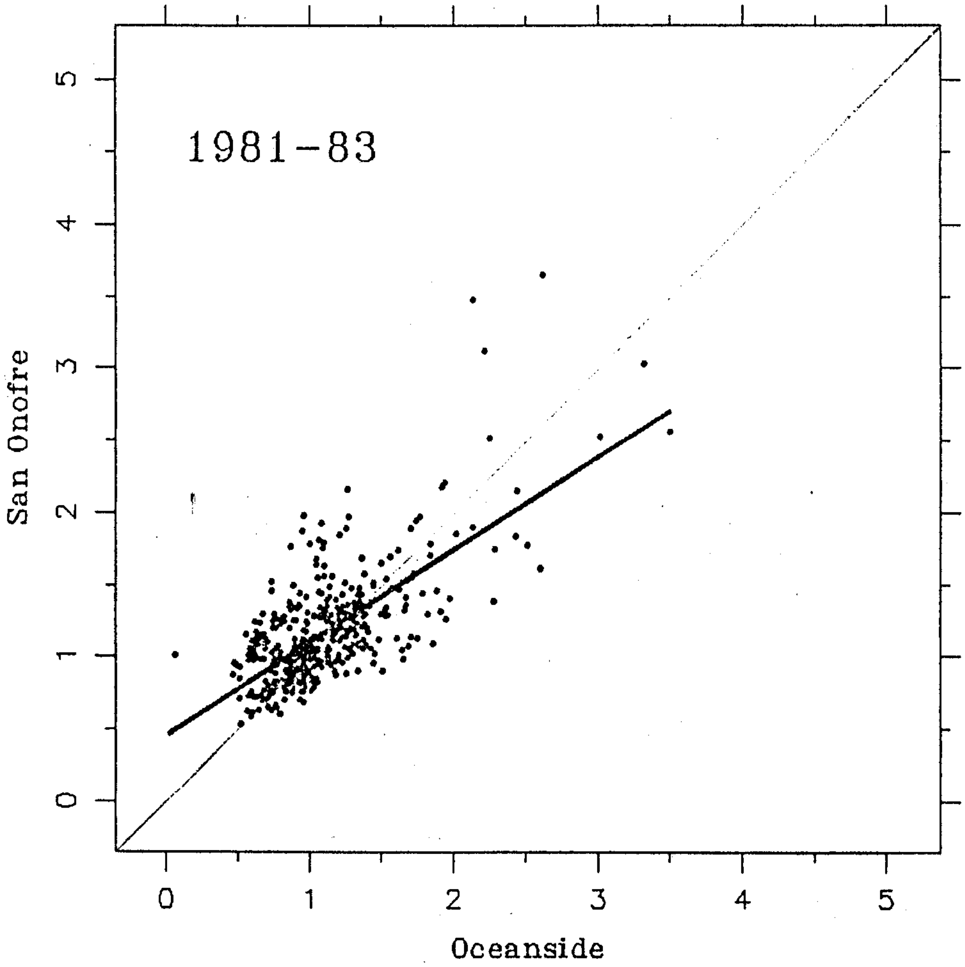


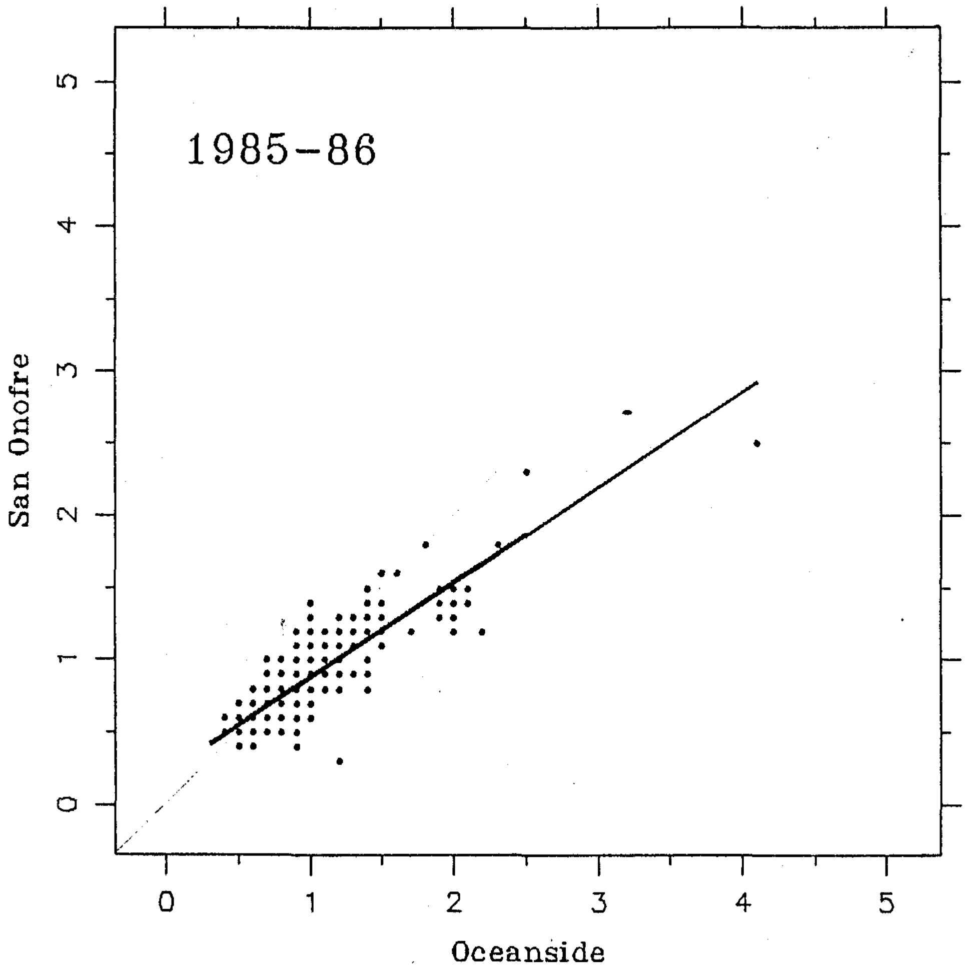
Figure 17. Beach width changes in the region of the construction laydown pad at San Onofre from May, 1985 through September, 1987 (courtesy of R. Flick).

Figure 18. Significant Wave Height (m) at San Onofre vs Oceanside, 1981-83.



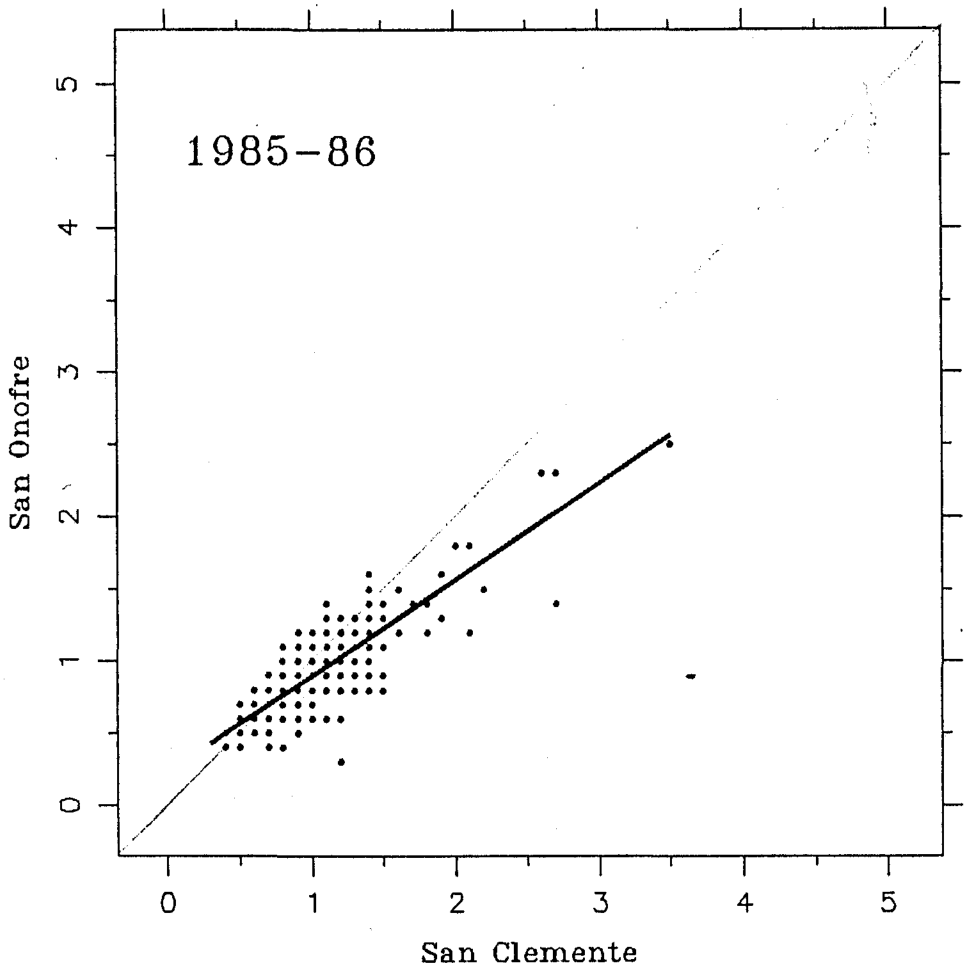
(Solid line is least squares fit)

Figure 19. Significant Wave Height (m) at San Onofre vs Oceanside, 1985-86.



(Solid line is least squares fit)

Figure 20. Significant Wave Height (m) at San Onofre vs San Clemente, 1985-86.



(Solid line is least squares fit)

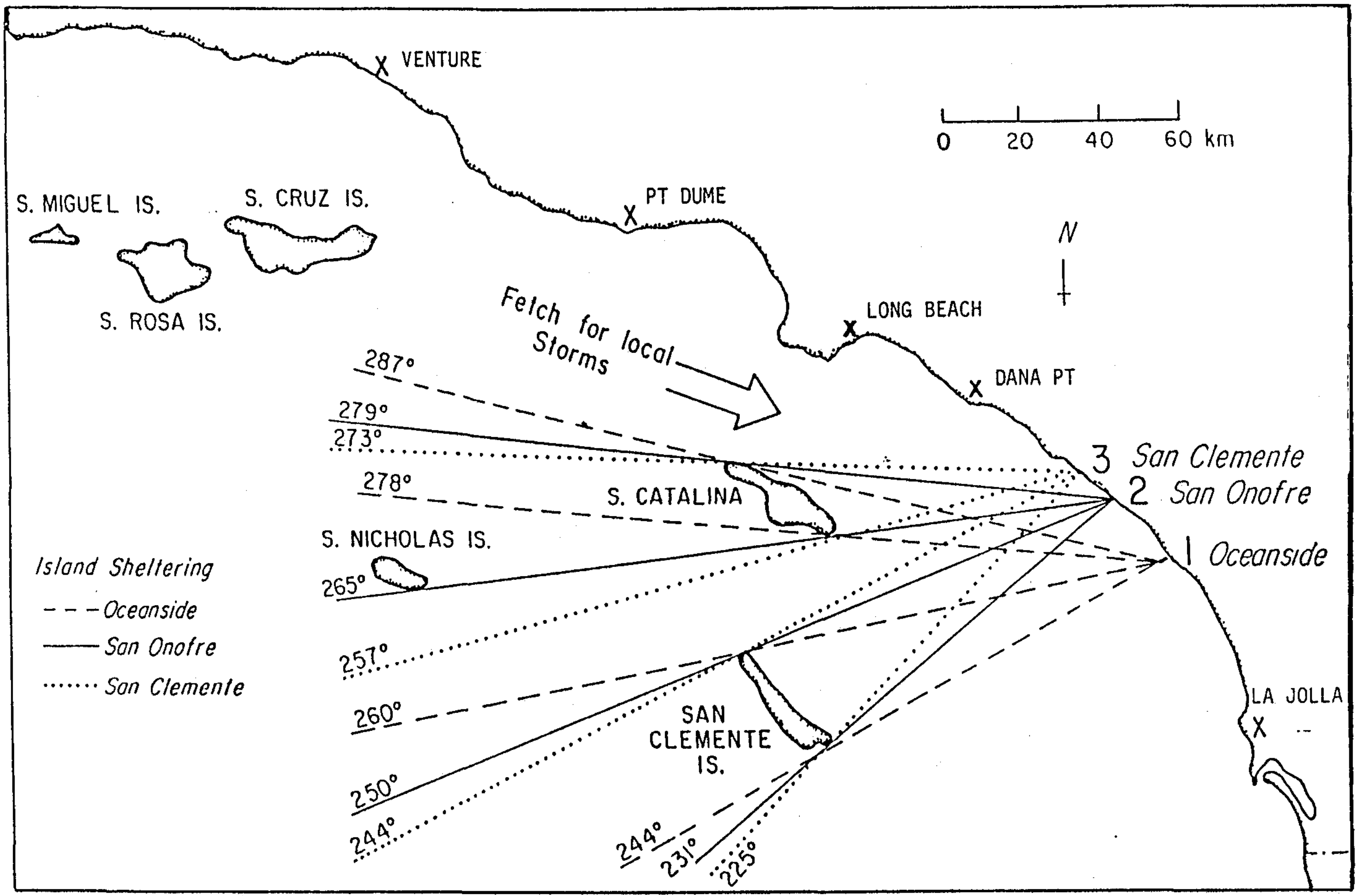


Figure 21. Sheltering from waves by offshore islands.

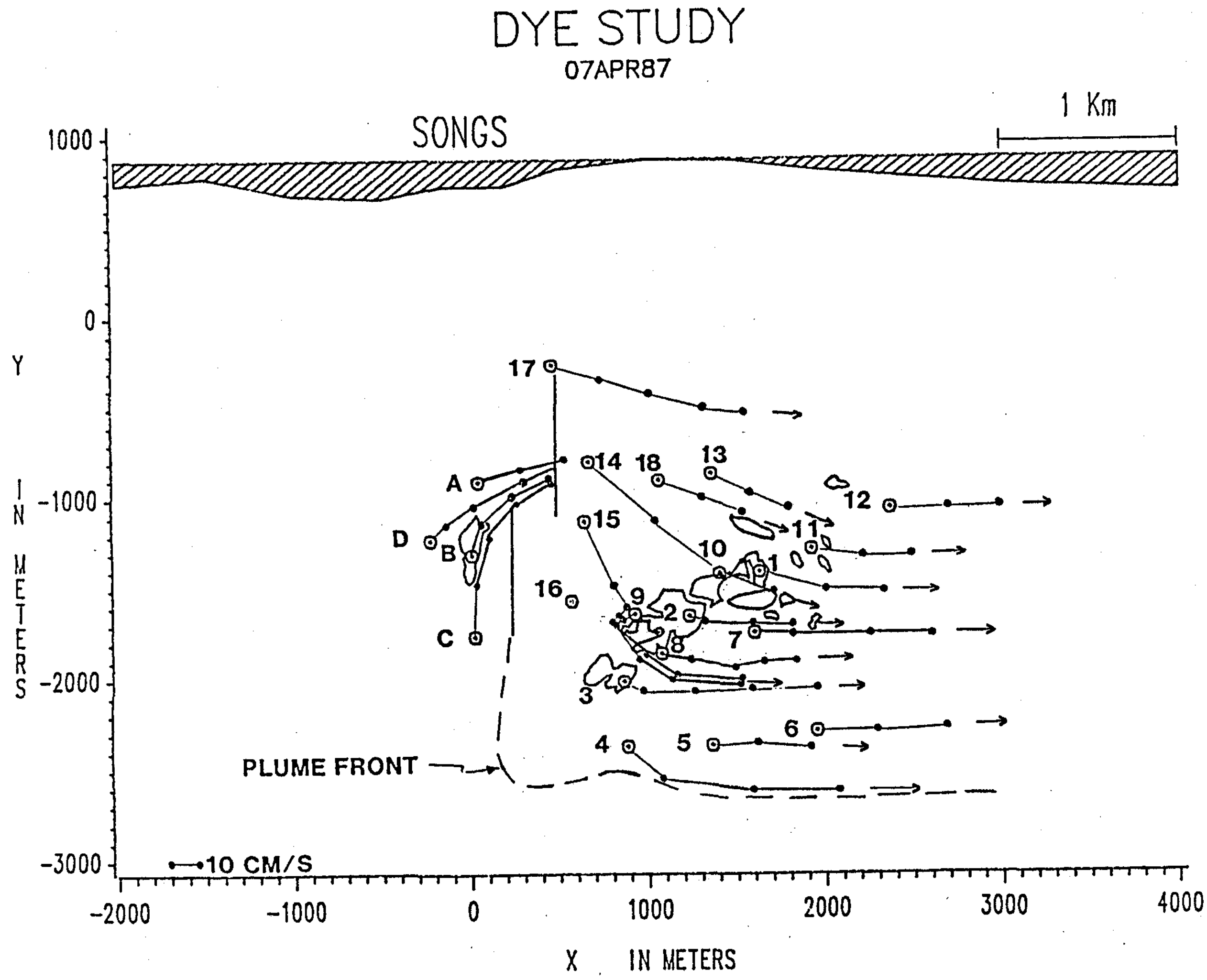


Figure 22. Starting locations and trajectories for 22 dye patches on April 7, 1987. Solid circles represent half hour intervals. Starting positions are indicated with solid dots in their centers.

Note: Patch 16 did not move appreciably from its release point.

APPENDIX A: METHODS

Field Collections of Sediment Samples

Samples of soft sediments were collected by divers in the field in October, 1985, on three surveys during 1986 (May, October, and December), on two surveys during 1987 (July/August and November), in July, 1988, and during one survey in spring, 1989. Samples collected before 1987 were primarily of anomalous sediments found overlaying cobble substrates in SOK, and non-cohesive soft sediments collected outside of the bed for comparison. The sampling effort was increased dramatically on surveys in 1987. Figure 2 shows the location of samples from 1987 collected randomly at about 55 sites located on a grid covering a 200 hectare area which included most of the cobble substrates of the kelp beds north (SOKN) and south (SOK) of the Unit 2 and 3 diffusers. The grid also covered soft substrates surrounding the two kelp bads. In addition to the sites shown in Figure 2, samples were collected at 3 sites along the 30 meter isobath. One was offshore of the end of the Unit 2 and 3 diffusers, one was 2000 meters upcoast, and the other was 2000 meters downcoast. Four additional samples were taken 2000 meters upcoast of the diffusers at 18, 15, 12, and 9 meter depths. In 1989, samples were collected from the San Onofre, San Mateo, and Barn Kelp Forests. At each area one station was placed on the 30-m isobath and three stations, spaced about 1 km apart along the coast, at both the 10-m and 20-m isobaths (Figure 3).

The 1985 sample was simply scooped into plastic bags. In subsequent surveys prior to 1989, the divers collected approximately 50 grams of sediment using cylindrical coring devices 10 cm long by 5 cm in diameter. The samples were kept cooled in ice chests in the field and transferred the same day to the laboratory where they were refrigerated or frozen. The frozen samples were thawed at a later date, and analyses sere done in the laboratory to determine grain size distributions and the percentage of total organic carbon (TOC).

In 1989, three 4-inch diameter, ABS plastic cores of sediment were collected at each station. The cores were brought to the surface where they were immediately placed in shallow basins filled with water. The lid of the core was removed and water was removed until it was about 1 cm deep over the surface of the core.

In Situ Field Identification

Two types of biological surveys were conducted during the period of interest: repeated sampling of fixed quadrats at four stations and sampling of random quadrats at about 35 stations (references). In the first type of survey, the substrate under 15 uniform points in each 1-m^2 quadrat was measured. Unconsolidated sediments were all called "sand" until the appearance in fall, 1985 of the anomalous sediments when the latter category was added. In the second type of survey, the percent cover of "boulder" ($d > 30$ cm), "cobble" ($d <= 30$ cm) and "sand" was visually estimated in 1-m^2 quadrats. In 1986, "anomalous sediment" was added as a category.

Initially, we hoped that four salient characteristics of the anomalous sediments would prove diagnostic:

1. Gelatinous consistency and easy penetrability;
2. Cohesiveness. When pressed the anomalous sediment took and held a hand print, and when squeezed held its shape;
3. Small grain size. When rubbed between the fingers the sediment felt more like mud than sand;
4. Brown diatom layer. The surface of the sediments had a brown film that appeared to be made up of diatoms. During a period of good

date, and analyses sere done in the laboratory to determine grain size distributions and the percentage of total organic carbon (TOC).

In 1989, three 4-inch diameter, ABS plastic cores of sediment were collected at each station. The cores were brought to the surface where they were immediately placed in shallow basins filled with water. The lid of the core was removed and water was removed until it was about 1 cm deep over the surface of the core.

In Situ **Field Identification**

Two types of biological surveys were conducted during the period of interest: repeated sampling of fixed quadrats at four stations and sampling of random quadrats at about 35 stations (references). In the first type of survey, the substrate under 15 uniform points in each 1-m^2 quadrat was measured. Unconsolidated sediments were all called "sand" until the appearance in fall, 1985 of the anomalous sediments when the latter category was added. In the second type of survey, the percent cover of "boulder" ($d > 30$ cm), "cobble" ($d <= 30$ cm) and "sand" was visually estimated in 1-m^2 quadrats. In 1986, "anomalous sediment" was added as a category.

Initially, we hoped that four salient characteristics of the anomalous sediments would prove diagnostic:

1. Gelatinous consistency and easy penetrability;
2. Cohesiveness. When pressed the anomalous sediment took and held a hand print, and when squeezed held its shape;
3. Small grain size. When rubbed between the fingers the sediment felt more like mud than sand;
4. Brown diatom layer. The surface of the sediments had a brown film that appeared to be made up of diatoms. During a period of good

> visibility we swam several meters above the bottom and searched for brown patches. Every one of the dozen or so patches we identified at a distance turned out to be the anomalous sediment when examined for bulk properties.

Unfortunately, as the anomalous sediment aged its appearance became less distinctive. As it lost water and compacted, the texture became firmer and more similar to nearby sand plains. Also, the brown surface film disappeared - possibly because the organisms causing it were seasonal. Finally, as we examined more and more shallow sites (9-18 m) in the vicinity of San Onofre, it became apparent that the anomalous sediment was at one end of a continuum of grain size, penetrability, and cohesiveness. For purposes of identification we devised the following quick field tests:

1. When squeezed, does it hold its shape?
2. When pressed, will it hold a hand print?
3. Is the consistency pudding-like? Is it easily penetrated and does it vibrate when struck?
4. When shaken into the water, does it form a cloud of turbidity rather than sink?
5. Does it feel "sticky"?

These tests evolved during the October, 1986 survey of many sites in SOK. The impression that all observers obtained when they viewed recently deposited anomalous sediments was that they were very fine, cohesive, and easily penetrated. The field tests were intended to evaluate those characteristics. Tests 1 and 2 are measures of cohesiveness, tests 2 and 3 are tests of penetrability, and tests 4 and 5 are evaluations of grain size. In practice, a diver would apply the tests and make a judgement. An unqualified "yes" to one of the first three questions would result in a sediment being considered anomalous. Tests 4 and 5 were subject to greater individual judgement, were difficult to apply consistently, and were generally ignored. The resultant field characterization often came with qualifiers. If it was clear in the field notes that the observer was uncertain or than two observers fundamentally disagreed, the sample was termed "intermediate". In 1989, essentially the same tested were performed, but they were formalized in a data sheet with three levels for each test to allow a bit finer discrimination and space for notes (Table A1). The divers recorded the results of the tests and the sample was later characterized based on those results and the notes. The same criteria for "anomalous" was use‘ as in previous years.

Penetrometer

The Pocket Penetrometer (CL-700, Soiltest, Inc) is a device which was developed to aid soil engineers in the field classification of clay soils based on penetrability. The penetrometer is simply a cylinder which contains a spring of known characteristics and a piston which pushes against the spring. Circular "feet" of various diameters attach to the end of the piston. The force exerted to push the foot a fixed distance (1/4 ") into the sediment is read off a graduated scale on the cylinder. The piston is .25-inch in diameter and the penetrometer is sold with a additional 1-inch diameter foot. We also fabricated 0.5-inch and 1.5-inch feet. For the range of materials we were examining, the 0.5-inch foot proved most useful.

In the field, the samples were left in the plastic core and kept awash in water. Three penetrometer readings were taken along one side of the sample.

Vane-Shear

Shear strength was tested in the field using a modified Torvane (CL-600A, Soiltest Inc). The Torvane is essentially a torque-wrench to which is attached a disk with multiple protruding thin vanes. The vanes are pressed into the sediment being tested and torque is applied until the material fails and the vanes rotate. The device is sold with three disks of different diameters and different vane-areas all of which are calibrated to the same standard. The Torvane is designed for use in clay soils and, as received, was much too insensitive for use with submarine sands and silts. We modified the torvane by replacing the internal spring with one which required 58% less torque to compress and by fabricating a disk with vanes with 2.7 times greater surface area than the largest vanes supplied.

In the field, three readings were generally taken from each core. Care was taken not to test areas of the core that had already been disturbed by the Torvane or Penetrometer.

"Shaker" Analysis

The shaker apparatus (Tsai and Lick, 1986) moves a perforated plunger up and down in the water above a sediment surface at frequencies of a few cycles per second, subjecting the interface to oscillations of pressure and velocity whose amplitudes increase with frequency. A measurement consists of running the shaker for ten minutes at a known fixed frequency, and then withdrawing a water sample from the water above the sediment. The seston concentration is later determined in the laboratory

In the field, the sediment is collected in plexiglass cores 11.7 cm in diameter and about 25 cm long. A sediment core approximately 10 cm long is collected and brought to the surface. The rest of the core is kept filled with water. Aboard the boat, the core is secured, the perforated plunger of the shaker is introduced, and the sample is tested.

Grain Size and Chemistry

Grain size distributions were determined by a combination of wet and dry sieving for particles with diameters greater than .062 mm, and pipette analyses for particles of smaller diameter (procedural details are in Eco-M, 1988a). Throughout this report we use the phi notation in referring to particle sizes, where phi=-log2 (diameter in mm). This convention is used because grain size parameters of a sample are determined by first separating it into whole or half phi units, and then weighing each fraction. The fraction of the sample with grain sizes greater than .062 mm in diameter is separated into phi categories by sieving through metal screens of standard mesh sizes. The fraction of the sample that is finer than 4 phi is separated from the coarser fraction by repeatedly washing that fraction caught by the .062-mm mesh screen and collecting the wash water. This fine fraction is further subdivided by pipette analysis. The analysis entails suspending the sediment in deionized water with a deflocculant, and withdrawing aliquots with a pipette from predetermined depths and times after the sediment has been suspended. Knowing the temperature of the water and settling rates as a function of particle size, this procedure allows one to subdivide the sample into 1 phi intervals (Eco-M, 1988a). Parameters such as the mean, median, standard deviation, skewness and, kurtosis are then determined by direct calculations or graphically using phi size categories weighted by the actual weights of the different fractions (Inman, 1952; Folk, 1966). Table 1 shows the correspondence between phi sizes, diameters in mm, and a standardized description of sediments by size according to the Wentworth scale. In most of our analyses we have used as the variate the percentage of particles smaller than 0.062 mm. This has the advantage of being a quantity that is directly measured, rather than calculated.

Prior to 1989, total organic carbon was estimated using a coulometric analyzer. The sediments were first dried and powdered. The percentage of inorganic carbon was estimated by dissolving replicate fractions of the sample in HCl and noting weight loss. The percentage of total carbon was estimated by dissolving other replicate fractions of the original sample in acid and titrating against a standard of known concentration in the coulometric analyzer. The analyzer compares the sample to the standard by noting current differences between the two (A. Margenheim, pers. communication). Organic carbon is estimated by subtracting estimates of inorganic carbon from those of total carbon. The absolute error for this method is 0.1% (Eco-M , 1988).

The 1989 samples were analyzed for inorganic carbon, total carbon, and organic carbon and nitrogen at the Scripps Institution of Oceanography. The following analytical methods were employed (J. Gieskes, personal communication).

Samples were dried at 1050 C for 24 hours, powdered in a carborundum ball mill, and stored in glass vials in a desiccator. Inorganic carbon was measured in a Coulometrics Carbon Analyzer, in which CO2 released by acid treatment was introduced in a titration vessel and subsequently titrated by coulometry. Accuracy is estimated to be + 0.03% at the low levels of 1% in the samples. Total carbon and nitrogen were measured gas chromatographically in a Perkin and Elmer 2400 CHN analyzer. Carbon and nitrogen are generated by combustion and analyzed in the form of CO_2 and N_2 gas. At low values of organic carbon, the accuracy of the method is at best 0.02% for Total Carbon and 0.005% in total nitrogen.

Mineralogical Analyses

Several groups of samples collected from near the diffusers and from the sand pad were subjected to x-ray diffraction analysis to determine the proportions of various clay minerals. The samples were treated to eliminate salt and organics. This was followed by sieving and pipette separation to select the fraction of the sample less than .002 mm in diameter (phi 9). This fraction was thinly spread on a glass slide, and subjected to x-ray analyses that enable one to determine characteristic distances between lattice planes of the crystalline structures. The analysis allows one to estimate the proportion of the different mineral types in the sample. For our analyses, we estimated the proportions of five kinds of clay minerals, and used these proportions to group samples. The five kinds of clay minerals were: chlorite, kaolinite, illite, smectite, and mixed layer clays. For our purposes, the main significance of the different clay mineral fractions is that they allow us to look for similarities among the different samples.

Spatial and Temporal Distributions

Spatial and temporal distributions of the cohesive deposits were estimated in the field using five different survey methods:

1) Samples were taken from three arrays of 40 fixed 1-m^2 quadrats used to monitor the effects of SONGS Units 2 and 3 on kelp bed invertebrates. Two of the arrays were located in the upcoast and downcoast portions of SOK at a depth of about 15 meters (SOKU45=F1 and SOKD45=F2, respectively), and at the same depth in the San Mateo kelp bed (SMK45=F3) (Figure 6). The percentage cover of the cohesive deposits was estimated by noting presence or absence beneath each of 15 points uniformly placed in each 1-m^2 quadrat. The depth of the deposit where it was deepest was also estimated to the nearest centimeter. Surveys of the fixed quadrats were made in October, 1985, and in March, June, September, and December, 1986.

2) Samples were taken in randomly positioned quadrats at many stations more or less uniformly spaced in the San Onofre kelp bed (SOK), the bed north of the diffusers (SOKN), and the San Mateo kelp bed (SMK) (Figure 6) in water depths between 10 and 18 meters. Percentage cover of cohesive deposits was estimated by eye in each of the randomly positioned quadrats at stations spread throughout SOK, SOKN, and SMK. Depths of the deposits were estimated to the nearest cm where they were most abundant in the quadrat. Surveys were conducted in March, June, and November of 1986, and July, 1987.

3) In 1987, soft sediments were sampled with cores at sites spaced more or less uniformly on a grid of stations extending 2000 meters upcoast and downcoast of the

midline of the diffusers of Units 2 and 3, and bounded by the 10- and 30-meter isobaths (Figure 2). Divers took a random core (10 cm long x 5 cm diameter) at the temporary buoy marking the station, and a second core if finer materials were encountered on a 20-meter swim downcoast. When the core was taken, the diver noted whether or not the sediments were cohesive. The divers also estimated the percent cover of the cohesive deposits in 1986 by noting whether it was present or absent under 100 uniformly spaced points. The samples were analyzed in the laboratory to determine grain size distributions and TOC as described above. In each of the diver-surveys, the divers distinguished the anomalous sediments from fine sands by bulk properties as described above.

Table A1. Field data sheet for diver observations of sediments.

DATE: STATION: DIVER:

VIS: SEDIMENT MOVEMENT: DEPTH (FT):

CORE TYPE: CORE NUMBERS:

CORE TYPE: CORE NUMBERS:

DIVER'S NARRATIVE DESCRIPTION OF SUBSTRATE:

FIELD TEST OF BULK PROPERTIES:

A. Does the sediment hold a hand print:

___ Distinct & Deep
___ Distinct, but shallow & sides erode
___ NO

B. When squeezed does sediment hold its shape:

___ Forms tight ball that doesn't erode
___ Forms ball that slowly crumble
___ NO

C. When shaken does sediment form turbidity cloud:

___ Persistent cloud
___ Sinking cloud
___ NO

D. When substrate is struck, does adjacent area vibrate:

___ Yes, over 10 cm away
___ Yes, but less than 10 cm away
___ NO

E. When rubbed between the fingers the sediment feels:

___ Talc-like
___ Gritty
___ Very Coarse

APPENDIX B: EFFECTS ON THE BIOTA

B1. Effects of Cohesive Sediments on Kelp Forest Invertebrates

Effects of the cohesive sediments on kelp forest invertebrates were determined by conducting a BACIP (Stewart-Oaten, 1986) analysis on data from the array of 40 fixed 1-m^2 quadrats at SOKU45 (=F1). Impacted quadrats were defined as those in which any of the cohesive sediment was found on or after October, 1985. Unimpacted quadrats were those in which cohesive sediments were never found. Samples taken prior to October, 1985 were classified as "Before" the impact; all others were classified as "After" the impact. Data from the final survey (conducted in December, 1986) were not used for the analysis, since cohesive sediments were present on more than 90% of the quadrats. For the purposes of this analysis, species were grouped into six large taxa: sessile invertebrates, all snails, muricid snails which lay their eggs in egg capsules attached to the bottom, sea stars, sea urchins, and brown algae. The individual species assigned to each taxon are listed in Table B1. The data were subjected to the usual statistical screens of the BACIP analysis: tests for lack of additivity, trends in the "Before" period, and serial correlations (Stewart-Oaten, 1986).

The cohesive sediments could have deleterious effects on invertebrates and algae in at least three ways. The most obvious, and least subject to debate, is by simply burying the hard substrate. In this case sessile organisms are killed and recolonization is prevented. Second, the average abundance of benthic organisms might be reduced by increased seston flux and siltation. This could decrease the feeding efficiency of suspension feeders and reduce the photosynthetic capability in benthic algae. The frequent dusting of hard substrates with up to a centimeter or so of fine sediments could also act to reduce the recruitment success of both invertebrates and algae. Finally, the increase of soft sediments might result in the emigration of motile invertebrates that are adapted to life on hard substrates.

There was a decline in abundances in all taxonomic groups in areas where cohesive sediments were present at SOKU45=F1 (Table 9). BACIP analyses indicate statistically significant declines for sessile invertebrates, sea stars, sea urchins, and brown algae. The mechanisms underlying the relative reductions in density at the impact site are not known. However, increased siltation is a likely mechanism.

B2. Effects of Cohesive Fine Sediments on Sessile Invertebrates and Algae on Boulders;

Sampling studies were conducted in August, 1986 and July, 1987 to determine how the percentage cover of algae and encrusting invertebrates varied with distance downcoast of Unit 2 and 3 diffusers. On each survey, boulders of approximately the same size (60 cm in longest diameter) were sampled along transects in SOK that extended perpendicular to the diffusers. The transects were at two depths (13.5 m and 14.5 m). Each began about 450 meters from the Unit 2 diffuser and extended 1200 m downcoast. Three boulders were randomly selected and sampled every 100 m along each transect. On each boulder, the percentage cover of algae and sessile invertebrates was estimated by eye. The percentage cover of cohesive sediments and the number of white sea urchins were estimated in a 1-m^2 quadrat placed next to each boulder. The average percentage cover of algae and sessile invertebrates were plotted against distance from the diffuser for each transect on each of the two survey dates. The plots were examined for patterns of percentage cover relative to the diffuser lines.

The results of surveys of boulders along transects perpendicular to the Unit 2 diffuser also suggest an adverse effect of the cohesive deposits. On the offshore transect where cohesive sediments were more abundant near the diffuser than far away, the percent cover of algae and sessile invertebrates increased with distance downcoast from the diffusers on surveys in the fall of 1986 and 1987 (Figure B1). The trends of percentage cover along the offshore transect suggest an effect of the cohesive sediments. This evidence is weakened by the fact that high percentage covers of sessile invertebrates, algae, and cohesive sediments occurred about 1400 m from the diffusers in October, 1987. There was no such trend with distance along a transect 200 meters inshore where cohesive sediments were less abundant (Figure B1). The changes in the percentage cover of sessile invertebrates and algae on the offshore transect are what one would expect were SONGS increasing sedimentation, but are not as compelling as the evidence from the BACIP analyses.

Table B-1. Results of BACIP analysis on effects of cohesive sediments on large kelp forest invertebrates. The analysis tests for the difference between impacted and non-impacted sites "Before" and "After" the appearance of anomalous sediments in October 1985. All data were log transformed before the analysis. Nb=number of "Before" samples, Na=number of "After" samples.

Taxon	P-value	% Change	Nb	Na
Sessile Invertebrates	0.002	-32.6	15	4
All Snails	0.326	-12.6	7	4
Muricid Snails	0.193	-20.1	7	4
Sea Stars	0.018	-55.7	15	4
Sea Urchins	0.018	-36.0	15	4
Brown Algae	0.0004	-79.3	15	4
% Cover Red Algae	0.037	-65.0	2	4

Sessile Invertebrates

Tethya aurantia, *Muricea californica*, *Muricea fruticosa*, *Styela montereyensis*.

All Snails

Haliotis spp., *Norrisia norrisi*, *Astraea* spp., *Tegula* spp., *Calliostoma* spp., *Crassispira semiinflata*, *Kelletia kelletii*, *Latiaxis oldroydi*, *Bursa californica*, *Terebra danai*, *Fusinus* spp., *Maxwellia gemma*, *Murexiella santarosana*, *Ocenebra* spp., *Pteropurpura* spp., *Roperia poulsoni*, *Trivia* spp., *Cypraea spadicea*, *Conus californicus*, *Ophiodermella inermis*, *Nassarius* spp., *Mitra idae*, *Olivella* spp., *Hesperato vittelina*, *Simnia vidleri*.

Muricid Snails

Maxwellia gemma, *Murexiella santarosana*, *Ocenebra* spp., *Pteropurpura* spp., *Roperia poulsoni*.

Sea Stars

Astrometis sertulifera, *Dermasterias imbricata*, *Henricia leviuscula*, *Linckia columbiae*, *Orthasterias koehleri*, *Patiria miniata*, *Pisaster* spp.

Sea Urchins

Strongylocentrotus purpuratus, *Strongylocentrotus franciscanus*, *Centrostephanus coronatus*, *Lytechinus anamesus*.

Brown Algae

Macrocystis pyrifera, *Cystoseira osmundacea*, *Pterygophora californica*, *Laminaria farlowii*, *Sargassum muticum*.

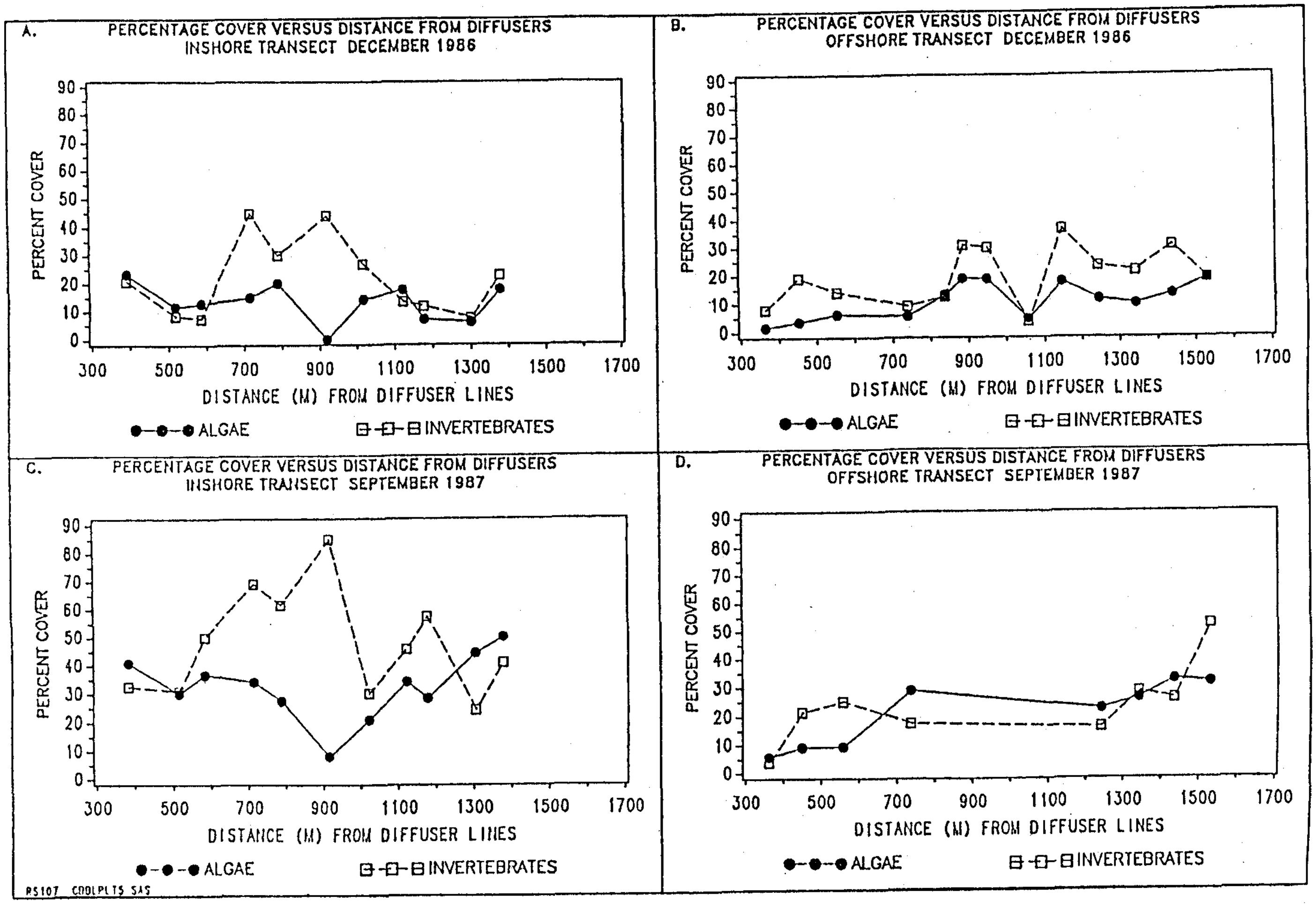


Figure B1. Percentage cover of sessile invertebrates and algae on tops of boulders as a function of distance (m) from the diffusers of SONGS Units 2 and 3. Estimates were made in December, 1986 and September, 1987 along two parallel transects spaced about 200 m apart in the cross-shelf direction.