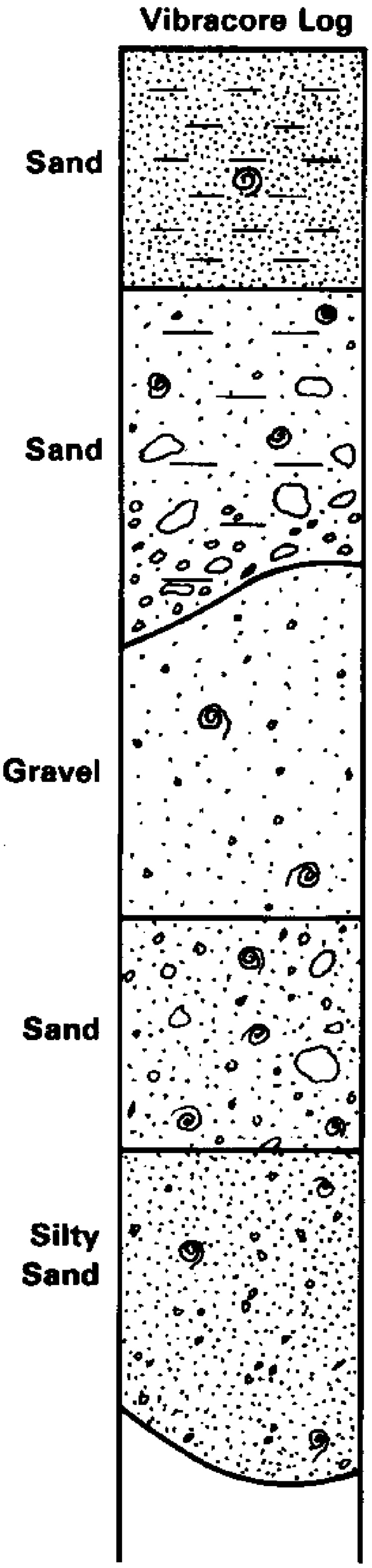
STATE OF CALIFORNIA — THE RESOURCES AGENCY
DEPARTMENT OF BOATING AND WATERWAYS



Report of Potential Offshore SAND and GRAVEL RESOURCES of the INNER CONTINENTAL SHELF of SOUTHERN CALIFORNIA

STATE OF CALIFORNIA — THE RESOURCES AGENCY
DEPARTMENT OF BOATING AND WATERWAYS
George Deukmejian, *Governor*
Gordon K. Van Vleck *Secretary for Resources*

Report of
POTENTIAL OFFSHORE SAND and GRAVEL RESOURCES of the INNER CONTINENTAL SHELF of SOUTHERN CALIFORNIA

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June 1983

STATE OF CALIFORNIA—RESOURCES AGENCY
GEORGE DEUKMEJIAN, *Governor*

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To the Reader:

The Department of Boating and Waterways, as part of a continuing program for protection of the California shoreline from erosion, supports studies and investigations which provide necessary information for beach nourishment and shoreline processes. Particular priority is given to investigations which will lead directly toward solutions to shoreline problems now facing California.

The Department contracted with the University of Southern California, Department of Geological Sciences, to inventory potential sand and gravel sources located within offshore coastal areas from Point Dume, Los Angeles County, to the International Boundary with Mexico. This investigation locates and delineates deep sediment areas with a combination of seismic reflection profiles and extensive vibracore data to define stratigraphic horizons, mechanical and textural properties of the material. These proposed future ocean borrow sites will provide abundant sources of sand to replace upland sites that are vanishing because of changing land use.

These data will provide coastal engineers, planners and marine geologists with detailed information on offshore sand and gravel sources as well as enhance their knowledge and understanding of the quantity and quality of sands available for beach nourishment along the Southern California coastline.

William H. Ivers
WILLIAM H. IVERS
Director

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INTRODUCTION

Rationale

Southern California continues to grow in population and economic strength. Projections for the next decade suggest these trends will continue. Careful planning is required to preserve the region's natural beauty and to systematically develop natural resources whose sources, in many cases, already are being greatly strained.

Sand and gravel are primary resources used in many phases of construction as well as in the maintenance of southern California's invaluable beaches and harbors. Although California has led the nation in the production of sand and gravel since 1942, deposits of saleable-grade material available under present political and economic conditions are rapidly becoming depleted. The sand and gravel needs of the construction, road-building, facilities-maintenance, and specialty sand industries and agencies can be met by: (1) changing zoning regulations to permit known deposits to be exploited and/or exploring for new sand and gravel deposits, taking commensurate care to evaluate the geological, socio-economic, environmental and legal aspects of exploitation. The first alternative can be undertaken only if such deposits can be developed without imposing substantial socio-economic problems or environmental hazards to adjacent property owners. Additional considerations would be whether areas mined could be rehabilitated in an environmentally acceptable manner, and whether adequate relatively low-cost reserves would be available for long-term local needs.

Since many land-based sand and gravel deposits are lost to competing land users and mining of these deposits is generally opposed by urban communities, the feasibility of mining offshore sand and gravel deposits deserves attention. Furthermore, many of the potential sand and gravel sources are located partly or wholly within offshore coastal areas.

Potential offshore sand and gravel resources of the inner continental shelf can help to alleviate transportation costs as well as provide large-scale supplies. For example, barges could transport large supplies at relatively low cost to distribution points along the entire southern California coast. Of particular importance to this report is the fact that geologists and engineers agree that offshore sand supplies are the only practical long-term source for the nourishment and restoration of beaches and harbors experiencing erosion. One can envision the ideal situation involving the recycling of sand from offshore sinks back to the respective depleted beach.

Economic considerations concerning offshore sand and gravel mining in southern California are presented in Spindt and Mead (1976), Mokhtari-Saghafi and Osborne (1980a, 1980b), and Evans and others (1982).

Project History and Purpose

The U.S. Army Corps of Engineers working through its Coastal Engineering Research Center in cooperation with the Los Angeles District, SPD, conducted a sediment and shallow structural survey of the inner continental shelf of the southern California borderland during June and July 1974. The principal objectives of the 1974 survey were to determine the character and map the extent of sand deposits on the shelf that are suitable for beach restoration and nourishment. The 1974 survey made it possible to identify a number of potential borrow areas on the Oxnard, Santa Monica and San Pedro shelves as reported in a draft copy of *Preliminary "Quick Look" Report on Offshore Sand Resources in Southern California* prepared by the Coastal Engineering Research

Center.

The present sand and gravel inventory was initiated by the Sedimentary Petrology Laboratory at the University of Southern California during October 1978, and should be viewed as a cooperative effort among the following institutions and agencies: California Department of Boating and Waterways (formerly Department of Navigation and Ocean Development); California State Lands Commission; U.S. Army Corps of Engineers, Coastal Engineering Research Center; U.S. Department of Commerce, NOAA Office of Sea Grant; University of Southern California, Sea Grant Institutional Program; and California State University at Northridge.

The present study area extends along the inner continental shelf from Point Dume at the northwestern extreme of Santa Monica Bay to the international border with Mexico (Fig. 1). This area will be discussed in terms of eight major divisions, which are from north to south: I. Santa Monica Bay, Los Angeles County; II. San Pedro Bay, Los Angeles and Orange Counties; III. the Dana Point area, Orange County; IV. the Oceanside area, San Diego County; V. Oceanside to La Jolla Area, San Diego County; VI. the La Jolla Area, San Diego County; VII. the Mission Beach Area, San Diego County; and VIII. San Diego Bay, San Diego County (Fig. 1). Unfortunately fluctuating funding levels and markedly escalating costs during the performance period resulted in uneven coverage in these eight divisions. For example, although related to the 1974 survey completed by the U.S. Army Corps of Engineers in Santa Monica and San Pedro Bays, this study substantially differs in the sense that it is directed toward detailed sedimentologic analyses of site-specific borrow areas in these two bays. Farther south, however, high-resolution seismic coverage and vibracore localities are more sparse, thus reducing the available information concerning site-specific borrow areas.

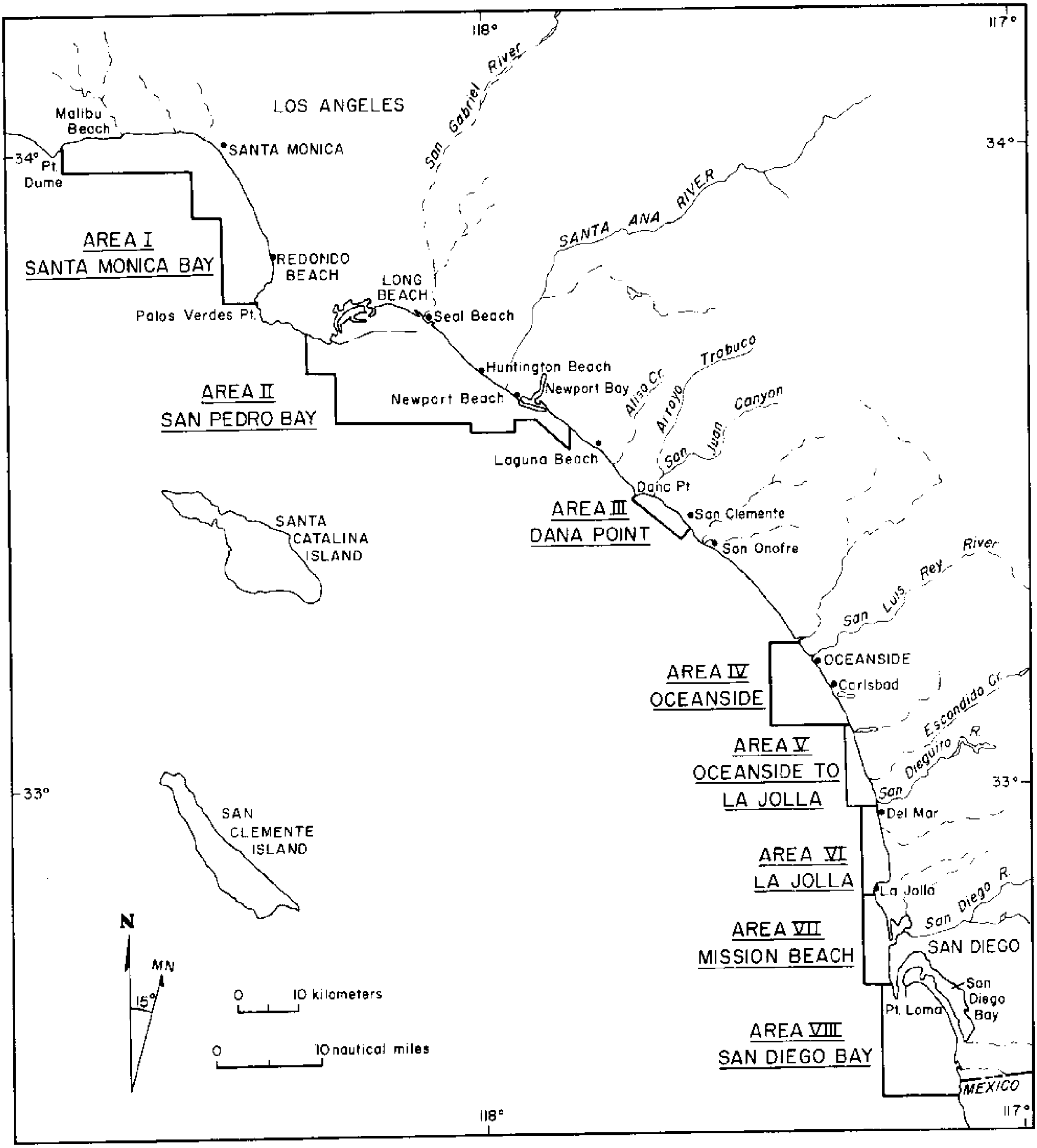


Figure 1. Index map of southern California showing locations of areas I through VIII.

The primary purpose of this report is to identify, locate and characterize site-specific borrow areas for sand and gravel, which occur on the inner continental shelf of southern California. Ancillary objectives, which are not developed in this report, are to examine the Quaternary stratigraphic and structural history of the inner shelf, to examine the sediment dispersal systems and depositional environments of Quaternary stratigraphic units, and to determine the nature of the provenances for these sedimentary strata.

Although considerable data is presented in this report, more detailed information is provided in sets of Appendices A through D, which have been reposited with the following institutions and agencies: University of Southern California, Sedimentary Petrology Laboratory and Sea Grant Institutional Program; California Department of Boating and Waterways; California State Lands Commission; and the U.S. Army Corps of Engineers, Coastal Engineering Research Center. The title and pagination for each volume is listed below, and the Table of Contents for each volume is included as an appendix in this report (Appendices A through D).

Appendix A. Vibracore Logs and Sediment Descriptions, 222 p.

Appendix B. Results of Sediment Grain size Analysis, 979 p.

Appendix C. Cumulative Frequency Curves for Sediment Samples, 1000 p.

Appendix D. Results of Petrographic Modal Analysis, 48 p.

In addition to the availability of sets of Appendices A through D, the California Department of Boating and Waterways is planning to publish a set of 27 associated maps at a scale of 1:24,000. The titles of these maps are listed in Table 1.

Table 1. Index of 1:24,000 scale maps.

1. Location of Tracklines, Area I, Santa Monica Bay, Los Angeles County, Point Dume to Marina del Rey.
2. Location of Tracklines, Area I, Santa Monica Bay, Los Angeles County, Marina del Rey to Palos Verdes Peninsula.
3. Vibracore Locations and Suitability of Recovered Sand, Area I, Santa Monica Bay, Los Angeles County, Point Dume to Marina Del Rey.
4. Vibracore Locations and Suitability of Recovered Sand, Area I, Santa Monica Bay, Los Angeles County, Marina del Rey to Palos Verdes Peninsula.
5. Isopach Map of Holocene Strata, Santa Monica Bay, Los Angeles County, Point Dume to Marina del Rey.
6. Isopach Map of Holocene Strata, Santa Monica Bay, Los Angeles County, Marina del Rey to Palos Verdes Peninsula.
7. Isopach Map of Potential Borrow Areas BIV and BV, Area I, Santa Monica Bay, Los Angeles County, Point Dume to Marina Del Rey.
8. Isopach Map of Potential Borrow Areas BI through BIV, Area I, Santa Monica Bay, Los Angeles County, Marina del Rey to Palos Verdes Peninsula.
9. Location of Tracklines, Area II, San Pedro Bay, Los Angeles and Orange Counties.
10. Vibracore Locations and Suitability of Recovered Sand, Area II, San Pedro Bay, Los Angeles and Orange Counties.
11. Isopach Map of Holocene Strata, Area II, San Pedro Bay, Los Angeles and Orange Counties.
12. Isopach Map of Potential Borrow Areas, Area II, San Pedro Bay, Los Angeles and Orange Counties.
13. Vibracore Locations and Suitability of Recovered Sand, Area III, Dana Point, Orange County.
14. Location of Tracklines, Area IV, Area V, and Area VI, San Diego County.
15. Location of Tracklines, Area IV, San Diego County.
16. Location of Tracklines, Area VII and Area VIII, San Diego County.

Table 1. Index of 1:24,000 scale maps, continued.

17. Vibracore Locations and Suitability of Recovered Sand, Area IV, San Diego County.

18. Vibracore Locations and Suitability of Recovered Sand, Area V and Area VI, San Diego County.

19. Vibracore Locations and Suitability of Recovered Sand, Area VII and Area VIII, San Diego County.

20. Isopach Map of Holocene Strata, Area IV, San Diego County.

21. Isopach Map of Holocene Strata, Area IV and Area VI, San Diego County.

22. Isopach Map of Holocene Strata, Area VII and Area VIII, San Diego County.

23. Isopach Map of Pleistocene Strata, Area VI, San Diego County.

24. Isopach Map of Pleistocene Strata, Area VII, San Diego County.

25. Isopach Map of Potential Borrow Areas, Area IV, San Diego County.

26. Isopach Map of Potential Borrow Areas, Area V and Area VI, San Diego County.

27. Isopach Map of Potential Borrow Areas, Area VII and Area VIII, San Diego County.

Delineation of Site-specific Borrow Areas

The following criteria were used to identify site-specific potential borrow areas.

1. The deposit must occur in water depths not exceeding approximately 30 m, which is the current pratical limit for commerical extraction. The landward edge of each potential borrow area is restricted by the outer limit of the breaker zone, here considered to be approximately 9 m. A number of deposits extend beyond this 9 to 30 m isobath zone, and such occurrences are identified in this report to more completely define the geologic limits of the available target material.
2. The deposit must not be covered by more than 1 m of fine-grained sediment, which would generate considerable turbidity during extraction.
3. The deposit must represent sedimentary environments capable of yeilding considerable sand- and/or gravel-size material with little fine-grained admixture. This criterion was confirmed at sites with numerous vibracore positions and satisfactory vibracore penetration and recovery. Where vibracore control is sparse or lacking, the suitability of the deposit was judged from seismic data and areal geological relationships.
4. The deposit must not be too indurated for dredging operations.

Inasmuch as the purpose of this report is to locate and characterize potential borrow areas on the inner continental shelf of southern California, associated economic, environmental and legal aspects are not considered here.

I. SANTA MONICA BAY, LOS ANGELES COUNTY

Introduction

Santa Monica Bay is located west of the Los Angeles basin, and is bounded by the Santa Monica Mountains on the north and the Palos Verdes Hills on the south (Fig. 2). Its narrow shelf is cut by the Pt. Dume, Santa Monica and Redondo submarine canyons. Initial work on the Santa Monica shelf was directed toward characterizing the texture and composition of surface sediment (Shepard and MacDonald, 1938; Emery, 1952, 1960; Terry and others, 1956). Handin (1951) studied textural and heavy mineral trends of beach and adjacent river samples, and additional heavy minerals analyses were completed by Azmon (1960), Judge (1970), Rice (1973), and Rice and others (1976). Light mineral analyses of coastal and shelf sediment samples have been completed by Gorsline and others (1968), Savula (1978), Scheidemann (1980), Crist (1980), and Osborne and others (1980).

Terry and others (1956) used fathogram records to map the micro-relief of Santa Monica shelf. Emery (1958) employed an echo sounder to construct a series of cross-profiles of the shelf, and recognized a series of submerged marine terraces. Yerkes and others (1967) were the first to use continuous reflection profiles to examine the Redondo submarine canyon and adjacent shelf stratigraphy. Vedder and others (1974), Greene and others (1975), Nardin (1976), Junger and Wagner (1977), and Nardin and Henyey (1978) have used various types of seismic-reflection data to examine the stratigraphic and structural evolution of the shelf. Nardin and others (1981) discuss a curve showing the sea-level changes in Santa Monica Bay over the past 18,000 years.

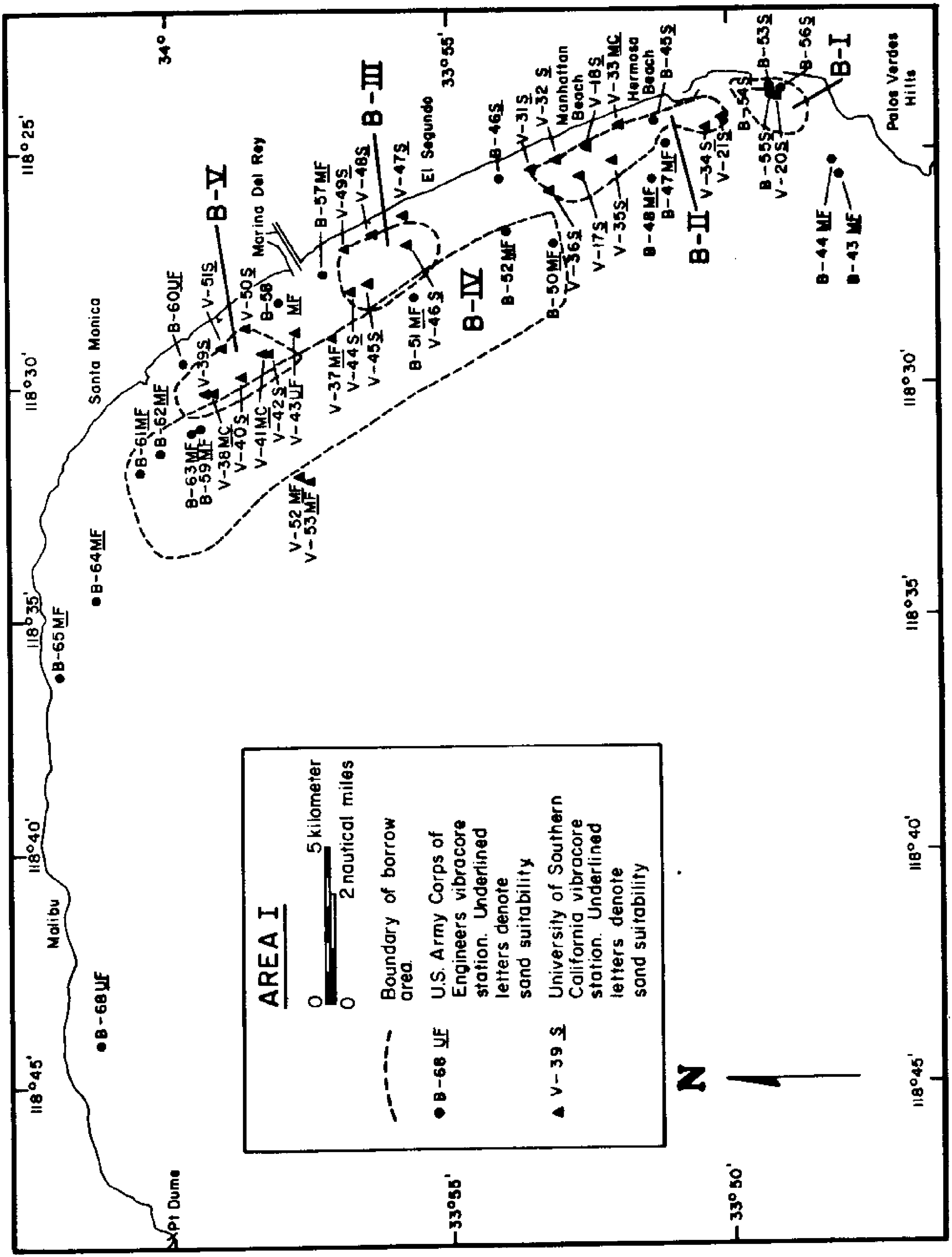


Figure 2. Map of area I showing location of borrow areas B-I through B-V with associated vibracore numbers and sand suitability symbols.

Although relevant to our study, space does not permit a discussion of the pre-Quaternary geology of the Santa Monica embayment and the western Los Angeles basin. Important and pertinent work in the Santa Monica and San Gabriel Mountains has been performed by Hoots (1931), Bailey and Jahns (1954), Birkeland (1972) and Ehlig (1975), and in the Los Angeles basin-Palos Verdes Hills by Woodring and others (1936, 1946), Woodford and others (1954), Poland and others (1959), and Yerkes and others (1965).

Methods

The present study is based on a network of high-resolution seismic-reflection profiles taken in conjunction with a series of 51 vibracores collected from the Santa Monica shelf (Fig. 2). A total of 608 km of high-resolution profiles (3.5 kHz) were used to examine the shelf stratigraphy. Approximately 230 km were obtained from the U. S. Army Corps of Engineers, and the other 378 were recorded aboard the R/V Velero IV on cruises between 1973 and 1978. A seismic trackline location map has been published in Osborne and others (1980) and Scheidemann (1980), and the California Department of Boating and Waterways plans to publish such maps at a scale of 1:24,000; therefore this illustration is not reproduced in this report. An average seismic velocity of 1700 m/sec (Fischer and others, 1977, Appendix D) was used to determine the thickness of Quaternary stratigraphic units in Santa Monica Bay. All water depths are based on a seismic velocity of 1460 m/sec. The seismic data provide a minimum visual resolution of about 1 m, and a maximum depth penetration of 60 m on parts of the records obtained from the U. S. Army Corps of Engineers.

The recognition of sedimentary strata and unconformitites, as inferred from these seismic records, is based on the examination of primary seismic reflections. These reflections are generated by velocity-density contrasts across depositional or erosional surfaces (Vail and others, 1977). Faults may be identified where stratification or other prominent horizons have been offset. Where a fault could not be identified on more than one profile, it was drawn normal to that particular line (Greene and others, 1975, p. 50).

During March and May of 1978, 27 vibracores were collected from the inner Santa Monica shelf (Fig. 2). The average length of recovered core is 3.5 m, and the maximum length is 5.7 m. Following collection, the cores were brought to the U.S.C. Sedimentary Petrology Laboratory, and each was split lengthwise, photographed, described and sampled while still wet. In addition. T. R. Nardin sampled 24 vibracores collected by the U. S. Army Corps of Engineers during 1973. A vibracore log and associated sediment description for each recovered core is included in the forementioned Appendix A.

The identification of upper Pleistocene and Holocene stratigraphic units in the vibracores is based on the calculated thickness of Holocene sediment above the seismic reflection surface, thought to be an unconformity, which presumably separates Pleistocene from Holocene strata. The boundary between upper Pleistocene and Holocene strata was placed where an abrupt lithologic change occurred within a given vibracore, within an error range of ±1 m.

Conventional grain-size analysis by sieving at half-phi intervals was performed on the sand population of 145 upper Pleistocene and 207 Holocene samples from Santa Monica Bay. Sediment parameters were calculated by the moments method. The results of these grain-size analyses are presented in the reposited sets of Appendices B and C.

Petrographic analyses were performed on grain thin sections prepared from the sand fraction of 79 samples from Santa Monica Bay. The petrographic methodology is presented in Appendix D of this report, and the resultant data are listed in the reposited sets of Appendix D.

Quaternary Stratigraphy

Upper Pleistocene Strata

Stratigraphy

The Quaternary stratigraphy, associated depositional environments, and geologic history of the Santa Monica shelf has recently been discussed by Osborne and others (1980), and much of the following discussion is taken from the paper. More detailed information is presented in Scheidemann (1980) and Crist (1980).

Deep penetration seismic-reflection profiles in Santa Monica Bay have enabled several major faults to be identified as well as the boundary between Tertiary and upper Pleistocene strata (Vedder and others, 1974; Greene and others, 1975; Nardin, 1976; Junger and Wagner, 1977; and Nardin and Henyey, 1978). In the northern part of the bay, the offshore trace of the Santa Monica fault zone is thought to approximately separate Tertiary strata to the north from upper Pleistocene strata to the south. In the central part of the bay, upper Pleistocene strata locally abut against and unconformably overlie Tertiary strata, whereas to the south, these units are separated by the Redondo Canyon fault.

The shelf sediment west of Marina del Rey and Venice is primarily composed of foreset beds which dip in a westerly direction. Junger and Wagner (1977) recognized this thick succession of cross-bedded strata, and suggested that these beds might be equivalent to the cross-stratified San Pedro Formation (Woodring and other, 1946; Poland and others, 1959) in the Los Angeles basin. Both Greene and others (1975) and Junger and Wagner (1977) suggested that these large-scale foreset beds were formed by a westwardly-prograding deltaic system during the Pleistocene. Recent work by Bandy (1972) indicates that the San Pedro Formation is less than 1 m.y. old. Nardin (1976) and Nardin and Henyey (1978) suggest that these cross-bedded strata are equivalent to the San Pedro Formation and unnamed upper Pleistocene deposits described along the adjacent coast by Poland and others (1959). The offshore extension of at least the San Pedro Formation is further suggested by the recent influx of marine water into this unit (Poland and others, 1959). Nardin and Henyey (1978) argue that these inclined foresets are undeformed, thus they represent the original depositional dip of a westerly-prograding sedimentary sequence deposited during late Pleistocene time.

Osborne and others (1980) report the presence of at least three stratigraphic units within the upper Pleistocene sedimentary package, which are locally separated by unconformities. These are referred to as stratigraphic units A, B and C in ascending order (Fig. 6). West of Santa Monica and El Segundo, unit A is characterized by foreset beds that dip from 4 to 7° to the west. Unit A has been truncated by an erosional surface which dips about 1° to the west, and is cut to a maximum depth of 46 m below present sea level (b.p.s.l.). Unit B overlies the outer edge of this erosional surface and is thin, discontinuous, and displays faint foreset beds dipping as much as 2.5° to the west. In turn, units A and B are cut by a second westward-dipping (0.25 to 0.5°) erosional surface, which is overlain by unit C. Unit C shows topset and foreset beds, and the foreset strata dip from 3 to 7° to the west and terminate near the present shelf break. Nardin (1976) reports horizontal bedding beneath the inclined strata at a depth of 200 m b.p.s.l., which defines the lower extent of the upper Pleistocene sedimentary package.

The erosional surface occurring within the upper Pleistocene package are interpreted as marine terraces associated with Illinoian and/or Wisconsin sea level fluctuations. Elsewhere in Santa Monica Bay, these erosional surfaces apparently are absent, and units A, B and C appear as a conformable stratal sequence.

Sangree and Widmier (1977) suggest that a seismic signature such as that displayed by units A, B and C is characteristic of fluvial-deltaic and associated coastal plain deposits. Although deposits equivalent to the marine Palos Verdes Sand are not recognized on the Santa Monica shelf, the presence of this unit as terrace deposits on the Palos Verdes Hills suggests a high stand of sea level in late Pleistocene time. The absence of the Palos Verdes Sand on the adjacent shelf may be due to shelf planation which occurred during and following the Wisconsin glaciation.

Lithology: As expected in sedimentary sequences of coastal sedimentary environments, the lithology of upper Pleistocene and Holocene strata varies considerably, particularly in nearshore areas. These units appear to be at least locally correlatable in terms of gross lithology, but there are many exceptions to the following generalities (Scheidemann, 1980).

Both seismic records and vibracores indicate that the Holocene cover north of Marina del Rey is less than 1 m thick, therefore vibracores recovered from this area essentially consist of upper Pleistocene strata. Here the upper Pleistocene strata are composed of light olive, poorly-sorted, silty, sandy, pebbly granule gravel (Folk, 1974). The clasts vary from subangular to subround, and predominantly are composed of felsic plutonic rock, with additional pebbles of anorthosite, gabbro, gneiss, spotted slate, siltstone, quartzite and rare siliceous metavolcanics.

More typical upper Pleistocene strata were recovered from vibracores collected southwest of Ballona Creek and in the Manhattan Beach area. These deposits consist of intercalated, very thin to massive beds of moderately well- to well-sorted, fine- to medium-grained sand, and moderate- to poorly-sorted, slightly granular to pebbly, medium-to coarse-grained sand. Where present, the subangular to subround pebbles are composed of predominantly acid plutonic rock, with occasional clasts of anorthosite, gneiss, quartzite, siltstone, slate and diatomite. Biotite often is present in the finer-grained intervals as are laminae of magnetite and ilmenite. These strata vary in color from light gray and light olive gray, to pale olive, to light olive gray, and are locally oxidized to light brown or dark yellowish orange. Small marine shells fragments locally occur, and were recovered in vibracores V-32, V-45 and V-46.

The upper Pleistocene samples have a mean grain size of 0.41 mm (1.29 ϕ), and are moderately sorted (phi standard deviation = 0.92). These samples vary in skewness from strongly coarse-skewed (phi skewness = -4.06) to strongly fine-skewed (phi skewness = 1.27), whereas kurtosis values range from very leptokurtic (phi kurtosis = 1.55) to extremely leptokurtic (phi kurtosis = 34.78). In general, the sand population for these samples is coarse-skewed and extremely leptokurtic (terminology after Folk, 1974).

Compositionally, the upper Pleistocene and Holocene samples are quite similar (Table 2), and principally are classified as lithic arkose and to a lesser extent, feldspathic litharenite (McBride, 1963). Weathered and fresh feldspar grains occur in all samples, which may suggest multiple source rocks, different transport histories, or differential in situ weathering. The higher percentage of heavy minerals in the upper Pleistocene samples may indicate sediment reworking and associated concentration of heavy minerals, or it may reflect sampling bias associated with localized magnetite and ilmenite rich laminae. It is interesting to note the increase in monocrystalline quartz coupled with a decrease in monocrystalline plagioclase from the upper

Table 2. Summary of lithologic composition of sand from samples recovered from Santa Monica Bay.

LITHOLOGIC COMPOSITION	UPPER PLEISTOCENE n = 74	HOLOCENE n = 57	TOTAL n = 131
<u>Monocrystalline Grains</u>			
Nonundulose Quartz	6.08	7.87	6.86
Undulose Quartz	22.89	23.88	23.32
Plagioclase Feldspar	20.53	17.67	19.28
Potassium Feldspar	5.04	6.14	5.52
Pyroxene	0.63	0.56	0.60
Amphibole	0.75	0.67	0.72
Biotite	1.90	0.81	1.43
Epidote	0.48	0.41	0.45
Sphene	0.22	0.18	0.20
Garnet	1.10	1.59	1.31
Magnetite-Ilmenite	3.52	0.84	2.36
<u>Polycrystalline Grains</u>			
Quartz with 2-3 subunits	3.81	4.66	4.18
Quartz with >3 subunits	2.36	2.94	2.61
Plutonic Rock	23.82	20.92	22.56
Metamorphic Rock	3.66	4.16	3.88
Volcanic Rock	0.29	1.76	0.93
Siliciclastic Rock	1.40	2.35	1.81
Allochemical Constituents	0.20	0.37	0.27
Microcrystalline Quartz	0.41	1.00	0.67

Pleistocene to Holocene samples, which probably reflects reworking of the upper Pleistocene deposits, perhaps coupled with a change in provenance (Osborne and others, 1980).

Holocene Strata

Stratigraphy: Two large, buried channels are cut into the upper Pleistocene strata west of Manhattan Beach (Osborne and others, 1980). The deeper of these two channels is preserved adjacent to the 91 m shelf re-entrant, and is cut to a maximum depth of 114 m b.p.s.l. These channels do not occur along the inner shelf, and therefore probably are not continuations of coastal river channels. Their proximity to a main tributary of Redondo submarine canyon suggests that they are extensions of that tributary cut during a low sea level stand near the end of Wisconsin time. However, a narrow v-shaped channel cuts to a depth of 117 m b.p.s.l. near the present canyon west of Hermosa Beach, which is not associated with the present canyon tributaries. This buried channel may represent a continuation of a late Wisconsin coastal river. If so, it may provide a datum for the maximum lowering of Wisconsin sea level; however, wave-cut terraces have not been observed at this depth.

As sea level rose at the close of Wisconsin glaciation, these channels were backfilled and the advancing sea began to plane stratigraphic units exposed on the Santa Monica shelf. Fluctuations in sea level during the Holocene transgression (Nardin and others, 1981) resulted in a complex wave-cut platform, which is well developed throughout Santa Monica Bay. The platform adjacent to the Santa Monica Mountains consists of a single terrace which truncates Neogene strata. The platform in this area dips seaward as much as 0.5°, and attains a maximum depth of 85 m b.p.s.l. near the shelf edge. This portion of the shelf is covered by undifferentiated Holocene strata as much as 28 m thick.

In the Redondo submarine canyon area, the platform consists of multiple terraces which truncate Miocene, upper Pleistocene and Holocene strata (Osborne and others, 1980). Holocene strata in this area can be locally differentiated into two units, D and E in ascending order, which are separated by an unconformity. To the west, units D and E are apparently conformable. North of the canyon, the lowest terrace is less than 4 km wide and for most of its width dips about 0.1° to the west. The outer edge of this terrace is defined by the shelf break at 80 m, and the inner edge by a shoreline angle at a depth of 58 m b.p.s.l. The formation of this terrace probably occurred during a relatively slow rise in sea level followed by a standstill at 58 m. Landward of the shoreline angle, the erosional surface dips as much as 10° and is truncated at 24 m b.p.s.l. During the sea level rise from 58 m to at least 24 m b.p.s.l., Holocene unit D was deposited along the inner part of this terrace. Unit D attains a maximum thickness of 24 m, and is characterized by sigmoidal clinoforms that dip as much as 5° to the southwest. The presence of cross stratification and the shape of unit D led Nardin (1976) to suggest that these strata represent prograding beach deposits. The configuration of these strata reflects a relatively low sediment supply coupled with a rapid rise in sea level (Mitchum and others, 1977), and may represent a small deltaic lobe. The apparent absence of an associated fluvial channel to the northeast of these beds argues in favor of the former interpretation.

The truncation of upper Pleistocene strata and Holocene unit D between Santa Monica and Redondo submarine canyon indicates a subsequent lowering of sea level. Locally this erosional surface extends as deep as 56 m b.p.s.l., which implies that sea level dropped to at least 46 m b.p.s.l., allowing 10 m for wave abrasion (Dietz, 1963). This erosional surface is locally observed immediately south of Redondo submarine canyon, but is absent along the shelf parallel to the Santa Monica Mountains, which perhaps reflects more continuous or a higher rate of sedimentation along the Malibu coast. Upper Pleistocene strata and Holocene unit D were exposed to additional erosion as sea level rose to its present position. The parallel, onlapping beds of Holocene unit E were deposited during this sea level rise. Changes in slope along this upper terrace at 43 m and 23 m b.p.s.l. suggest variations in the rate of sea level rise, sediment input or both.

Lithology: Holocene strata typically consist of massive olive-gray, slightly biotitic, moderately well-sorted, very fine-to fine-grained sand, which is locally intercalated with very thin to thick beds of clayey silt and mud. Holocene deposits vary in color from olive gray to a greenish black, and locally grade to a poorly-sorted, fossiliferous, silty, sandy granular pebble gravel. Where present, the gravel is composed of subangular to subround pebbles of acid plutonic, siliceous metavolcanic and argillaceous rock with additional clasts of gneiss, quartzite and slate. Similar sediment fills parts of the submerged Ballona Creek channel. Marine pelecypod and gastropod shell fragments often occur in the Holocene strata as do occasional scaphopod shells.

Holocene samples have a mean grain size of 0.28 mm (1.83 ϕ) and are moderately well-sorted with a mean phi standard deviation of 0.68. They vary in skewness from strongly coarse-skewed (phi skewness = -9.51) to strongly fine skewed (phi skewness = 2.50), whereas kurtosis values range from leptokurtic (phi kurtosis = 1.44) to extremely leptokurtic (phi kurtosis - 99.99). In general, the sand population from the Holocene samples is strongly coarse-skewed and extremely leptokurtic.

Compositional data for the Holocene samples in Santa Monica Bay have been presented in table 2.

Potential Sand and Gravel Resources

The forementioned Preliminary "Quick Look" Report on Offshore Sand Resources in Southern California prepared by the U. S. Army Coastal Engineering Research Center Identified three nearshore borrow areas (B-I, B-II and B-III) that were estimated to contain a minimum total volume of 26 x 10^6 m^3 of sand suitable for beach restoration and nourishment. In addition, a fourth offshore area (B-IV) was identified, but was considered to be only marginally suited for beach nourishment.

In the present study, additional seismic data and a greater density of vibracores have resulted in substantial modifications in the volumetric estimates of available sand and gravel on the Santa Monica shelf. Furthermore, a new potential borrow area (B-V) was identified north of Marina del Rey. The locations of borrow areas B-I through B-V and associated lines of geologic cross sections are shown in Figure 3.

The potential borrow areas will be discussed in order from north to south, and the following information is presented for each area: a tabulated summary of the principal characteristics, an isopach map, a geologic cross section, and a representative vibracore log. The minimum volumes reported were computed using a planimeter in conjunction with the weighted mean thickness of suitable material recovered from the vibracores at each site. The maximum volumes were computed from the isopach maps constructed for each borrow area using the mathematical technique described by Craft and Hawkins (1964, p. 27).

Potential Borrow Area B-V

Borrow area B-V occurs between the 9 and 26 m isobaths north of Marine del Rey (Table 3; Figs. 3, 4 and 5). At this location, strata assigned to upper Pleistocene unit C are locally exhumed (Figs. 6 and 10), which contain

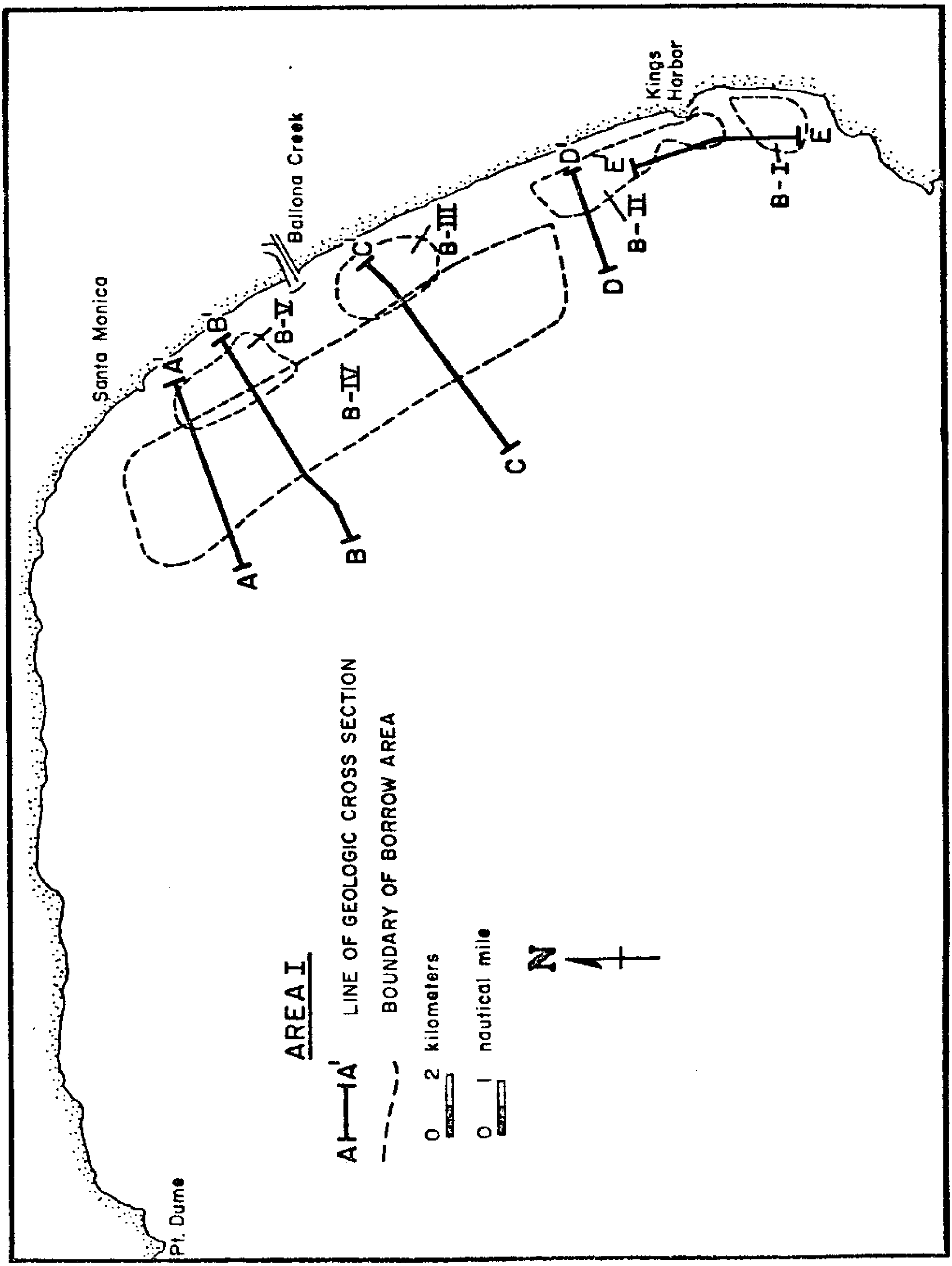


Figure 3. Map of area I showing locations of borrow areas B-I through B-V and associated lines of geologic cross sections A-A' through E-E'.

Table 3. Summary of potential borrow area B-V.

Type of Deposit:

Upper Pleistocene unit C

Water Depth:

Minimum: 9 meters

Maximum: 26 meters

Range in Mean Grain Size: n = 30

Minimum: 2.83 phi 0.14 mm

Maximum: 0.27 phi 0.83 mm

Mean: 0.76 phi 0.59 mm

Range in Thickness:

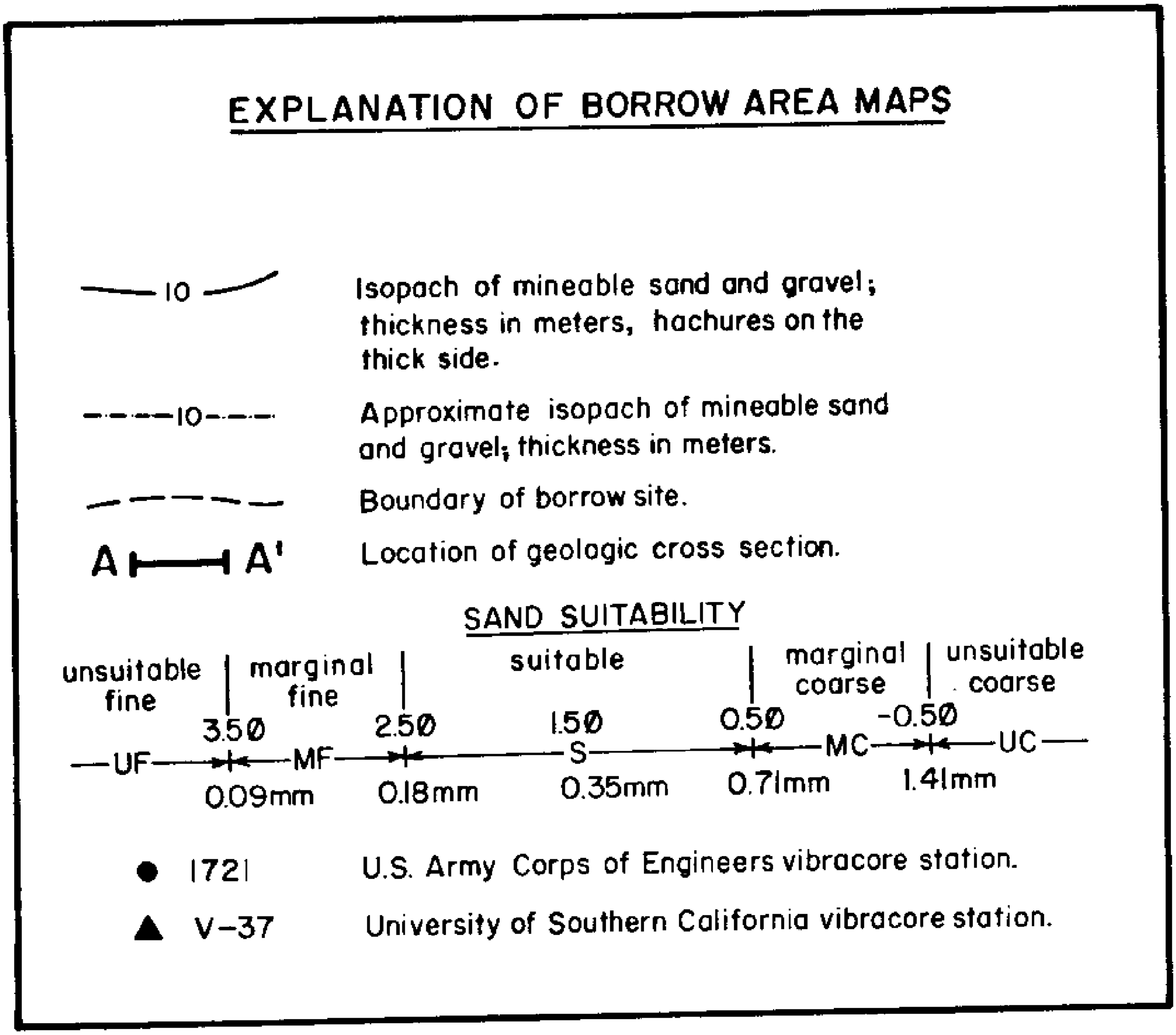
Minimum: <2 meters

Maximum: 14 meters

Estimated Volume	(x 10^6 m^3)	(x 10^6 yd^3)
Minimum:	13.8	18.0
Maximum:	50.5	66.0

Vibracores Penetrating Deposit:

V-38; V-39; V-51; V-40; V-50; V-41; V-42



EXPLANATION OF BORROW AREA MAPS

10 — Isopach of mineable sand and gravel; thickness in meters, hachures on the thick side.

10 - - - Approximate isopach of mineable sand and gravel; thickness in meters.

Boundary of borrow site.

A A' Location of geologic cross section.

SAND SUITABILITY

● 1721 U.S. Army Corps of Engineers vibracore station.

▲ V-37 University of Southern California vibracore station.

Figure 4. Explanation of borrow area maps.

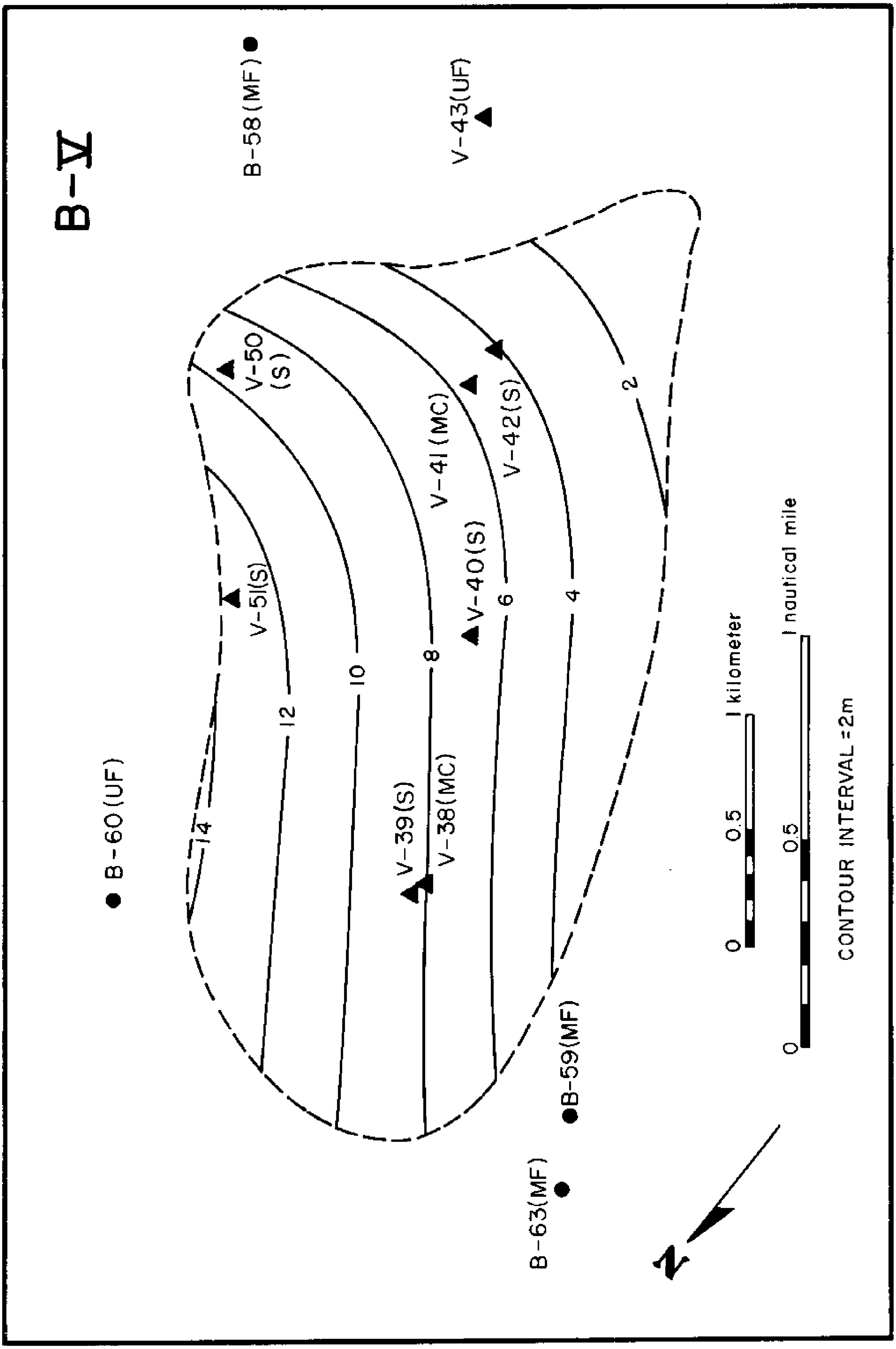


Figure 5. Isopach map of borrow area B-V with associated vibracore numbers and sand suitability symbols.

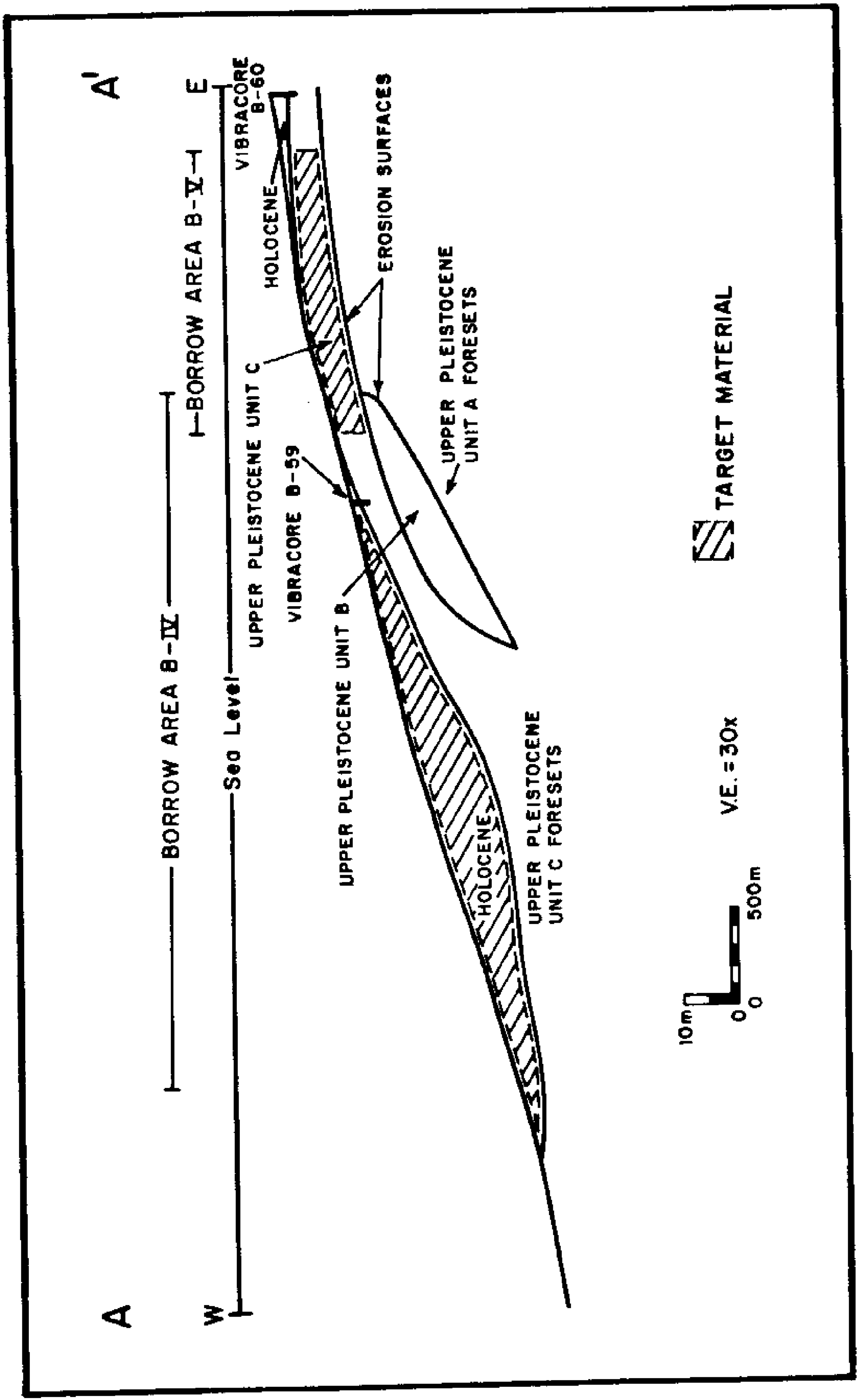


Figure 6. Geologic cross section A-A'.

from 13.8 to 50.5 x 10^6 m^3 of silty, sandy gravel and gravelly sand (Figs. 7 and 8). Although sand suitable for beach restoration and nourishment is available in this borrow area, the high gravel content of this deposit indicates that this sediment is better suited for construction aggregate. Although no vibracores were taken immediately north of cores V-38 and V-39 (Fig. 5), it is likely that similar upper Pleistocene strata may extend north of Santa Monica Pier.

Potential Borrow Area B-IV

Borrow area B-IV occurs between the 13 and 49 m isobaths covering an extensive offshore area from Santa Monica south to Manhattan Beach (Table 4; Figs. 3 and 9). These strata are assigned to the relatively thick, offshore, undifferentiated Holocene sediment package that parallels the present coastline from Pt. Dume to the Palos Verdes Hills (Figs. 6, 10 and 13). Although quite voluminous (at least 248.5 x 10^6 m^3), this deposit consists of light- to olive-gray, fine- to very fine-grained sand, sandy silt, and greenish-black mud and clay. Unfortunately this deposit is only of marginal quality for beach restoration and nourishment (Fig. 11).

Potential Borrow Area B-III

Borrow area B-III lies between the 9 and 26 m isobaths in the nearshore area southeast of Ballona Creek and northwest of El Segundo (Table 5; Figs. 3 and 12). In the western part of this area, upper Pleistocene strata are covered by a thin veneer of Holocene sediment (Fig. 13), and are composed of sand with occasional interbeds of sandy gravel. Nearer the present coastline, the Holocene strata thicken and contain interstratified sand and sandy gravel (Fig. 14). Together, the Pleistocene and Holocene strata in borrow area B-III are estimated to contain from 26.8 to 60.4 x 10^6 m^3 of material suitable for beach nourishment.

SYMBOLS FOR VIBRACORE LOGS

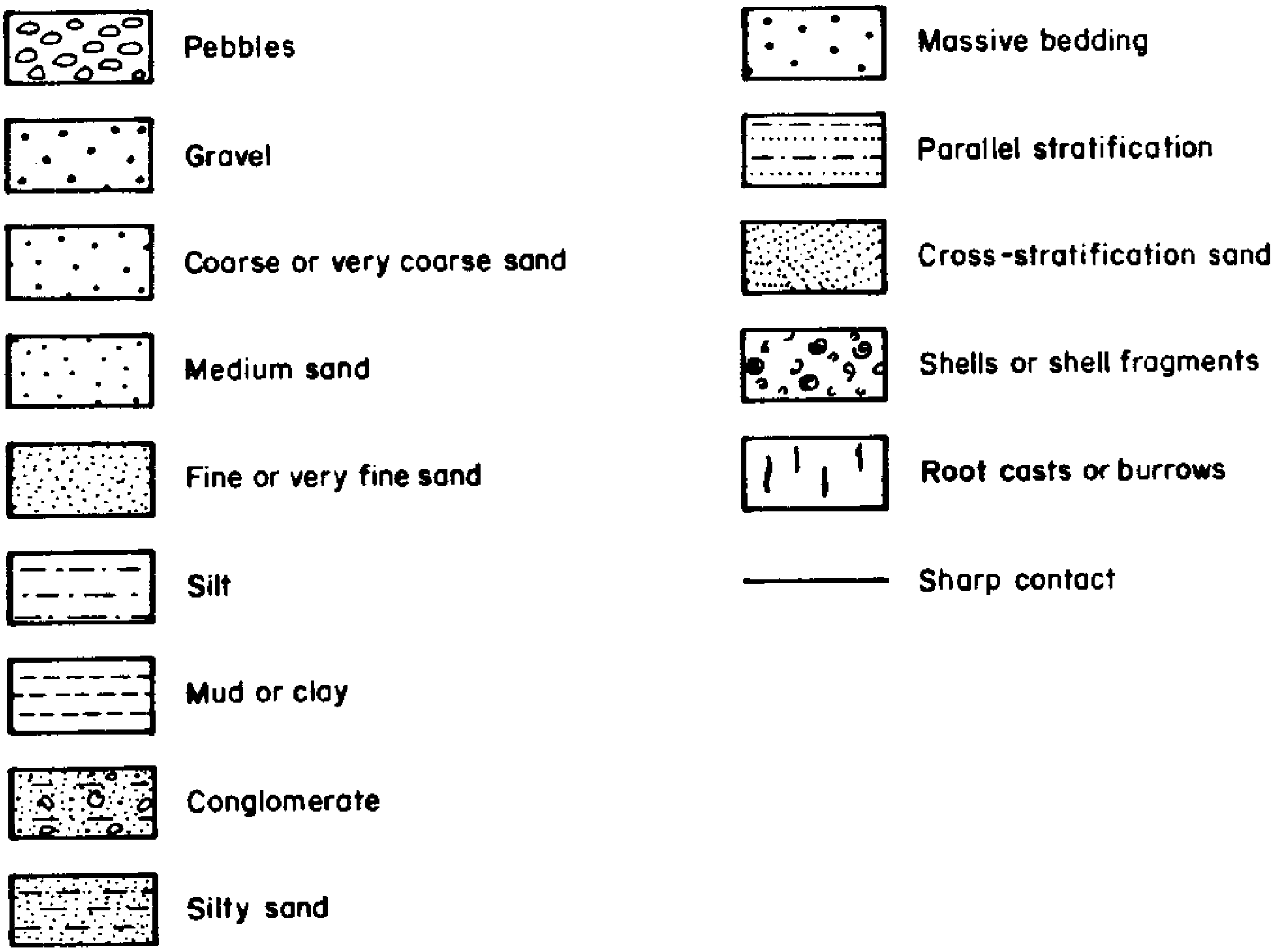


Figure 7. Explanation of symbols for vibracore logs.

VIBRACORE LOG

Core number: V-39

Date:

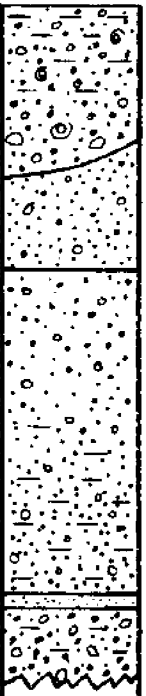
Total core length (cm): 223

Sheet 1 of 1

Number of core sections:

Water depth (ft):

Vertical scale: 1 cm = 25 cm

Distance in cm from top of core	Description	Log
0-55	Gravel: silty, sandy, pebbly; grayish olive (10 Y 4/2), grades downward to a sandy, granular pebble gravel; slightly micaceous; light olive gray (5 Y 5/2); poorly-sorted; small to large, subangular to subround, acid plutonic, spotted slate and siltstone clasts, with rare pebbles of anorthosite and quartzite; small marine shell fragments are present near the top and several of the pebbles are encrusted by bryozoa; bottom contact inclined due to the vibracoring process.	
55-85	Sand: medium grained, slightly gravelly; moderately sorted; yellowish gray (5 Y 7/2); a few small, subangular to subround, acid plutonic pebbles.	
85-195	Gravel: sandy, pebbly, granular, which gradationally varies to a pebbly, silty, medium to coarse sand; poorly sorted; color varies from a dark yellowish brown (10 YR 4/2) to a dusky brown (5 YR 2/2); small to medium, subangular to subround, felsic plutonic pebbles.	
195-198	Sand: fine grained, granular; poorly sorted; micaceous; yellowish gray (5 Y 7/2).	
198-223	Gravel: silty, sandy, granular, pebbly; poorly sorted; micaceous; color varies from a yellowish gray (5 Y 7/2) to an oxidized dark yellowish orange (10 YR 6/6); small, subangular to subround, acid plutonic pebbles are present along with one siliceous metavolcanic clast.	

Figures 8. Log of vibracore V-39 which is illustrative of the sedimentologic character of borrow area B-V.

Table 4. Summary of potential borrow area B-IV.

Type of Deposit:

Undifferentiated Holocene strata

Water Depth:

Minimum: 13 meters

Maximum: 49 meters

Range in Mean Grain Size: n = 53

Minimum:	3.64 phi	0.08 mm
Maximum:	1.19 phi	0.44 mm
Mean:	2.91 phi	0.13 mm

Range in Thickness:

Minimum: 4 meters

Maximum: 23 meters

Estimated Volume	(x 10^6 m^3)	(x 10^6 yd^3)
Minimum:	248.5	325.0
Maximum:		
Other:		Explanation of value:

Vibracores Penetrating Deposit:

B-61; B-62; B-63; B-59; V-37; B-51; B-52; B-50

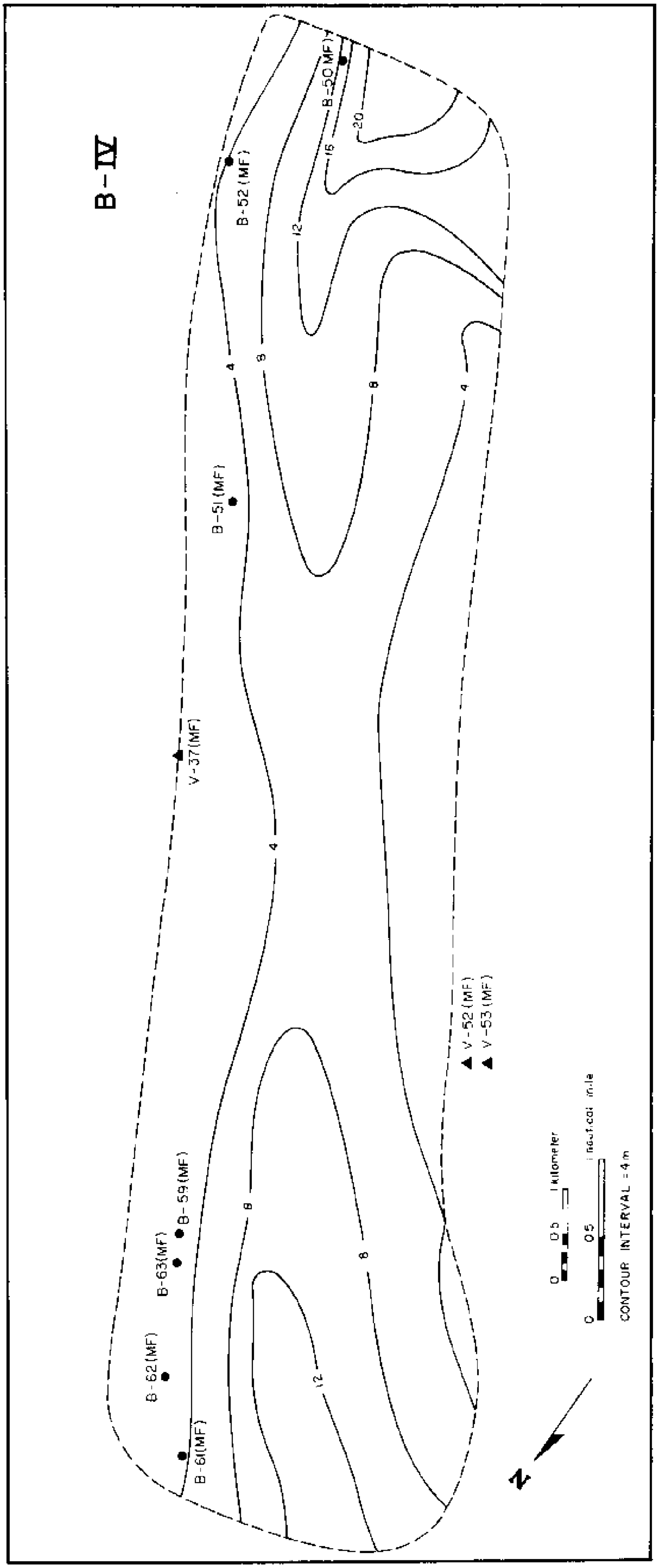


Figure 9. Isopach map of borrow area B-IV with associated vibracore numbers and sand suitability symbols.

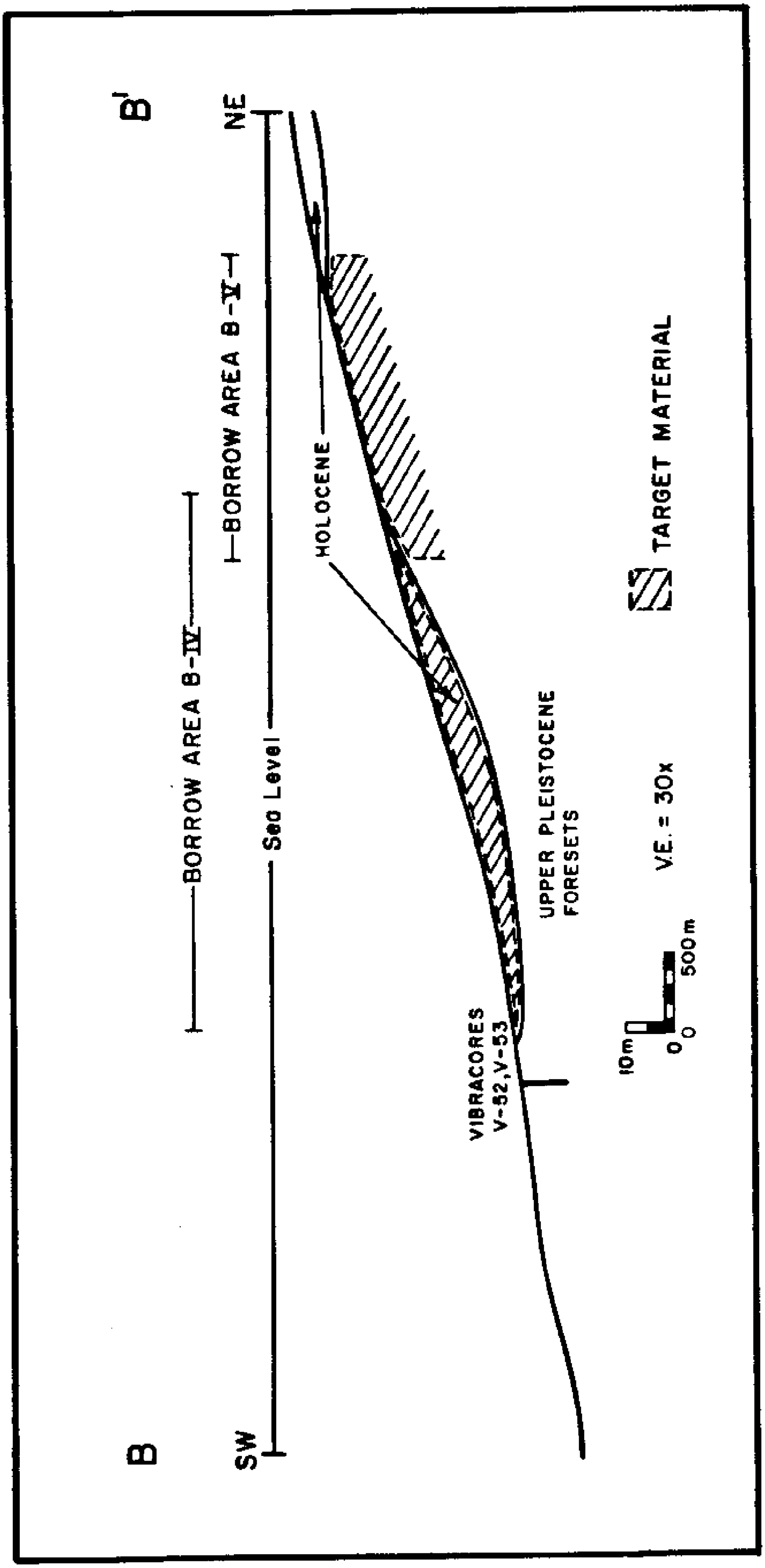


Figure 10. Geologic cross section B-B'.

VIBRACORE LOG

Core number: V-37
Date:
Total core length (cm): 384
Sheet 1 of 1
Number of core sections:
Water depth (ft):
Vertical scale: 1 cm = 25 cm

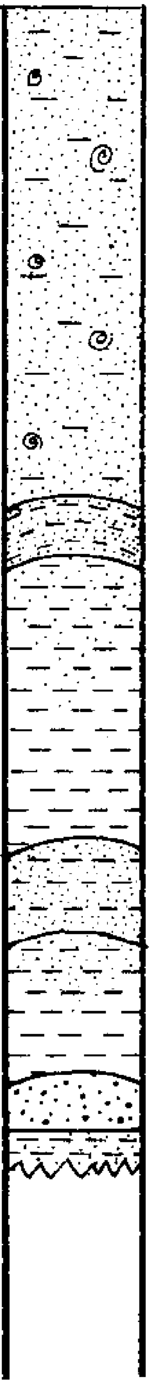
Distance in cm from top of core	Description	Log
0-164	Silty Sand: very fine grained; moderately well sorted; greenish black (5 G 2/1); slightly micaceous; marine gastropod and pelecypod shell fragments; lower contact is concave downward due to the vibracoring process.	
164-185	Sand: very fine grained, silty; moderately well sorted; slightly micaceous; medium light gray (N6), intercalated with very thin to thin beds of olive black (5 Y 2/1), clay.	
185-280	Mud: slightly sandy; greenish black (5 G 2/1); grades downward to an olive black (5 Y 2/1), clay; lower contact is concave downward due to the vibracoring process.	
280-310	Sand: fine grained, muddy, slightly granular; poorly sorted; slightly micaceous; olive gray (5 Y 4/1); lower contact is concave downward due to the vibracoring process.	
310-355	Mud: slightly sandy; greenish black (5 G 2/1); grades downward to an olive black (5 Y 2/1), clay, lower contact concave downward due to the vibracoring process.	
355-370	Sand: medium to coarse grained, slightly granular; poorly sorted; olive gray (5 Y 4/1).	
370-384	Sandy Mud: olive gray (5 Y 4/1).	

Figure 11. Log of vibracore V-37 which is illustrative of the sedimentologic character of borrow area B-IV.

Table 5. Summary of potential borrow area B-III.

Type of Deposit:

Upper Pleistocene unit C and nearshore Holocene deposits

Water Depth:

Minimum: 9 meters

Maximum: 26 meters

Range in Mean Grain Size: n = 47

Minimum:	2.74 phi	0.15 mm
Maximum:	-0.08 phi	1.06 mm
Mean:	0.97 phi	0.51 mm

Range in Thickness:

Minimum: 4 meters

Maximum: 16 meters

Estimated Volume	(x 10^6 m^3)	(x 10^6 yd^3)
Minimum:	26.8	35.0
Maximum:	60.4	79.0
Other:		Explanation of value:

Vibracores Penetrating Deposit:

V-44; V-49; V-45; V-48; V-46

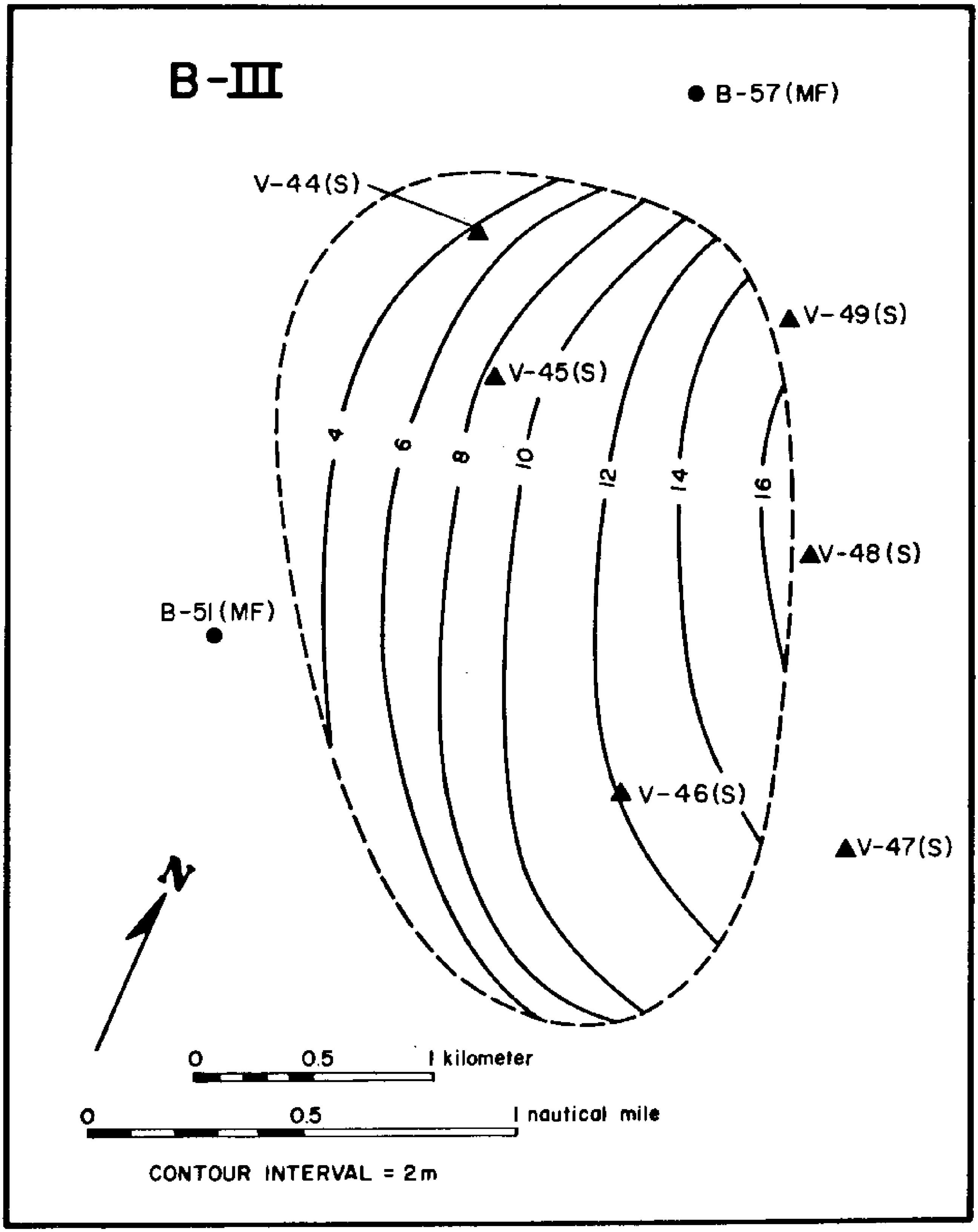


Figure 12. Isopach map of borrow area B-III with associated vibracore numbers and sand suitability symbols.

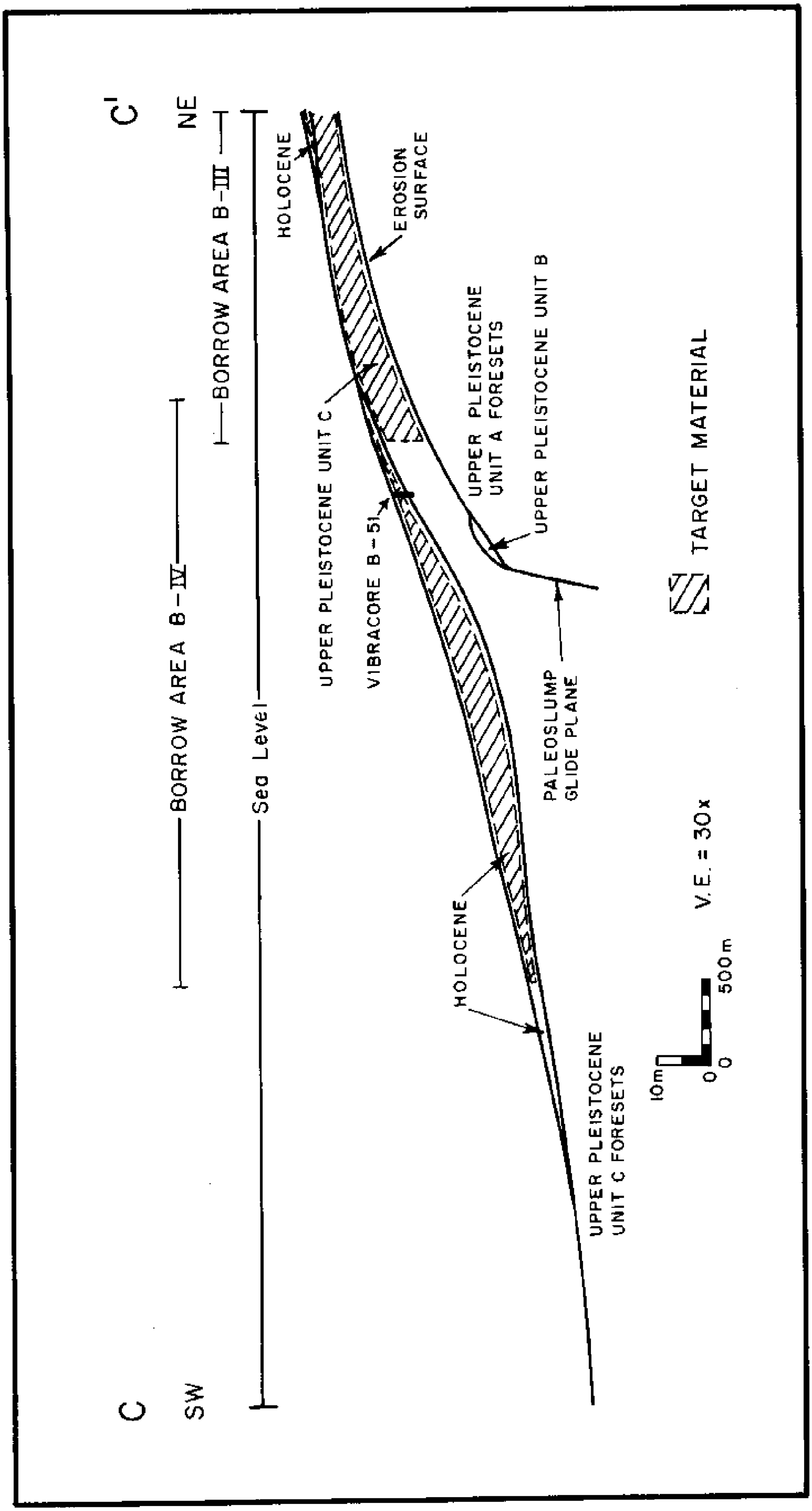


Figure 13. Geologic cross section C-C'.

VIBRACORE LOG

Core number: V-49

Date:

Total core length (cm): 447

Sheet 1 of 2

Number of core sections:

Water depth (ft):

Vertical scale: 1 cm = 25 cm

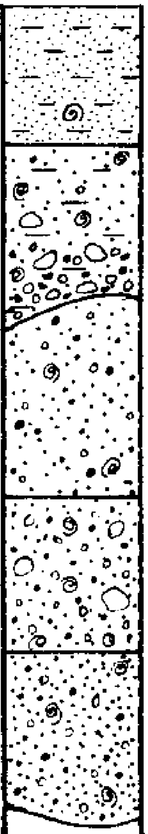
Distance in cm from top of core	Description	Log
0-44	Silty Sand: very fine grained; slightly micaceous; moderately well sorted; greenish black (5 GY 2/1); large marine gastropod shell at base.	
44-105	Sand: medium grained, slightly pebbly, silty, grades down to a silty, sandy, granular pebble gravel; poorly sorted; grayish black (N2); small to large, subround, acid plutonic, siliceous metavolcanic, siltstone and shale clasts, with a few pebbles of gneiss and quartzite; marine pelcypod and gastropod shell fragments; lower contact disturbed by the vibracoring process.	
105-161	Sand: medium to coarse grained, slightly gravelly; moderately sorted; medium gray (N5); small, subround, siliceous metavolcanic, siltstone and shale clasts; scattered marine shell fragments.	
161-212	Gravel: sandy, granular, pebbly; poorly sorted; light olive gray (5 Y 6/1); small to large, subangular to subround; siliceous metavolcanic; acid plutonic, siltstone and shale clasts, with additional pebbles of quartzite and gneiss marine pelecypod shell fragments.	
212-262	Sand: medium to coarse grained, slightly gravelly; moderately sorted; medium gray (N5); small subround, siliceous metavolcanic, acid plutonic and siltstone pebbles; assorted small marine shell fragments; irregular lower contact due to the vibracoring process.	

Figure 14.1 Log of vibracore V-49 which is illustrative of the sedimentologic character of borrow area B-III.

VIBRACORE LOG

Core number: V-49
Date:
Total core length (cm): 447
Sheet 2 of 2
Number of core sections:
Water depth (ft):
Vertical scale: 1 cm = 25 cm

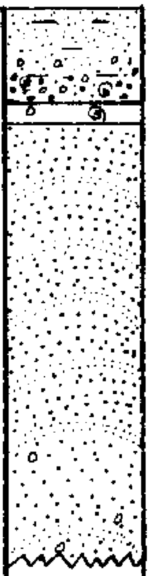
Distance in cm from top of core	Description	Log
262-292	Silty Sand: very fine grained; moderately sorted; grades down to a silty, sandy, granular pebble gravel; poorly sorted; color varies from a olive gray (5 Y 4/1) to an oxidized light olive brown (5 Y 5/6); small, subround, acid plutonic clasts, with a few pebbles of siltstone and quartzite; marine pelecypod shell fragments.	
292-301	Sand: medium grained, gravelly; poorly sorted; pale olive (10 Y 6/2); small subround, acid plutonic, siltstone and quartzite clasts; marine shell fragments.	
301-447	Sand: medium to coarse grained, intercalated with thin to medium beds of fine sand; moderately well to well sorted; occasional concave downward laminae of magnetite and ilmenite; color varies from a medium light gray (N5) to a light olive gray (5 Y 6/1) and appears to be locally oxidized to a grayish orange (10 YR 7/4); a few small, subround acid plutonic, siliceous metavolcanic, siltstone and jasper pebbles are present.	

Figure 14.2 Log of vibracore V-49 which is illustrative of the sedimentologic character of borrow area B-III.

Potential Borrow Area B-II

Borrow area B-II occurs between the 9 and 28 m isobaths immediately north of Redondo submarine canyon (Table 6; Figs. 3 and 15). Pleistocene foreset strata are believed to either crop out in this area or are buried by a thin veneer of Holocene unit E (Figs. 16 and 19). Recovered vibracores from this borrow area (Fig. 17) display olive-gray, fine- to medium-grained sand with interbeds of silty sand and sandy gravel. In the Hermosa Beach-Kings Harbor area, a buried Holocene channel transects this part of the shelf, and contains sand and sandy gravel in the nearshore area. Borrow area B-II contains from 32.9 to 77.2 x 10^6 m^3 of sand suitable for beach restoration and nourishment.

Potential Borrow Area B-I

Borrow area B-I occurs between the 9 and 27 m isobaths immediately south of Redondo submarine canyon and just offshore from Redondo Beach (Table 7; Figs. 3 and 18). This potential borrow area is near the site used in 1967-68 for the restoration of Redondo Beach. Within the nearshore area, several cores contain medium- to coarse-grained, moderately well-sorted sand and slightly gravelly sand, which is assigned to upper Pleistocene and Holocene stratigraphic units (Figs. 19 and 20). This borrow area contains from 16.0 to 26.0 x 10^6 m^3 of sand suitable for beach nourishment programs.

Based on the current economic and technologic limits for offshore dredging operations, the estimates for sand suitable for beach replenishment and nourishment in Santa Monica Bay (B-I, B-II, and B-III) range from a minimum of 75.7 x 10^6 m^3 to a maximum of 163.6 x 10^6 m^3. In addition, borrow area B-V contains from 13.8 x 10^6 m^3 to 50.5 x 10^6 m^3 of sediment more suitable for construction aggregate.

Table 6. Summary of potential borrow area B-II.

Type of Deposit:

Upper Pleistocene foreset strata and Holocene unit E

Water Depth:

Minimum: 9 meters

Maximum: 28 meters

Range in Mean Grain Size: n = 82

Minimum:	3.64 phi	0.08 mm
Maximum:	-3.41 phi	10.60 mm
Mean:	1.00 phi	0.50 mm

Range in Thickness:

Minimum: 4 meters

Maximum: 18 meters

Estimated Volume	(x 10^6 m^3)	(x 10^6 yd^3)
Minimum:	32.9	43.0
Maximum:	77.2	101.0
Other:		Explanation of value:

Vibracores Penetrating Deposit:

V-36; V-32; V-17; V-18; V-35; V-33; B-45; V-34; V-21

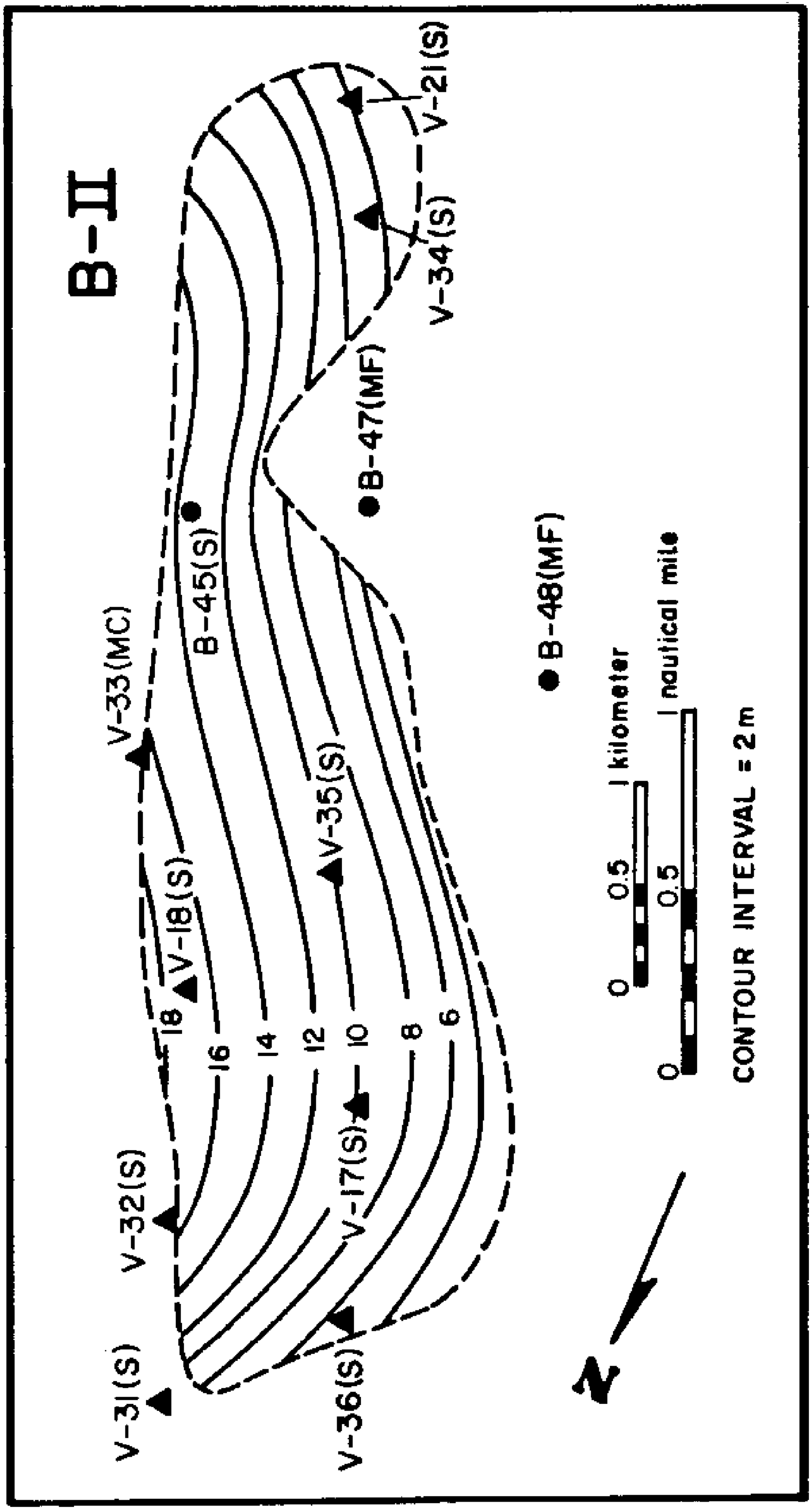


Figure 15. Isopach map of borrow area B-II with associated vibracore numbers and sand suitability symbols.

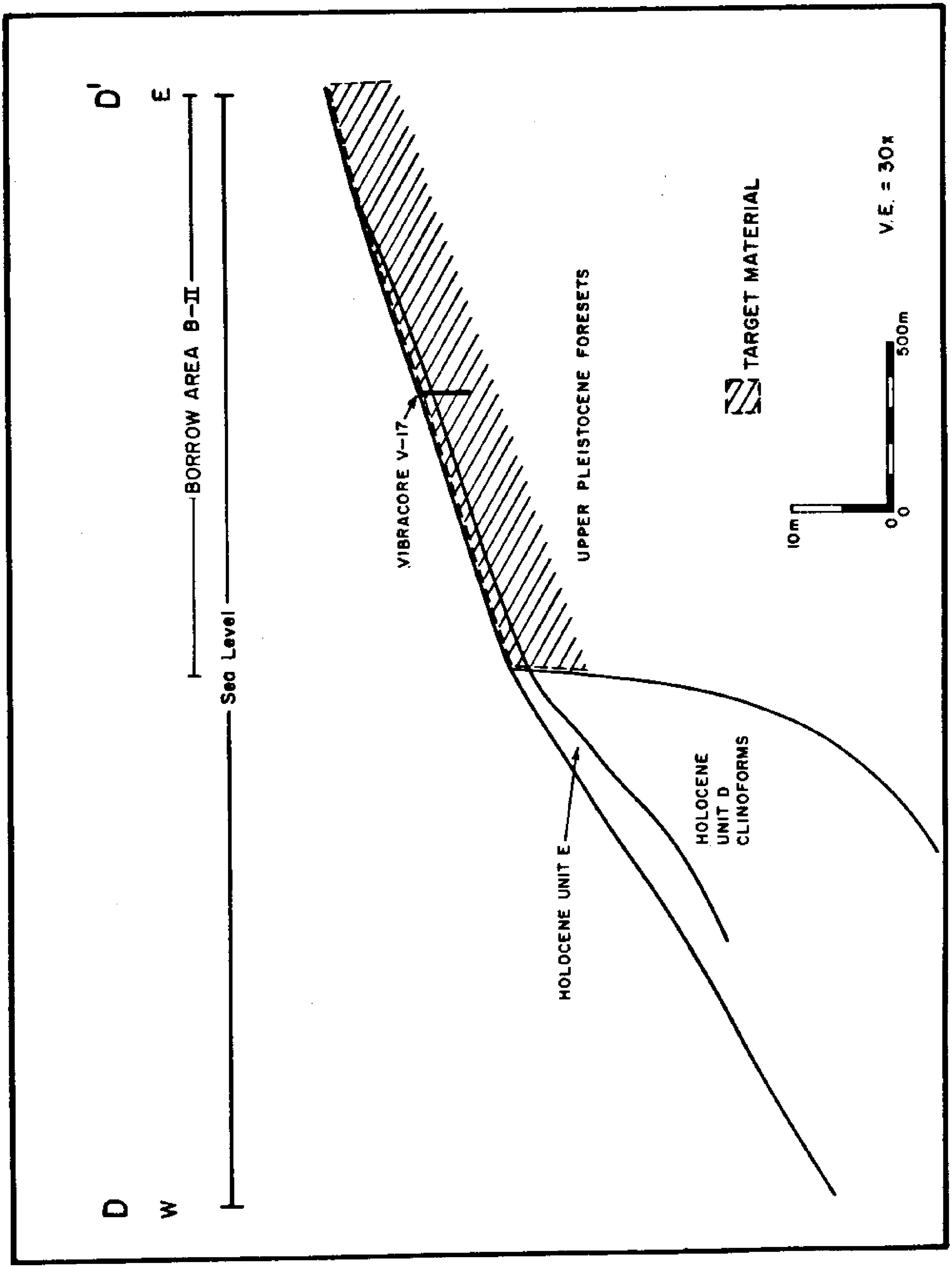


Figure 16. Geologic cross section D-D'.

VIBRACORE LOG

Core number: V-17

Date:

Total core length (cm): 515

Sheet 1 of 2

Number of core sections:

Water depth (ft):

Vertical scale: 1 cm = 25 cm

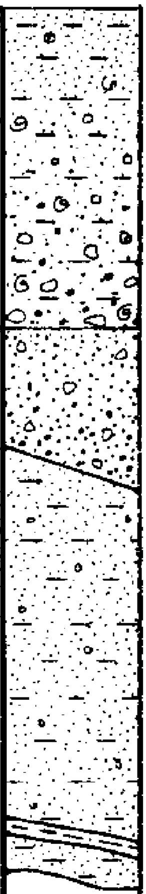
Distance in cm from top of core	Description	Log
0-104	Sand: very fine to fine grained; silty; micaceous; grades downward to a silty, sandy, granular pebble gravel; moderately well-to poorly sorted; dark greenish gray (5 GY 4/1); small to large, subangular to subround, acid plutonic pebbles, with clasts of siltstone, slate, gneiss, quartzite, and siliceous metavolcanics, pelecypod and gastropod shell fragments.	
104-145	Sand: fine to medium grained, slightly gravelly grading downward to a slightly gravelly, medium to coarse sand; poorly sorted; light olive gray (5 Y 5/2); locally oxidized to light olive brown (5 Y 5/6); now micaceous grading to slightly micaceous; small to medium, subangular to subround, acid plutonic pebbles, with a few clasts of gneiss, anorthosite, siltstone and slate; lower contact is inclined due to the vibracoring process.	
145-268	Sand: very fine to fine grained; ranging from silty to slightly gravelly; moderately sorted; grayish olive (10 Y 4/2); micaceous; slightly oxidized in places; small, subangular to subround, acid plutonic pebbles, lower contact inclined due to the vibracoring process.	
268-273	Clayey silt: moderate olive brown (5 Y 4/4); micaceous; bed dips steeply due to the vibracoring process.	
273-285	Silty Sand: very fine to fine grained; moderately well sorted; light olive gray (5 Y 5/2); micaceous; lower contact deformed due to the vibracoring process.	
285-333	Sandy Silt: grayish olive (10 Y 4/2); micaceous; grades to a silty, very fine sand; moderately well sorted; yellowish gray (5 Y 7/2); micaceous; magnetite and ilmenite are present; lower contact dips steeply due to the vibracoring process.	

Figure 17.1 Log of vibracore V-17 which is illustrative of the sedimentologic character of borrow area B-II.

VIBRACORE LOG

Core number: V-17

Date:

Total core length (cm): 515

Sheet 2 of 2

Number of core sections:

Water depth (ft):

Vertical scale: 1 cm = 25 cm

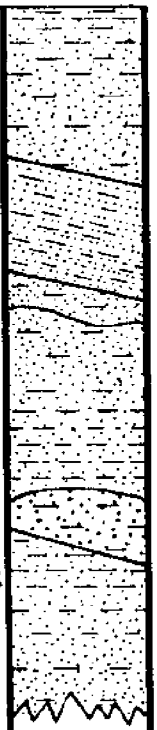
Distance in cm from top of core	Description	Log
333-370	Sand: very fine to fine grained, silty, moderately well sorted; intercalated with laminae of magnetite and ilmenite; slightly oxidized to a dusky yellow (5 Y 6/4); micaceous; beds inclined due to the vibracoring process.	
370-382	Silty Sand: very fine to fine grained, moderately well sorted; light olive gray (5 Y 5/2); micaceous; lower contact is deformed due to the vibracoring process.	
382-445	Sand: silty very fine grained, grades to a clayey sandy silt; moderately well sorted; moderate olive brown (5 Y 5/4); micaceous; bottom contact is concave upward due to the vibracoring process.	
445-455	Sand: medium grained, ranges from silty to slightly gravelly; poorly sorted; light olive gray (5 Y 5/2); micaceous; lower contact inclined due to the vibracoring process.	
455-515	Sandy Silt: color varies from a light olive gray (5 Y 5/2) to an oxidized moderate brown (5 YR 4/4); micaceous; grades downward to silty very fine to fine sand, moderately well sorted; dusky yellow (5 Y 6/4); micaceous, magnetite and ilmenite are locally present.	

Figure 17.2 Log of vibracore V-17 which is illustrative of the sedimentologic character of borrow area B-11.

Table 7. Summary of potential borrow area B-I.

Type of Deposit:

Upper Pleistocene strata and Holocene channel fill

Water Depth:

Minimum: 9 meters

Maximum: 27 meters

Range in Mean Grain Size: n = 38

Minimum:	3.05 phi	0.12 mm
Maximum:	0.46 phi	0.73 mm
Mean:	1.19 phi	0.44 mm

Range in Thickness:

Minimum: <2 meters

Maximum: 14 meters

Estimated Volume	(x 10^6 m^3)	(x 10^6 yd^3)
Minimum:	16.0	20.9
Maximum:	26.0	34.0
Other:		Explanation of value:

Vibracores Penetrating Deposit:

B-55; B-54; B-53; V-20; B-56

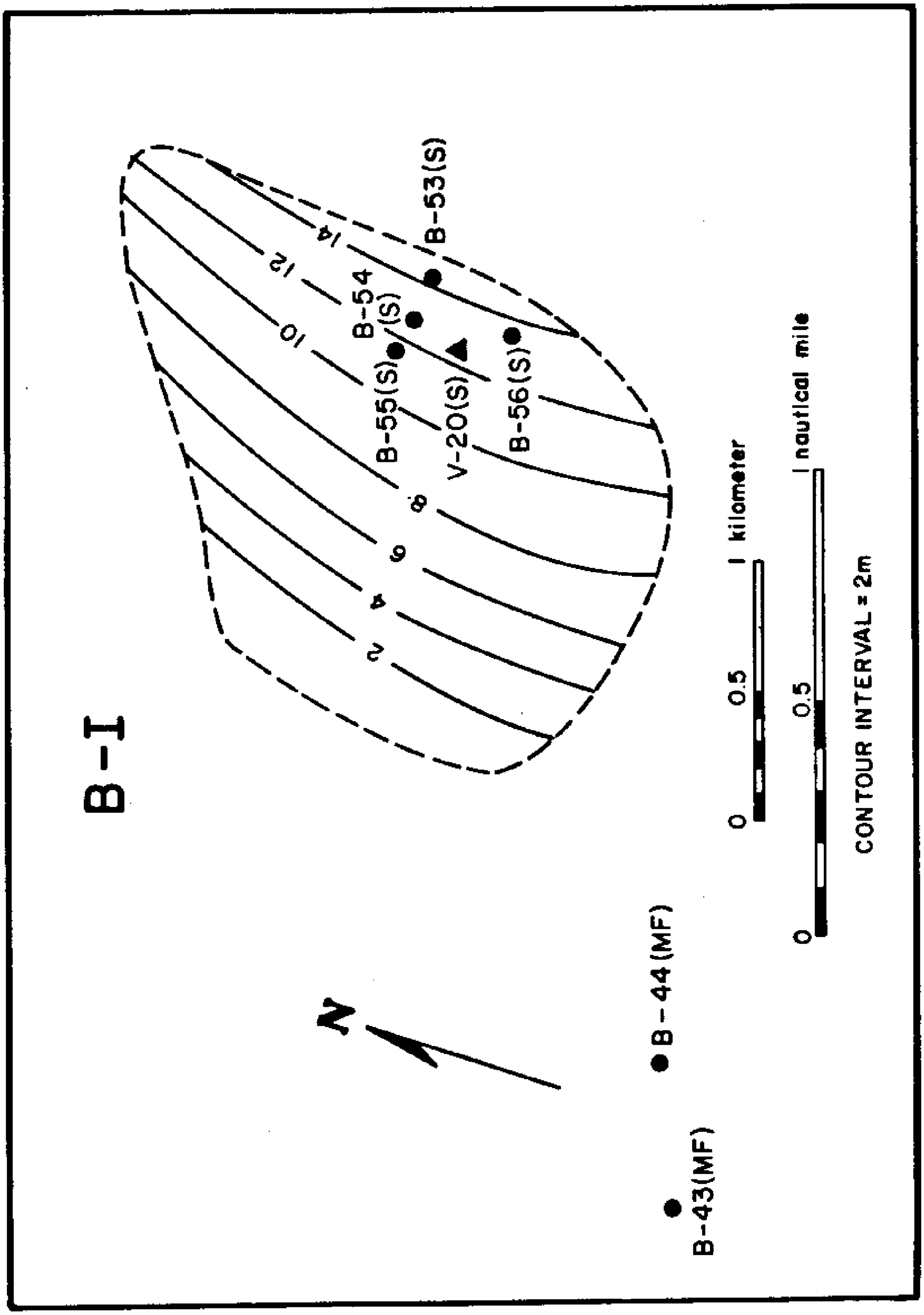


Figure 18. Isopach map of borrow area B-I with associated vibracore numbers and sand suitability symbols.

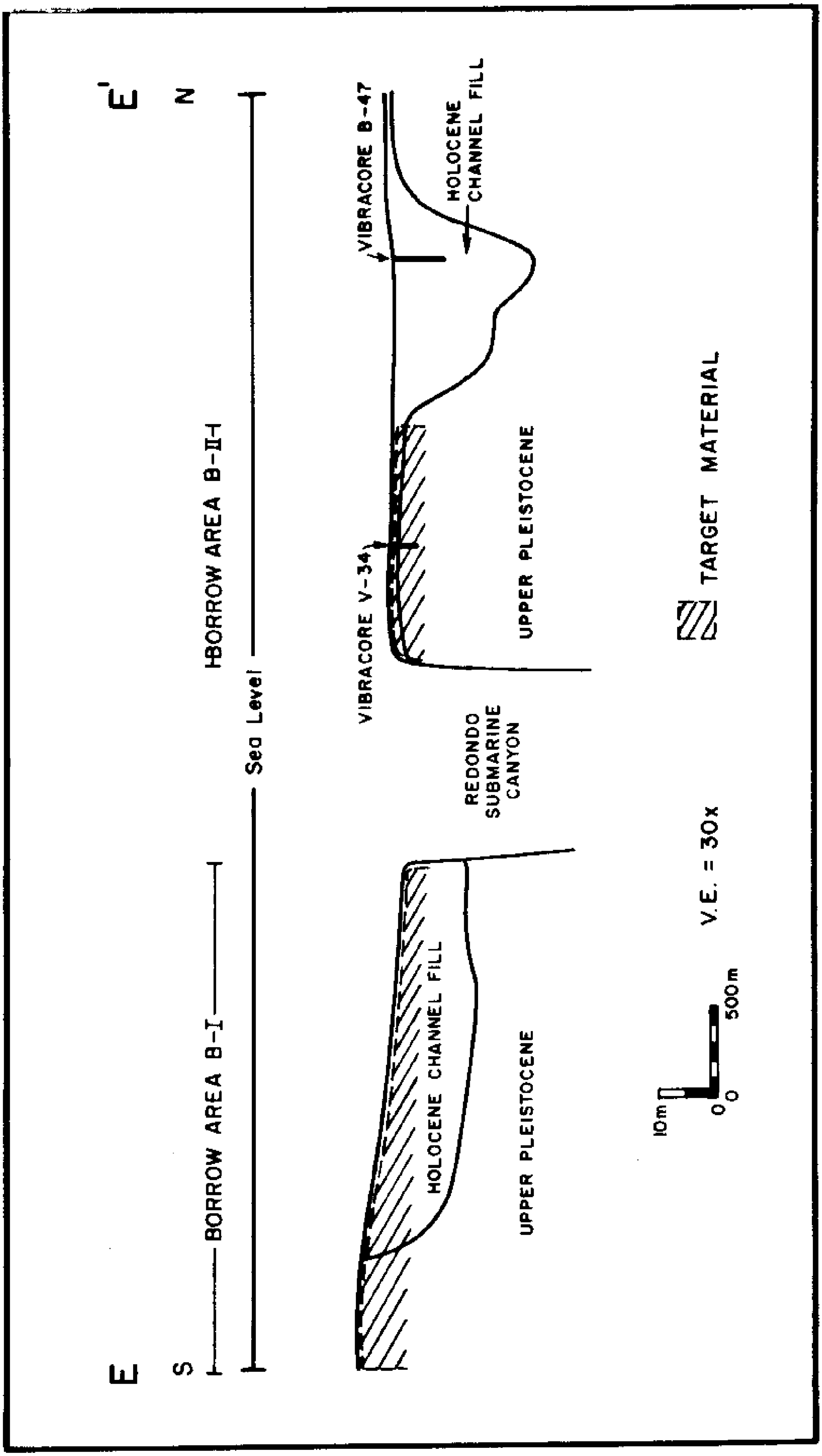


Figure 19. Geologic cross section E-E'.

VIBRACORE LOG

Core number: V-20

Date:

Total core length (cm): 221

Sheet 1 of 1

Number of core sections:

Water depth (ft):

Vertical scale: 1 cm = 25 cm

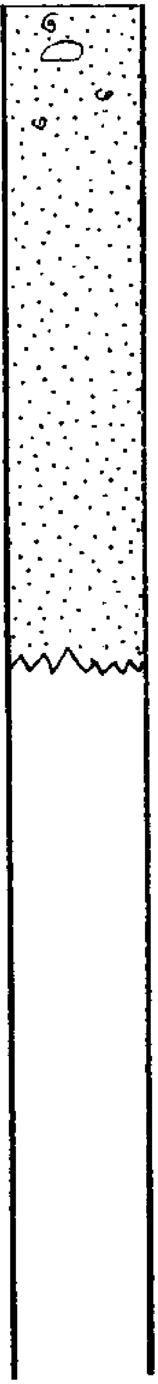
Distance in cm from top of core	Description	Log
0-221	Sand: medium to coarse grained; moderately well sorted; color changes to in the core at 110 cm from a light olive gray (5 Y 5/2) to a grayish black (N2); one large, subround, acid plutonic pebble near top; rare scattered marine shell fragments in upper half of the core.	

Figure 20. Log of vibracore V-20 which is illustrative of the sedimentologic character of borrow area B-I.

II. SAN PEDRO BAY, LOS ANGELES AND ORANGE COUNTIES

Introduction

The San Pedro shelf trends approximately northwest and includes an area of approximately 500 km^2 (Fig. 21). It is bounded to the northwest by the Palos Verdes Hills and a narrow shelf leading seaward to the San Pedro escarpment. To the southeast, the Newport submarine canyon and an abrupt decrease in the thickness of Quaternary strata define the shelf boundary, which generally occurs at the 100 fathom isobath. The shelf ranges in width from 20 km south of Long Beach to 2 km south of Point Fermin.

The isobaths (Fig. 21) show a smooth, gently seaward-sloping surface with a broad topographic ridge trending N 50°W, which expresses the position of the Palos Verdes fault zone and adjacent deformed Miocene-Pliocene strata. The associated Wilmington graben occurs northeast of the Palos Verdes fault zone, and, in turn, is bounded on its northeastern flank by an unnamed fault zone described by Junger and Wagner (1977), Fischer and others (1977), and Nardin and Henyey (1978).

The San Pedro shelf lies within the southwestern block of the Los Angeles basin (Yerkes and others, 1965) and the Peninsular Ranges geomorphic province (Jenkins, 1938; Jahns, 1954). Nardin and Henyey (1978) concluded that the deformation of the Santa Monica and San Pedro Bay areas was the result of late Tertiary and Quaternary shear stress accompanied by regional convergence. Dextral shear is manifested in the Palos Verdes and inland Newport-Inglewood fault zones (Fig. 21), whereas contemporaneous convergent forces have formed the series of en echelon anticlinoria trending in a more westerly direction than the strike-slip faults. On the San Pedro shelf, the Palos Verdes Hills anticlinorium trends northwest nearly parallel to the Palos Verdes fault zone, and then changes trend to the west-northwest on the Palos Verdes Peninsula.

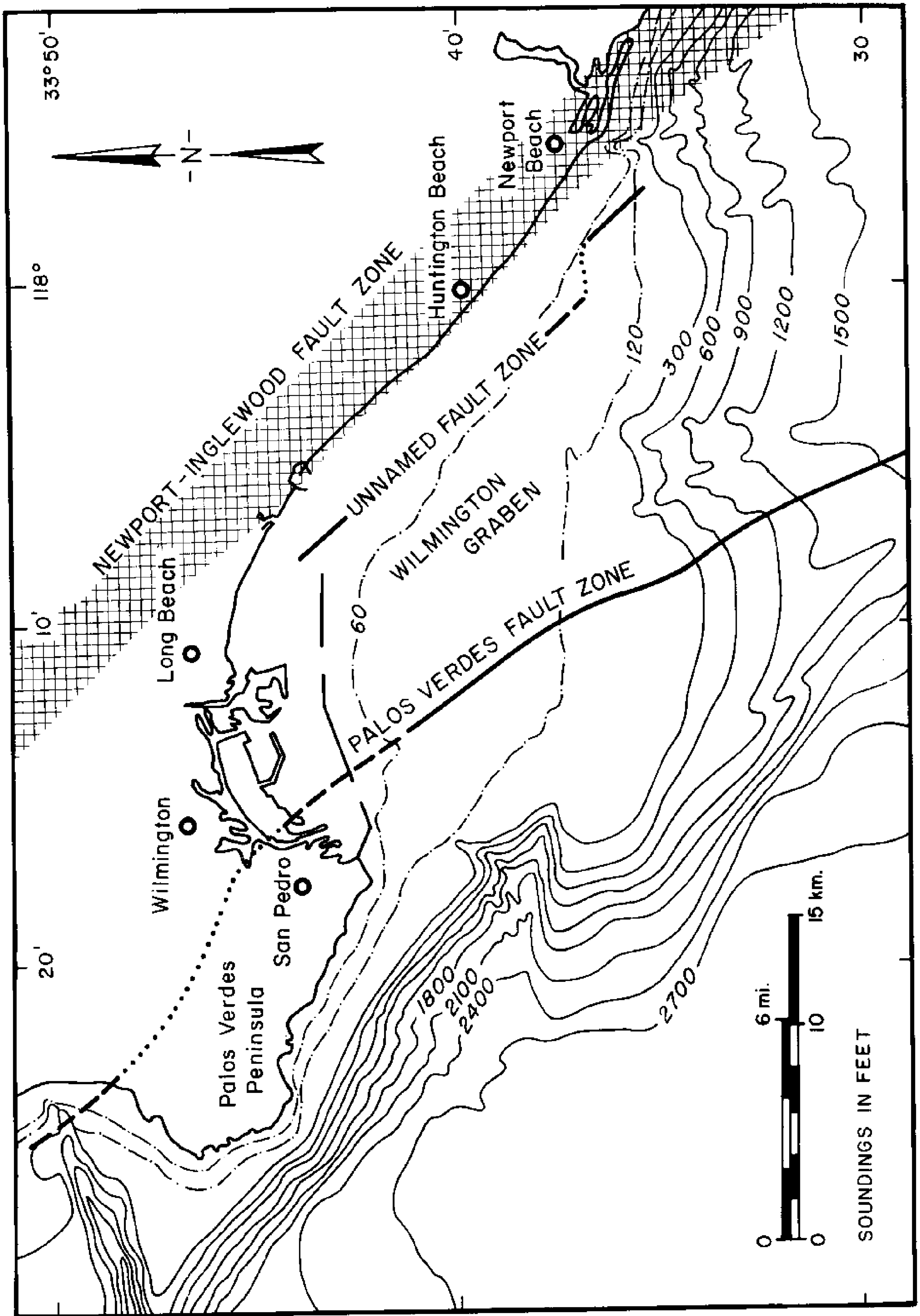


Figure 21. Map of San Pedro shelf showing bathymetry and major structural elements (after Fischer and others, 1977).

The San Pedro anticlinorium parallels the fault zone in the southern part of the shelf, but diverges westward near the Palos Verdes Hills anticlinorium. The syncline between these two features forms the San Pedro sea valley.

Folding of strata assigned to the Monterey Shale (middle to late Miocene-early Pliocene), which occurs in the Palos Verdes Hills and underlies a broad ridge in the bay, occurred after deposition of lower Pliocene strata and prior to deposition of much of lower Pleistocene strata (Yerkes and other, 1965). The Palos Verdes fault zone was active in middle to late Pleistocene time, which resulted in uplifting the Palos Verdes Hills at least 390 m above present sea level, and depressing the adjacent block from 150 to 300 m (Yerkes and others, 1965). Continued activity of the Palos Verdes fault zone to the present is demonstrated by seismic data (Hileman and others, 1973; Teng and Henyey, 1975).

The Newport-Inglewood fault zone is expressed at the surface as a series of discontinuous low hills or mesas in the San Pedro Bay area (Poland and others, 1956). Landing Hill, Bolsa Chica, Huntington Beach and Newport Mesas border San Pedro Bay. These are transected by Dominguez, Alamitos, Sunset and Santa Ana gaps through which Holocene alluvial deposits of the Los Angeles basin extend to the coast. The Newport-Inglewood fault zone extends offshore south of Newport Mesa, and is characterized by dexteral shear with associated vertical separation not exceeding 60 m at the base of the Quaternary (Yerkes and others, 1965). Poland and others (1956) discussed the Quaternary history of this deformed area. Several of the mesas, the lowest terrace of the San Joaquin Hills, and the lowest terrace of the Palos Verdes Hills formed a continuous surface of marine planation at the end of the Pleistocene. The present gaps originated as antecedent stream valleys. Trenching associated with the Santa Ana and Dominguez gaps occurred to a maximum depth of 75 m, or to 45 m b.p.s.l.

The Wilmington graben forms the major structural depression in the San Pedro shelf. The Palos Verdes fault zone borders the graben to the southwest (Fig. 21), and associated faults cause strata in the graben to flank against beds assigned to the Monterey Shale. These strata dip toward the graben and attain an almost horizontal attitude in the central part of the graben. The eastern boundary of the graben is less distinct. Junger and Wagner (1977) suggest either a discontinuous series of faults terminating in lower Pliocene strata or a dip flank with no faults. Seismic reflection data used for the present study show that a major east-trending dip flank occurs directly offshore of Huntington Beach. It is associated with several faults cutting Pleistocene and Holocene strata with offsets less than 10 m. These may be tensional structures resulting from dextral shearing.

Although San Pedro shelf is thought to be part of a continous crustal block linked with the Palos Verdes Hills and the Santa Monica shelf, it shows a different recent geologic history than that of the adjacent coastal plain, which suggests that this block has not always been in contact with the remainder of the western margin of the Los Angeles basin (Nardin and Henyey, 1978).

Moore (1954) studied the western part of the San Pedro shelf, and identified six types of sediment based on color and grain-size characteristics. Gorsline and Grant (1972) described the sediment texture and areal distribution of major, near-surface strata on San Pedro shelf in terms of sediment transport mechanisms, particularly resedimentation and wave and current transport. Gorsline and Grant (1972) reported that most of the near-surface sediment on the shelf is silt and fine sand, and the coarse-grained sand consists of iron-oxide stained grains that were deposited in coastal environments near to outcrops of Tertiary strata. The occurrence of Pleistocene foraminifera in the yellowish-brown sand units (Crouch, 1954) suggests that these are relict strata, perhaps correlative with the Timm's Point Silt Member of the San Pedro Formation.

Greene and others (1975) prepared two isopach maps for strata on the San Pedro shelf: one map shows the combined thickness for both Pleistocene and Holocene strata, and the second shows only those strata above a nearly horizontal erosional surface cut during the last major Wisconsin emergent event.

Junger and Wagner (1977) used seismic reflection profiles to interpret much of the pre-Quaternary stratigraphy of the San Pedro shelf.

Methods

The methodology used to study the stratigraphy of San Pedro shelf is very similar to that employed in Santa Monica Bay. A total of 383 km of high-resolution (3.5 kHz) seismic reflection profiles was obtained from the U. S. Army Coastal Engineering Research Center, as were sample splits from 23 vibracores taken during June and July, 1974. An additional 26 vibracores were collected by the University of Southern California during May and June, 1978, and a final set of 8 vibracores was taken in October, 1979. Both the U. S. Army Corps of Engineers' and the University of Southern California's vibracoring programs were concentrated east of the Palos Verdes fault zone, where thicker Quaternary strata occur in the Wilmington graben (Fig. 22). It should be noted that many of the sedimentary packages on the San Pedro shelf are rather linear and discontinuous, particularly near the fault zones. The average length of recovered core is 3.03 m, and the maximum length is 6.75 m.

Conventional grain-size analysis by sieving at half-phi intervals was performed on the sand population of 24 Pleistocene and 355 Holocene samples. Petrographic analysis was performed on the sand fraction of 9 Pleistocene and

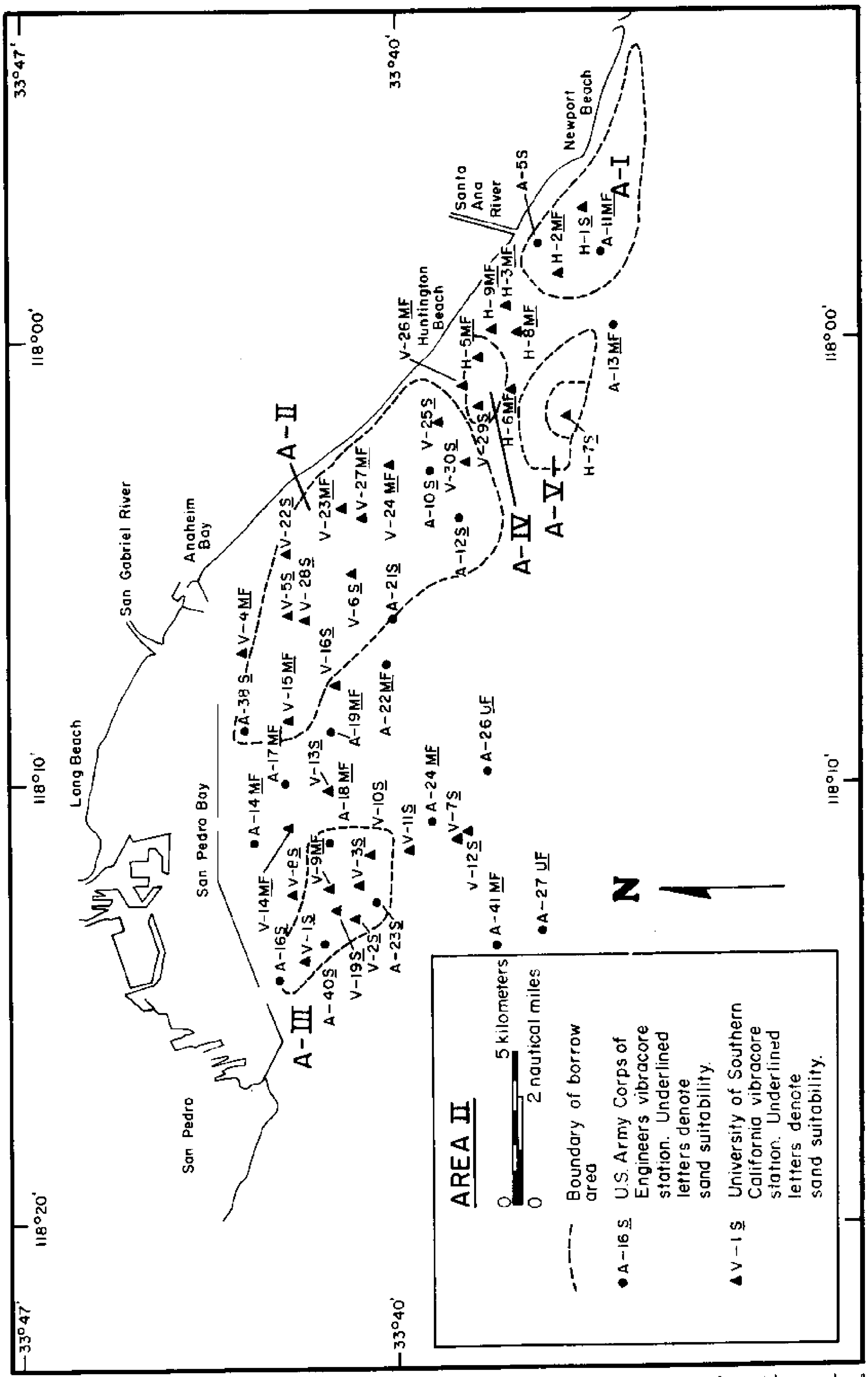


Figure 22. Map of area II showing locations of borrow areas A-I through A-V with associated vibracore numbers and sand suitability symbols.

115 Holocene samples. Relevant core and sediment sample data are presented in Appendices A through D.

Quaternary Stratigraphy

Upper Pleistocene Strata

The San Pedro shelf contains upper Pleistocene strata within the Wilmington graben and possibly west of the Palos Verdes fault zone. Greene and others (1975) have indicated the locations of Pleistocene strata using Quaternary and Holocene isopach maps. West of the Palos Verdes fault zone, they show Pleistocene deposits existing only in the San Pedro sea valley, and suggest that such deposits formed as slump or canyon fill. Pleistocene deposits from 10 to 20 m thick occur as a feeder channel to the San Pedro sea valley just south of the breakwater and across the broad ridge of exposed Monterey Shale.

Greene and others (1975) show a maximum thickness of 70 to 80 m of Pleistocene strata within the Wilmington graben, whereas Fischer and others (1977) estimate a maximum thickness of 300 to 350 m within this structure. Fischer and others (1977) have described the upper 120 to 150 m of late Pleistocene strata from cores taken at the shelf edge and slope west of the San Gabriel submarine canyon. They identified four stratigraphic units, which are, in ascending order: (1) approximately 30 m of silty clay and clayey silt dated at approximately 90,000 to 100,000 years BP; (2) and (3) two similar sedimentary packages (60 m and 30 m thick, respectively) consisting of basal channel deposits and clay, sand and gravel channel fill, and silt, all of which grade to silt downslope, and (4) the uppermost Pleistocene unit consisting of clayey silt and channel fill deposits found in slope gullies (0 to 30 m thick), which have an apparently gradational contact into strata assigned to the Holocene. Uplift along the Palos Verdes fault zone has truncated and draped these strata to the west. Junger and Wagner (1977) identified Pleistocene cross-stratified deposits in the San Pedro shelf. These strata extend to the shelf edge, where the foreset units apparently continue as slope deposits. The large-scale cross-stratified character of these deposits suggest possible lithostratigraphic correlation with the San Pedro Sand (Junger and Wagner, 1977).

Considering that many of these late Pleistocene sedimentary packages formed as nonmarine terrace cover or shallow marine deposits, they are thought to contain suitable sand for beach nourishment and restoration programs. It should be noted that it is difficult to correlate the vibracore and seismic data, because the recovered cores barely penetrate depths below the initial signal pulses. Furthermore the absence of radiometric age determinations and microfaunal analyses make it difficult to assign accurate ages to these deposits.

Upper Pleistocene strata are tentatively identified in only five cores: A-16, V-1, A-40, V-2 and A-23. Figures 21 and 22 show that these cores occur in a narrow strip within and adjacent to the Palos Verdes fault zone. The sand within this strip is iron-oxide stained, medium- to coarse-grained, moderately- to well-sorted, subrounded to rounded, and has a dull polish. Although this upper Pleistocene sand is only slightly more rounded than Holocene sand on San Pedro shelf, its worn appearance and dull polish are quite distinctive.

On the Holocene isopach map prepared for this study, cores A-40, V-2 and A-23 are aligned with the Palos Verdes fault zone in an area of zero Holocene thickness. These vibracores occur in a northwest-trending strip of dipping, stratified deposits which are upthrown between folded Mio-Pliocene shale to the west and Holocene strata to the east. The relatively mature textural characteristics of this Pleistocene sand may reflect initial deposition in a high mechanical-energy environment or selective sorting associated with periodic uplift along the Palos Verdes fault zone.

Although Pleistocene sand is concentrated within the Palos Verdes fault zone, it might be expected to overlap other strata over a more extensive area. Vibracores A-16 and V-1 contain sediment with characteristics similar to those observed in the area of submarine exposure (vibracores A-40, V-2 and A-23), i.e. iron-oxide stained sand and gravel with a dull polish. In core A-16, presumed Pleistocene coarse-grained sediment is intercalated with and overlaps Holocene fossiliferous silt and clay, which suggests continued resedimentation of older and coarser-grained sediment over at least parts of San Pedro shelf.

Another area of possible Pleistocene exposure occurs offshore of Huntington Beach. Obtained seismic reflection profiles indicate that this is an area of upthrown blocks along the eastern margin of the Wilmington graben. Greene and others (1975) and Rudat (1980) suggested the presence of late Pleistocene deposits in this area, but recovered cores from this area do not contain the stained, rounded and polished sand grains typical of late Pleistocene strata within the Palos Verdes fault zone. Instead, these strata are predominantly silt and very fine-grained sand with intercalated conglomeratic lenses with pebbles and cobbles as much as 15 cm in diameter. Although it is possible that these strata are late Pleistocene and represent a different stratigraphic interval or facies, most cores demonstrate that these conglomeratic lenses are encased in very fine-grained sand, silt and clay, which are very similar to Holocene strata on other parts of the shelf. Thus it seems equally or perhaps more likely that these conglomeratic lenses represent Holocene channel fill and/or landslide deposits associated with Santa Ana or Bolsa gaps. Due to the small number of recovered Pleistocene samples, their textural and compositional characteristics are included with the discussion of Holocene lithology.

Holocene Strata

Greene and others (1975) show sedimentary deposits which occur above a nearly horizontal, shelf-wide erosional surface, which is thought to have been cut during the last major Wisconsin emergent event. Thicknesses assigned to these deposits range from zero where Monterey Shale is exposed on the sea floor to as much as 50 m extending into the San Gabriel submarine canyon. Most of the shelf area is characterized by Holocene strata ranging from 5 to 15 m thick (Greene and others, 1975). Locations of zero Holocene thickness were indicated off Huntington Beach, Sunset Beach, Landing Hill, and behind the breakwater near Long Beach. Several discontinuous faults which offset the base of the Holocene were identified, and these are on trend with the northeastern boundary of the Wilmington graben.

A similar Holocene isopach map was prepared by Rudat (1980), which concentrated on the area of the San Gabriel submarine canyon. Rudat (1980) identified several thick channel deposits and ancient feeder canyons in this area, and suggested three major areas with zero Holocene thickness; offshore of Huntington Beach, the Landing Hill-Anaheim Bay area, and an elongate area between these two locations.

Fischer and others (1977) studied a small area of the slope and shelf edge near the San Gabriel submarine canyon, where they identified the Pleistocene-Holocene boundary from 10 to 13 m below the present sea floor. Basal Holocene strata at this locality consist of silty sand with abundant molluscs, which grade upward into silt and silty clay, and then to very fine sand and silt. Middle-neritic, Holocene foraminifera occur throughout these deposits. Core samples from the slope indicate continuous deposition through the Pleistocene-Holocene boundary, whereas Holocene strata at the shelf edge unconformably overlie latest Pleistocene channel deposits.

Surficial sediment on the San Pedro shelf have been studied by Gorsline and Grant (1972) in terms of grain-size characteristics and the distribution of major sediment groups. The surficial sediment may be divided into five groups: (1) a reddish-stained, coarse-grained sand, thought to be a relict sand; (2) a Holocene detrital silt and sandy silt; and (3-5) three varieties of mixed populations of relict and modern detrital sediment. Two small patches of the relict sand occur near the Palos Verdes fault zone and a third occurs south of Anaheim Bay. The mixed populations occur adjacent to either relict patches or other mixed populations. However, the majority of San Pedro shelf is covered by detrital silt and sandy silt of Holocene age. Fischer and others (1977) describe surficial sediment at the shelf edge as very fine sand and silt.

High-resolution seismic reflection profiles used in the present study cover most of the San Pedro shelf. Strata identified in the profiles range in age from Miocene to Holocene, but much information is excluded for strata buried deeper than the first multiple. Nearshore data also is obscure due to multiples. In the absence of a single, nearly-horizontal erosional surface, the base of the Holocene is extrapolated from land-based data and correlated with major offshore reflectors.

Holocene Strata West of the Palos Verdes Fault Zone: Little or no Holocene sediment was identified in the area of folded and uplifted Monterey Shale west of the Palos Verdes fault zone; however, the 1 m limit of resolution of the seismic data must be kept in mind. Where strata are present above truncated Monterey Shale, there is no obvious, single erosional or nondepositional break within the sedimentary packages, therefore such units are arbitrarily assigned to the Holocene.

Due to their parallel, nearly horizontal stratification, these beds may have accumulated, given a low but rather continuous sediment supply, during a submergent event and/or the seaward tilting of the upthrown Palos Verdes Hills block. Several stronger reflectors within this package may indicate minor periods of nondeposition perhaps related to sea level standstills. Due to the presence of the Palos Verdes Hills and submarine ridge of Tertiary rocks, the western part of San Pedro Bay probably did not receive fluvial sediment during the late Pleistocene and early Holocene; however, fluvially-derived sediment is a major stratigraphic component east of the Palos Verdes fault zone.

Along the western edge of the shelf, several faults offset the presumed base of the Holocene. Such faults are located immediately offshore from Point Fermin and along the nose of the San Pedro Bay anticlinorium. The positions of these faults are not in exact agreement with Greene and others (1975), but they are similar in location and abundance. These faults generally show very abrupt vertical offsets of 5 to 10 m, but as much as 23 m of vertical offset is documented offshore of Point Fermin.

Holocene Strata Within the Palos Verdes Fault Zone: The Palos Verdes fault zone consists of a series of parallel faults. Miocene and Pliocene strata occur at the surface west of this fault zone, whereas Holocene strata occur to the east. A thin upthrown strip within the fault zone is of uncertain age, but lithologic characteristics suggest it is most likely late Pleistocene in age.

Immediately south of the breakwater, the zone of faulting widens, and as much as 10 m of Holocene strata have accumulated in this area. North of the breakwater, Greene and others (1975) indicate the presence of at least 20 m of Holocene sediment within the fault zone, and suggest that this succession continues unbroken across the fault zone to the northeast. Although this area contains a thinner Holocene sequence than the adjacent Wilmington graben, the accumulation of sediment here probably represents a stratigraphic extension or component of the lower Holocene tongue which lies beneath Dominguez gap.

Holocene Strata Within the Wilmington Graben: The western margin of the Wilmington graben contains the thickest section of Holocene channel-fill deposits. Onshore, the Dominguez gap is marked by a lower Holocene basal gravel occurring 45 m b.p.s.l. (Poland and others, 1956). If this deposit is extended seaward on trend with the Palos Verdes fault zone, the base of the Holocene corresponds with a series of channeled, discontinuous reflectors ranging from 45 to 55 m b.p.s.l. The Holocene isopach map prepared in conjunction with this report shows the thickest area, exceeding 30 m, occurs in the central part of the San Pedro shelf. The thickness of Holocene strata decreases southeastward along the fault zone, and thins to about 10 m along the uplifted eastern flank associated with the Wilmington graben. These values are slightly greater than those reported by Greene and others (1975) and Rudat (1980), but are consistent in terms of relative proportions.

There are at least two distinct reflectors in the mid-graben area which may represent the Pleistocene-Holocene boundary. These two reflectors occur approximately 35 and 45 m b.p.s.l., or about 10 and 20 m below the sea floor. Vibracores in this area do not penetrate identifiable Pleistocene deposits, therefore the upper reflector probably lies wihin the Holocene stratal package. Poland and others (1956) mention a secondary standstill of the Holocene rise in sea level, which allowed basal gravels to accumulate beneath Bolsa Gap to the north. Such an event also might explain the occurrence of one or more distinct seismic reflectors within the offshore

Holocene deposits.

In a general sense, the Wilmington graben is a broad syncline with its axis aligned with the thickest part of Holocene channel-fill deposits. Several distinct and continuous seismic reflectors occur within late Pleistocene strata underlying the Holocene package. Such reflectors are quite deep, and are obscured in many places by multiples. In the central part of the graben, two major horizons occur approximately 70 and 75 m b.p.s.l. These surfaces may be correlative with the uppermost Pleistocene strata described by Fischer and others (1977) at the shelf edge, but no lithologic or palentologic data are available to support this concept.

Holocene Strata East of the Wilmington Graben: East of the Wilmington graben, late Pleistocene tectonism along the Newport-Inglewood fault zone created relief on the order of tens of meters. This paleotopography resulted in the deposition of fluvial strata and the occurrence of terraces. A similar structural and sedimentologic style continued into the early Holocene, as the eastern part of the San Pedro shelf is characterized by many small faults, which controlled fluvial deposition during this time. Structural contours shallow toward shore between the San Gabriel River and Newport Bay, which reflects control by the coastal topography. Holocene strata between Bolsa and Santa Ana gaps enable the identification of two lowered base levels along the coast at approximately 25 and 45 m b.p.s.l. (Poland and others, 1956). Lower Holocene strata in Bolsa gap probably extend offshore and curve to the west.

Although stratal thicknesses generally agree with those proposed by Greene and others (1975) and Rudat (1980), differences exist regarding the location and areal extent of zero Holocene thickness (Pleistocene sediment exposures). Both Greene and others (1975) and Rudat (1980) indicate a large Pleistocene exposure just offshore of Anaheim Bay, but this is not evident on obtained seismic profiles. Present data suggest that one, rather large

Holocene channel extends from Anaheim Bay through the area of presumed zero Holocene thickness. Further east along the coast, other areas of zero Holocene thickness coincide with but are generally smaller in areal extent than suggested by previous authors. These differences probably reflect the difficulty of interpreting nearshore data due to obscuring multiples.

Although the eastern boundary of the Wilmington graben only can be identified in Quaternary strata as a series of small discontinuous faults, a steeply-dipping flank within the faulted area occurs offshore of Huntington Beach. Pleistocene strata beneath the Holocene cover in this area dip more steeply and show greater fault separations than the Holocene deposits.

West of Newport submarine canyon, Holocene strata become as thick as 40 m, and can be divided into two distinct depositional packages. The lower package is characterized by relatively strong, parallel, flat-lying, discontinuous reflectors, which change seaward to obliquely prograding strata. The upper package is thickest nearshore and just west of Newport submarine canyon, and is characterized by weaker reflectors occurring in a low-angle, S-shaped configuration. The relatively steep, prograding strata asssigned to the lower unit formed in higher-energy depositional environments than the low-angle prograding strata assigned to the upper unit (Mitchum and others, 1977). A change from higher to lower mechanical energy can be accomplished by a sea level rise or basinal subsidence, and/or a decrease in the volume or a change in the type of sediment delivered to the shelf. Considering the Holocene sea level rise, regional and local tectonic activity and resultant sedimentologic response, all of the factors probably contributed to the observed stratigraphic relationships.

East of the Newport submarine canyon, the lower and upper Holocene units extend for approximately 1 km, and then thin to a stratigraphic package generally less than 20 m thick.

Lithology

Due to the marked variability of the upper Pleistocene and Holocene sedimentary packages in San Pedro Bay, the general lithology of each major unit was presented in the preceding sections regarding "Quaternary Stratigraphy."

Pleistocene sand samples (n = 25) in San Pedro Bay average about 0.40 mm (1.32 phi) in diameter, and are moderately sorted (phi standard deviation = 0.91). The sand fractions are generally negatively skewed, and range from strongly coarse-skewed (phi skewness = -2.92) to strongly fine-skewed (phi skewness = 0.36). Kurtosis values range from very leptokurtic (phi kurtosis = 1.09) to extremely leptokurtic (phi kurtosis = 4.62).

Holocene sand samples (n = 317) average 0.18 mm (2.47 phi) in diameter, and are moderately well sorted (phi standard deviation = 0.69). The Holocene sand fractions also are generally negatively skewed, and range from strongly coarse-skewed (phi skewness = -6.42) to strongly fine-skewed (phi skewness = 1.04). Kurtosis values range from very leptokurtic (phi kurtosis = 2.17) to extremely leptokurtic (phi kurtosis = 67.72).

Compositionally, the upper Pleistocene and Holocene sand samples from San Pedro Bay are quite similar (Table 8). As in Santa Monica Bay, most samples may be classified as lithic arkose and a subordinate number as feldspathic litharenite (McBride, 1963). Due to the relatively small size of the upper Pleistocene sample set (n = 9), critical comparison with the Holocene set is not justified.

Observed pebbles and lithic clasts identified petrographically are dominantly acid plutonic rock as well as gabbro, syenite, gneiss and basalt. The presence of these lithologic constituents indicate that the San Gabriel

Table 8. Summary of lithologic composition of sand from samples recovered from San Pedro Bay.

LITHOLOGIC COMPOSITION	UPPER PLEISTOCENE n = 9 Mean %	HOLOCENE n = 115 Mean %	TOTAL n = 124 Mean %
Monocrystalline Grains			
Nonundulose Quartz	0.67	1.04	1.02
Undulose Quartz	12.21	11.74	11.78
Plagioclase Feldspar	25.82	28.90	28.68
Potassium Feldspar	12.01	11.47	11.51
Pyroxene	0.82	0.56	0.58
Amphibole	0.53	0.97	0.94
Biotite	0.67	2.83	2.68
Magnetite-Ilmenite	0.27	0.13	0.14
Polycrystalline Grains			
Quartz with 2-3 subunits	1.14	1.66	1.62
Quartz with >3 subunits	3.26	4.15	4.08
Plutonic Rock	13.82	12.19	12.31
Metamorphic Rock	5.06	2.98	3.13
Volcanic Rock	0.11	0.68	0.64
Siliciclastic Rock	6.23	7.27	7.20
Allochemical Constituents	2.88	3.40	3.36
Microcrystalline Quartz	0.44	0.23	0.25

Mountains were the principal source terrain for Quaternary strata in San Pedro Bay. Yerkes and others (1965) reached a similar conclusion. As in Santa Monica Bay, feldspar predominates over quartz and plagioclase over k-feldspar in both the upper Pleistocene and Holocene sample sets.

Potential Sand and Gravel Resources

The Preliminary "Quick Look" Report on Offshore Sand Resources in Southern California (U. S. Army Coastal Engineering Research Center) identified three potential borrow areas (A-I, A-II and A-III) that were estimated to contain at least 349 x 10^6 m^3 of sand suitable for beach nourishment and restoration (Fig. 22). Additional seismic and vibracore data available in the present study indicate that this estimate should be revised to a minimum of approximately 243.9 x 10^6 m^3 and a maximum of 349.4 x 10^6 m^3 for these three areas. Furthermore, two additional borrow areas (A-IV and A-V) have been located offshore of Huntington Beach (Fig. 22). The total volume of suitable sand in these two areas range from 17.8 x 10^6 m^3 to 33.1 x 10^6 m^3, thus the total volume of suitable sand from the five potential borrow areas in San Pedro Bay range from 261.7 x 10^6 m^3 to 382.5 x 10^6 m^3. These borrow areas are discussed in a format similar to that used for Santa Monica Bay. The interested reader also might refer to Evans and others (1982) who discuss various aspects of offshore sand and gravel mining on the San Pedro and San Diego shelves.

Due to the sedimentologic and structural complexity of the San Pedro shelf and adjacent coastal areas, three basic stratigraphic units are employed for this resources analysis: (1) an older Pleistocene unit (PI), which is characterized by large-scale, planar cross-strata; (2) a younger Pleistocene unit (PII) characterized by indistinct reflectors; and (3) undifferentiated Holocene strata characterized by distinct, parallel seismic reflectors.

Potential Borrow Area A-III

Borrow area A-III is located between the 16 and 24 m isobaths southeast of Palos Verdes Peninusla and south of the Los Angeles-Long Beach breakwater (Table 9, Figs. 22 and 23). The strata included within this borrow area are assigned to the undifferentiated Holocene package with minor quantities assigned to Pleistocene units PI and PII (Fig. 24). The target material generally consists of fossiliferous, dark- to olive- to yellow-gray, moderately- to well-sorted, fine- to medium-grained sand (Fig. 25). This borrow area is estimated to contain from 34.0 to 78.8 x 10^6 m^3 of suitable sand.

Potential Borrow Area A-II

Borrow area A-II lies between the 2 and 29 m isobaths and extends from the eastern end of the Los Angeles-Long Beach breakwater southeastward to Huntington Beach (Table 10, Figs. 22 and 26). These strata are assigned to the undifferentiated Holocene unit with a minor quantity assigned to Pleistocene units PI and PII (Fig. 27). Lithologically, these beds consist of dark- to medium-gray, moderately well-sorted, silty, fine- to medium-grained sand (Fig. 28). Borrow area A-II is the largest of the potential borrow sites in San Pedro Bay, and is estimated to contain from 148.3 to 168.2 x 10^6 m^3 of suitable sand.

Potential Borrow Area A-IV

Borrow area A-IV occurs between the 5 and 18 m isobaths south of Huntington Beach (Table 11, Figs. 22 and 29). This borrow area includes subequal volumes of strata assigned to Pleistocene unit PII and the undifferentiated Holocene unit (Fig. 30). This deposit contains at least 11.3 x 10^6 m^3 of suitable sand, which consists of dark-gray, moderately well-sorted, pebbly sand, locally underlain by an olive-brown, poorly-sorted,

Table 9. Summary of potential borrow area A-III.

Type of Deposit:

Undifferentiated Holocene strata and minor quantity of Pleistocene units PI and PII

Water Depth:

Minimum:	16 meters
Maximum:	24 meters

Range in Mean Grain Size: n = 63

Minimum:	3.64 phi	0.08 mm
Maximum:	0.92 phi	0.53 mm
Mean:	1.90 phi	0.27 mm

Range in Thickness:

Minimum:	2 meters
Maximum:	5.2 meters

Estimated Volume (x 10^6 m^3)		(x 10^6 yd^3)
Minimum:	34.0	44.5
Maximum:	78.8	103.1
Other:		Explanation of value:

Vibracores Penetrating Deposit:

A-16; V-I; A-=40; V-9; A-18; V-19; V-2; V-3; V-10; A-23

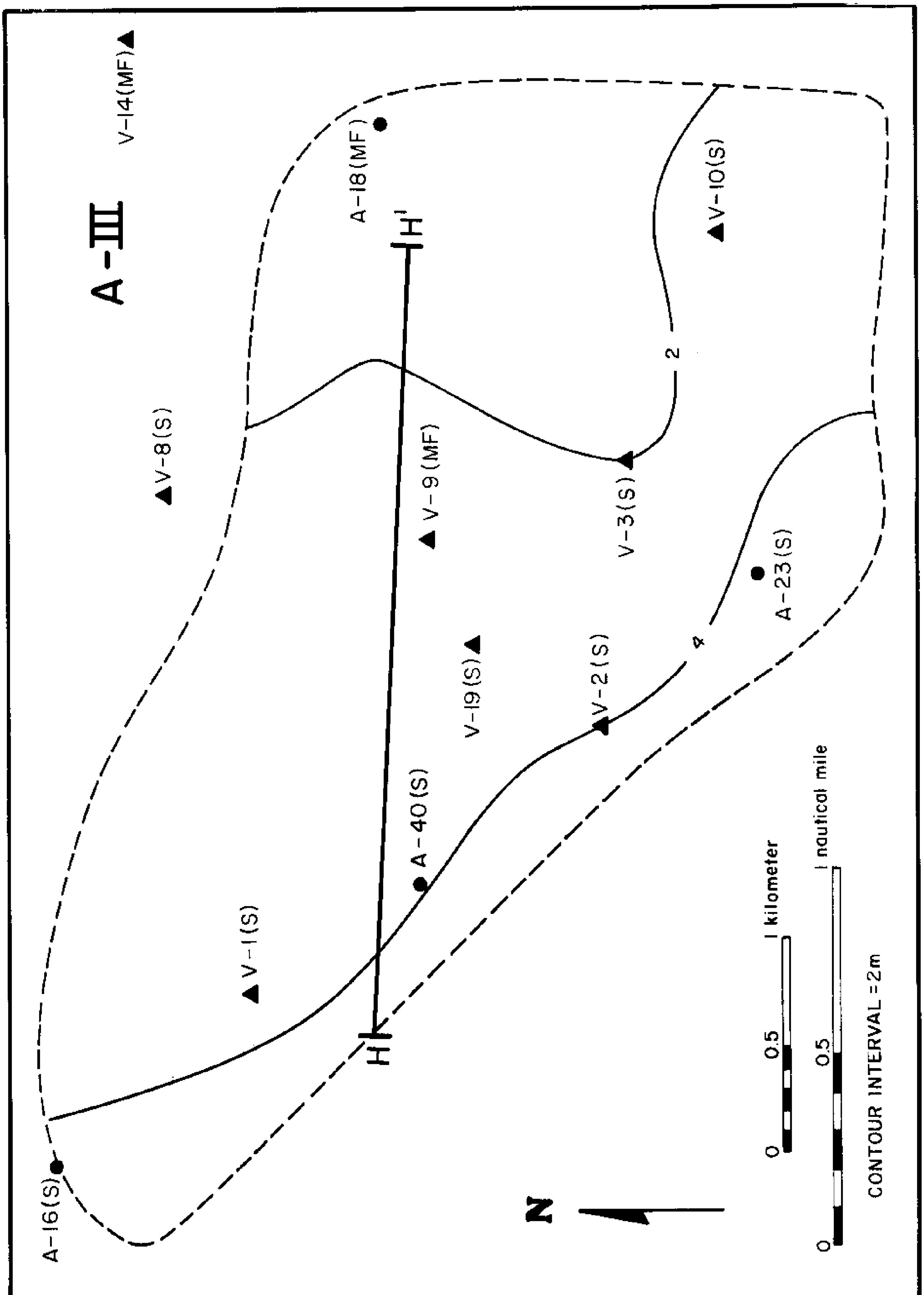


Figure 23. Isopach map of borrow area A-III with associated vibracore numbers, sand suitability symbols, and line of geologic cross section H-H'.

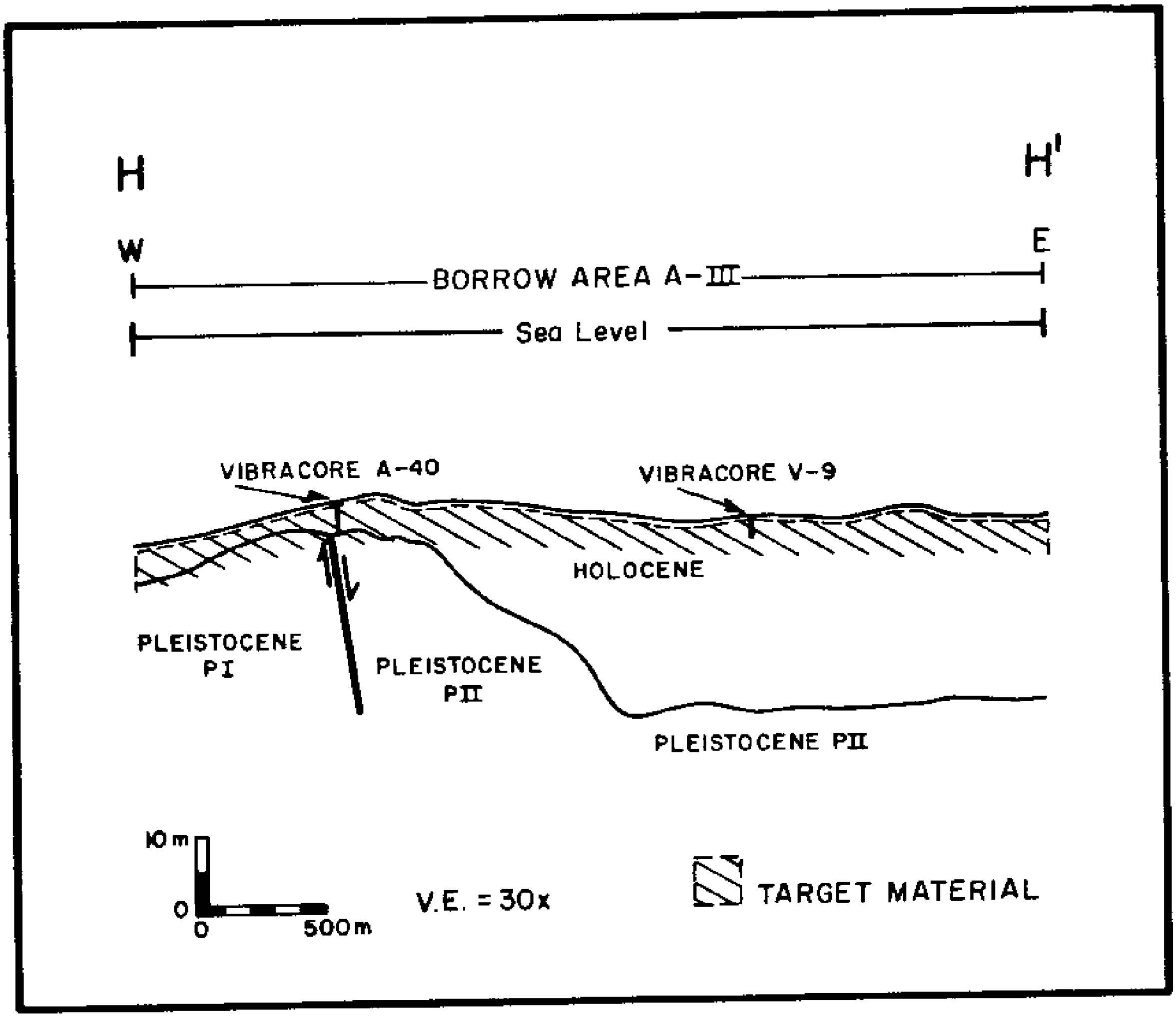


Figure 24. Geologic cross section H-H'.

VIBRACORE LOG

Core number: V-10

Date: 11/81

Total core length (cm): 665

Sheet 1 of 3

Number of core sections: 3

Water depth (ft):

Vertical scale: 1 cm = 25 cm

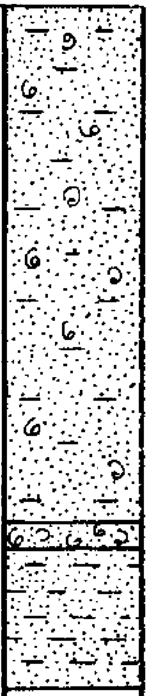
Distance in cm from top of core	Description	Log
0-109	Sand: fine-medium grained; ranges from clay silt size material to medium sand; light olive gray (5 Y 5/2); shell fragments; gradational lower contact.	
109-170	Sand: fine-medium grained; ranges from clay silt size material thru medium sand; dark gray (5 GY 4/1); abundant shell fragments; sharp lower contact.	
170-176	Sand: fine-medium grained; moderate yellow brown (10 YR 5/4); abundant shell fragments; sharp lower contact.	
176-222	Sand: fine grained; ranges from silt to fine sand; dark grey (N3); sparse shell fragments.	

Figure 25.1 Log of vibracore V-10 which is illustrative of the sedimentologic character of borrow area A-III.

VIBRACORE LOG

Core number: V-10
Total core length (cm): 665
Number of core sections: 3
Water depth (ft):
Date: 11/81
Sheet 2 of 3
Vertical scale: 1 cm = 25 cm

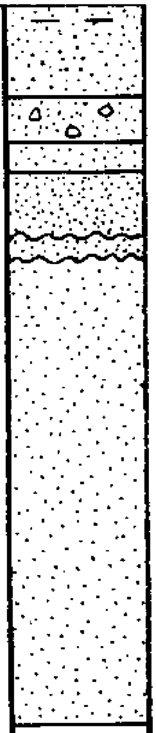
Distance in cm from top of core	Description	Log
222-252	Sand: fine grained; ranges from clay-silt material to some coarse pebbles; olive gray (5 Y 3/2); abundant shell fragments; sharp lower contact.	
252-267	Sand: fine-medium grained; ranges from fine sand to cobble size; dark gray (N3); sharp lower contact.	
267-277	Sand: fine-medium grained; yellow gray (5 Y 7/2); some layering shown by concentration of darker material; sharp color change below.	
277-300	Sand: fine-grained; medium dark gray (N4) to dark gray (N3); slightly mottled appearance; sharp lower contact.	
300-305	Sand: fine-medium grained; yellow gray (5 Y 7/2); contorted looking bed; sharp, comforted lower contact.	
305-323	Sand: fine grained; gray black (N2); gradational lower contact.	
323-357	Sand: fine grained; medium dark gray (N4); gradational contact concave up.	
357-377	Sand: fine-medium grained; yellow gray (5 Y 7/2); gradational lower contact.	
377-459	Sand: fine-medium grained; green gray (5 GY 6/1); mottled with fine-medium sand colored dary gray (N4).	

Figure 25.2 Log of vibracore V-10 which is illustrative of the sedimentologic character of borrow area A-III.

VIBRACORE LOG

Core number: V-10

Date: 11/81

Total core length (cm): 665

Sheet 3 of 3

Number of core sections: 3

Water depth (ft): ____

Vertical scale: 1 cm = 25 cm

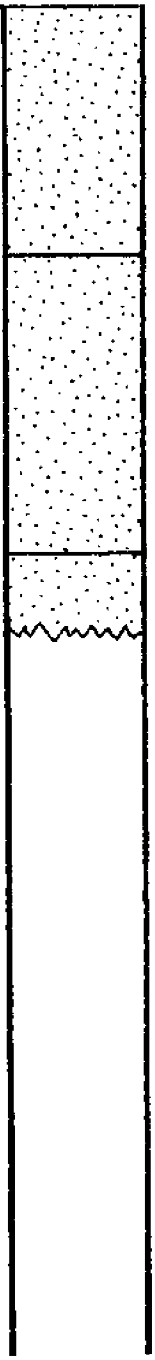
Distance in cm from top of core	Description	Log
459-542	Sand: fine-medium grained; 2 basic colors; dary gray (N3) and green gray (5 GY 6/1); darkness is a function of high % of dark minerals, not organics.	
542-640	Sand: fine-medium grained; interbedding between beds colored dark gray (N3) and green gray (5 GY 6/1); noticable lack of fossil fragments in this whole core; interbeds here dip at 60° angle due to vibracores going in at an angle.	
640-665	Sand: fine-medium grained as in 459-542.	

Figure 25.3 Log of vibracore V-10 which is illustrative of the sedimentologic character of borrow area A-III.

Table 10. Summary of potential borrow area A-II.

Type of Deposit:

Undifferentiated Holocene strata and minor quantity of Pleistocene units PI and PII

Water Depth:

Minimum: 2 meters

Maximum: 29 meters

Range in Mean Grain Size: $n = 93$

Minimum:	3.64 phi	0.08 mm
Maximum:	0.54 phi	0.69 mm
Mean:	2.17 phi	0.22 mm

Range in Thickness:

Minimum: <2 meters

Maximum: 5.5 meters

Estimated Volume	(x 10^6 m^3)	(x 10^6 yd^3)
Minimum:	148.3	194.0
Maximum:	168.2	220.0
Other:		Explanation of value:

Vibracores Penetrating Deposit:

A-38; V-15; V-5; V-22; V-28; V-6; V-23; V-27; V-24; A-10; V-25; A-12; V-30

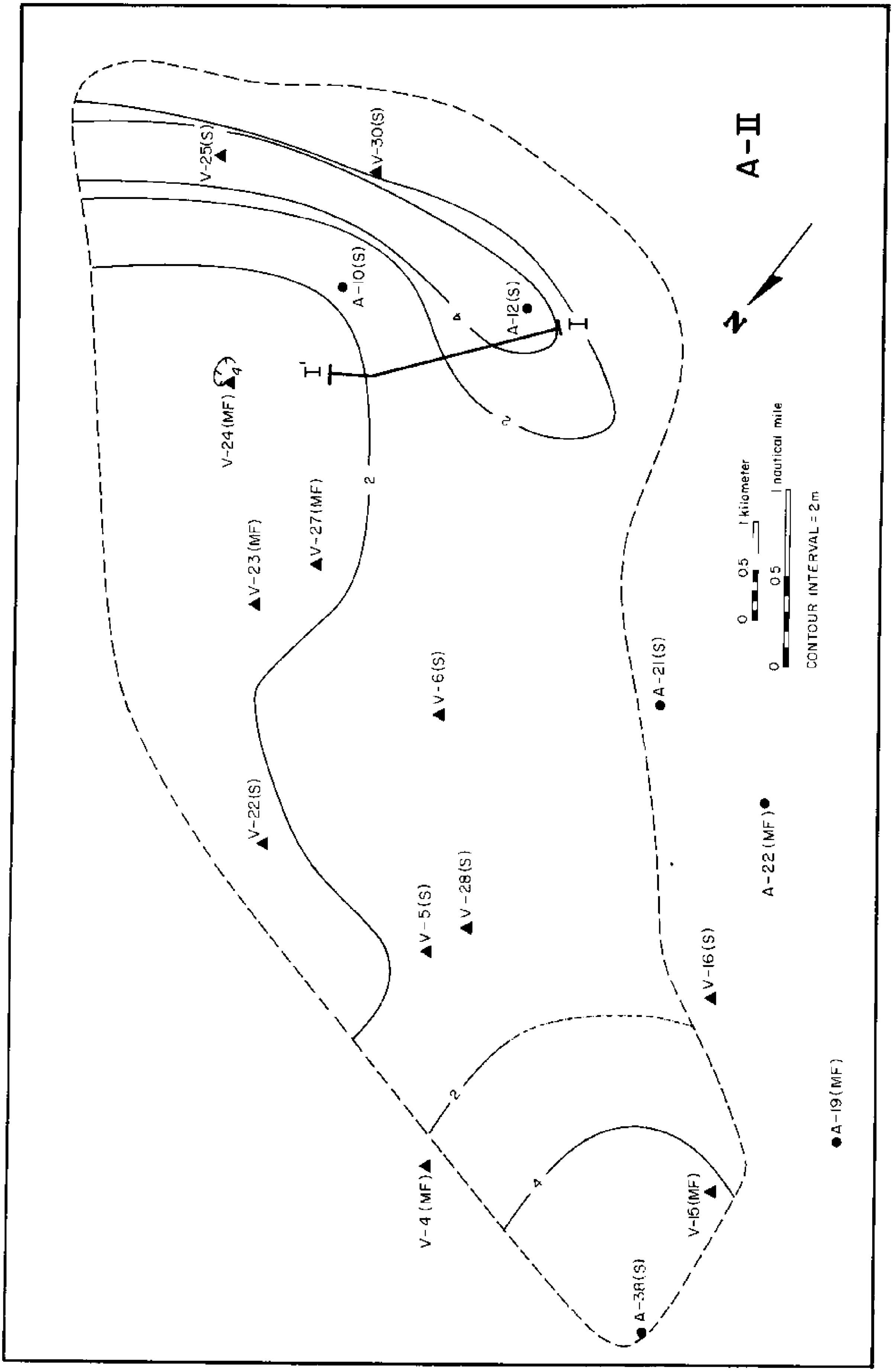


Figure 26. Isopach map of borrow area A-II with associated vibracore numbers, sand suitability symbols, and line of geologic cross section I-I'.

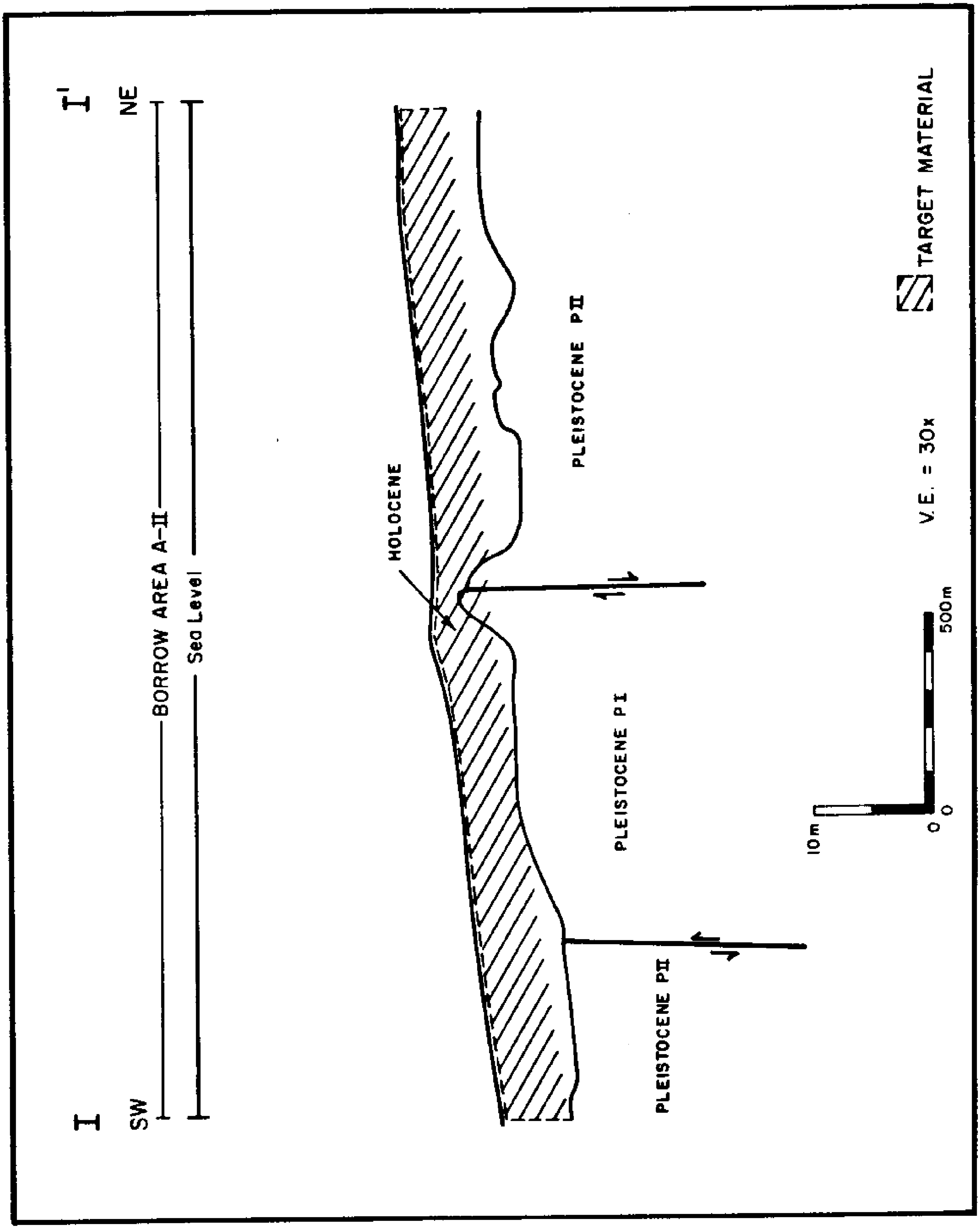


Figure 27. Geologic cross section I-I'.

VIBRACORE LOG

Core number: V-25
Date: 11/81
Total core length (cm): 530
Sheet 1 of 2
Number of core sections: 2
Water depth (ft):
Vertical scale: 1 cm = 25 cm

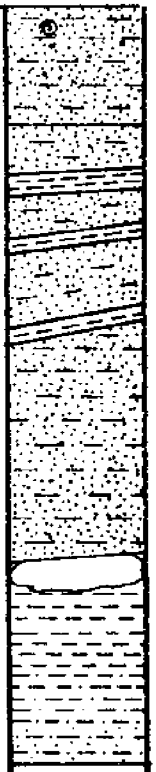
Distance in cm from top of core	Description	Log
0-36	Sand: silty very fine grained; moderately well sorted; olive black (5 Y 2/1); slightly micaceous; scarce shells sharp lower contact.	
36-52	Sand: silty fine-medium sand; moderately well sorted; oxidized a light olive brown (5 Y 5/6) to moderate olive brown (5 Y 4/4); slightly micaceous; sharp inclined lower contact.	
52-59	Silt: medium bluish gray (5 B 5/1); micaceous; sharp inclined lower contact.	
59-70	Sand: silty very fine to fine sand; moderately well sorted; slightly oxidized to olive gray (5 Y 4/1); micaceous with much muscovite; sharp inclined lower contact.	
70-74	Silt: clayey silt seam; medium bluish gray (5 B 5/1); sharp lower contact.	
74-100	Sand: silty very fine to fine grained; moderately well sorted; medium gray (N5) locally oxidized to a dark yellowish orange (10 YR 6/6); sharp lower contact.	
100-105	Silt: clayey silt; medium bluish gray (5 B 5/1); micaceous.	
105-177	Sand: silty very fine sand to sandy silt; moderately well sorted; medium blue gray (5 B 5/1) to medium dark gray (N4) with a few thin oxidation horizons; sharp lower contact.	
177-182	Rip up clast of mudstone composed of a silty clay; dusky yellow (5 Y 6/4) to medium bluish gray (5 B 5/1); sharp lower contact.	
182-246	Silt: clayey silt grading to a very thin bedded silty very fine to fine sand; moderately well sorted; medium bluish gray (5 B 5/1) to medium dark gray (N4) locally mottled by oxidation (moderate yellowish brown, 10 YR 5/4).	

Figure 28.1 Log of vibracore V-25 which is illustrative of the sedimentologic character of borrow area A-II.

VIBRACORE LOG

Core number: V-25

Date: 11/81

Total core length (cm): 530

Sheet 2 of 2

Number of core sections: 2

Water depth (ft):

Vertical scale: 1 cm = 25 cm

Distance in cm from top of core	Description
246-345	Sand: silty very fine grained grading downward to a silty, sandy, pebbly gravel; color ranges from medium gray (N5) to an olive black (5 Y 2/1) downward; pebbles are up to 2-3 cm and are subangular to subround granitics and siltstones; sharp lower contact.
345-399	Sand: slightly granular mud by fine to medium sand; poorly sorted; medium dark gray (N4); one large pebble at 590 cm.
399-442	Sand: silty fine to medium grained; moderately sorted; medium dark gray (N4); sandstone and plutonic pebble @ base: some granules and small pebbles throughout; sharp lower contact.
442-530	Sand: silty fine to medium sand; poorly sorted; grades downcore to a silty pebbly granular medium-coarse and; olive black (5 Y 2/1) locally oxidized to a moderate brown (5 YR 4/4).

Log

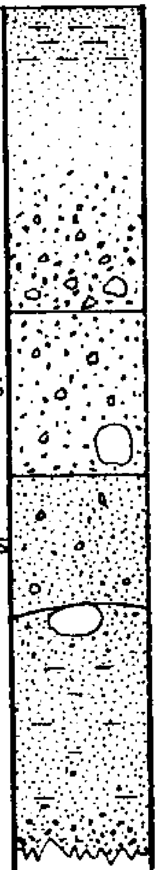


Figure 28.2 Log of vibracore V-25 which is illustrative of the sedimentologic character of borrow area A-II.

Table II. Summary of potential borrow area A-IV.

Type of Deposit:

Pleistocene unit PII and undifferential Holocene strata

Water Depth:

Minimum:	5 meters
Maximum:	18 meters

Range in Mean Grain Size: n = 7

Minimum:	3.47 phi	0.09 mm
Maximum:	1.00 phi	0.50 mm
Mean:	2.04 phi	0.24 mm

Range in Thickness:

Minimum:	3 meters	Vibracore and seismic coverage insufficient to isopach
Maximum:		

Estimated Volume	(x 10^6 m^3)	(x 10^6 yd^3)
Minimum:	11.3	14.8
Maximum:		
Other:		Explanation of value:

Vibracores Penetrating Deposit:

V-29; H-5

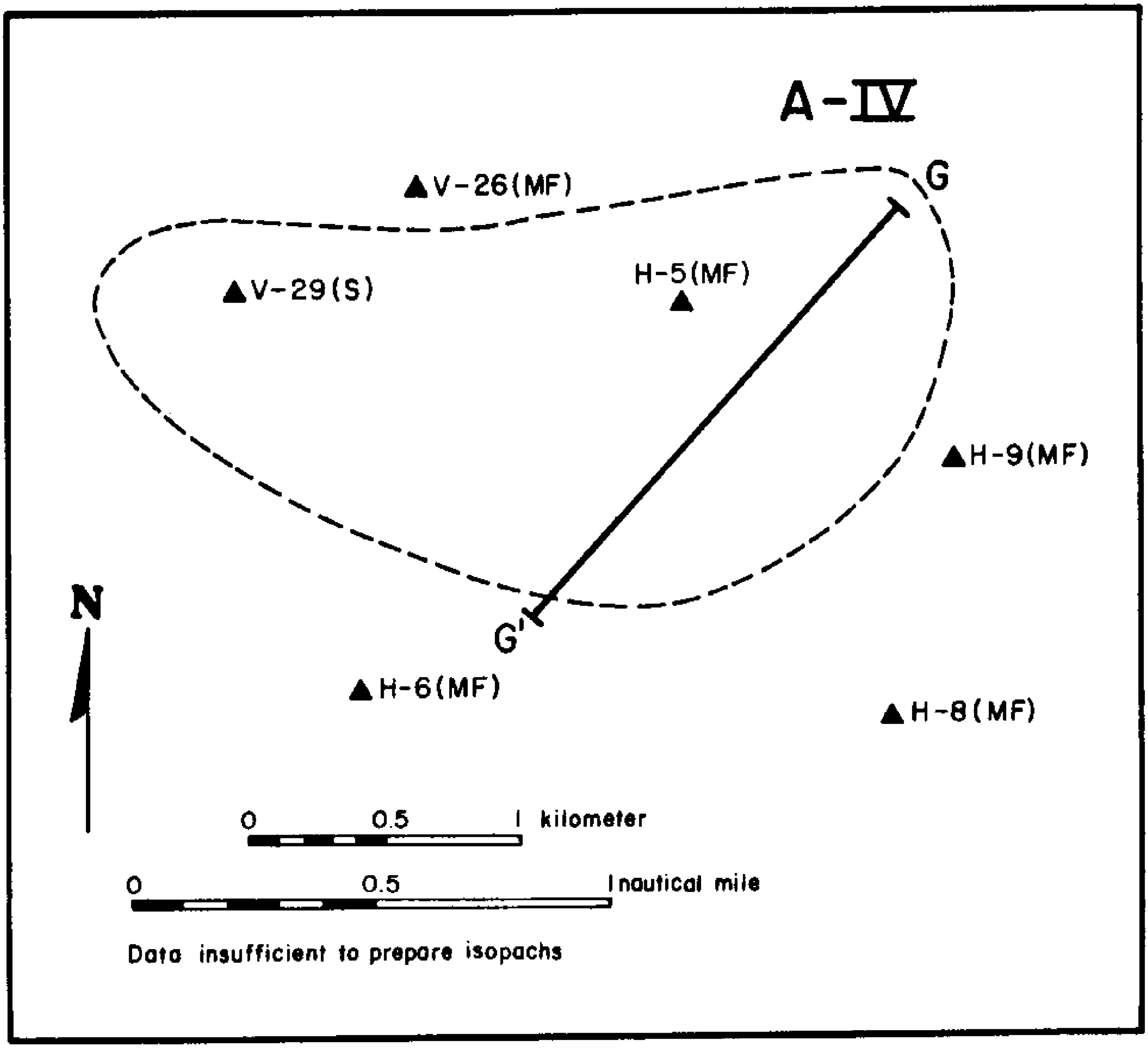


Figure 29. Map of borrow area A-IV with associated vibracore numbers, sand suitability symbols, and line of geologic cross section G-G'.

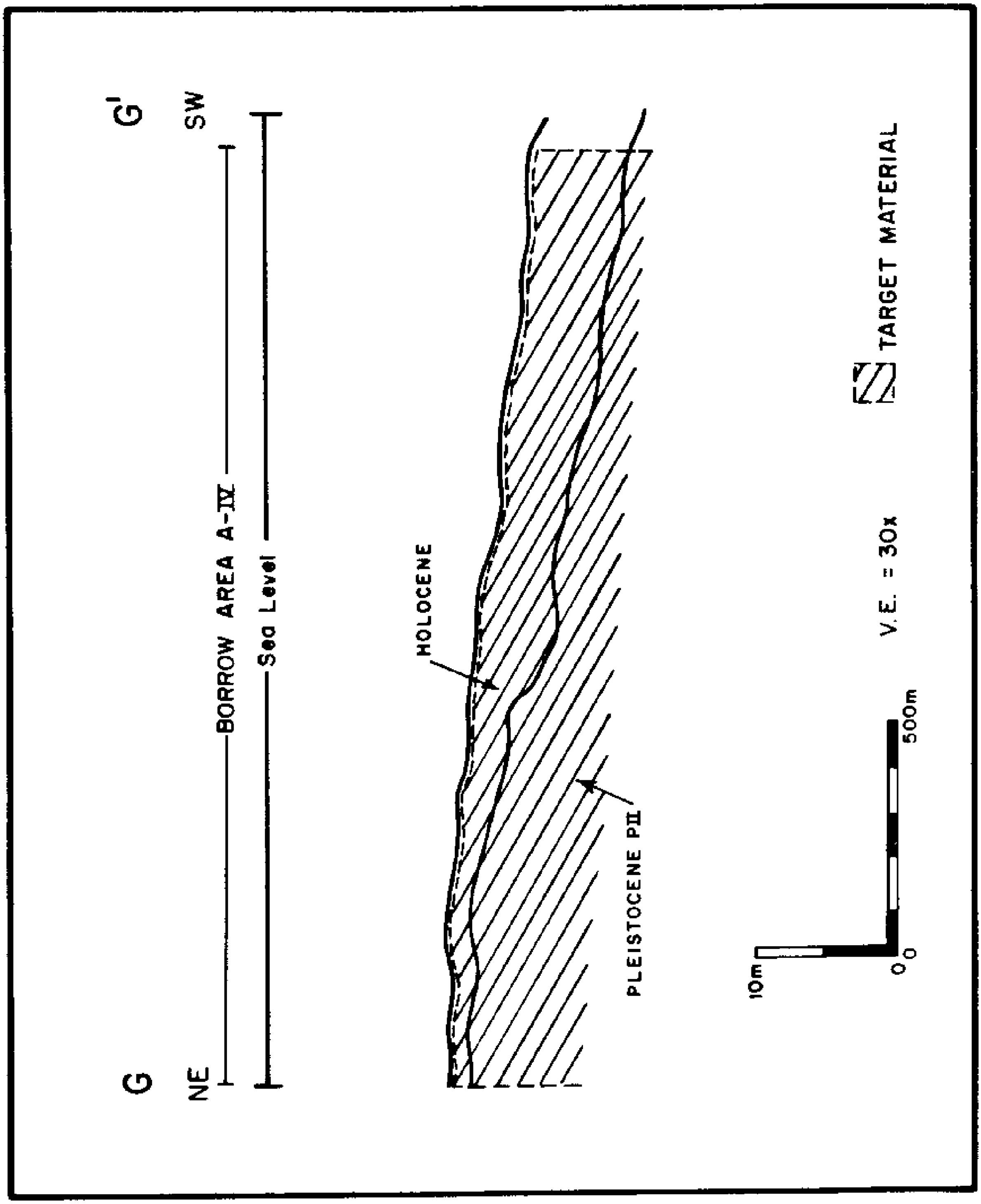


Figure 30. Geologic cross section G-G'.

VIBRACORE LOG

Core number: V-29

Date: 11/81

Total core length (cm): 132

Sheet 1 of 1

Number of core sections: 1

Water depth (ft):

Vertical scale: 1 cm = 25 cm

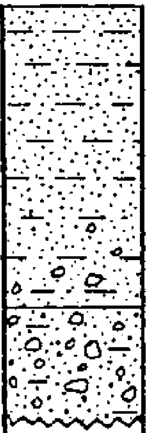
Distance in cm from top of core	Description	Log
0-99	Sand: silty very fine grained; moderately well sorted; medium dark gray (N4); slightly fossiliferous becoming abundant from 70-100 cm as sediments grade to a silty fine sandy pebbly gravel of plutonic composition; sharp lower contact.	
99-132	Gravel: silty coarse sandy pebbly gravel; poorly sorted; oxidized to a light olive brown (5 Y 5/6); pebbles are of plutonic composition; no shell fragments.	

Figure 31. Log of vibracore V-29 which is illustrative of the sedimentologic character of borrow area A-IV.

sandy gravel (Fig. 31). The lower gravel may be better suited for construction aggregate.

Potential Borrow Area A-V

Borrow area A-V is located between the 22 and 29 m isobath south of Huntington Beach and borrow area A-IV (Table 12, Figs. 22 and 32). The target material is assigned to the undifferentiated Holocene package, and consists of olive-gray, sparsely fossiliferous, moderately-sorted, fine- to coarse-grained sand (Figs. 33 and 34). Borrow area A-V is estimated to contain from 6.5 to 21.8 x 10^6 m^3 of suitable sand.

Potential Borrow Area A-I

Borrow area A-I lies offshore between the Santa Ana River and Newport Beach in water ranging from 5.5 to 42 m deep (Table 13, Figs. 22 and 35). These strata are assigned to the undifferentiated Holocene unit, and consist of olive-gray to olive brown, fossiliferous, moderately well-sorted, silty, very fine- to fine-grained sand (Figs. 36 and 37). This borrow area contains from 61.6 to 102.4 x 10^6 m^3 of suitable to marginally suitable (fine) sand.

Table 12. Summary of potential borrow area A-V.

Type of Deposit:

Undifferentiated Holocene strata

Water Depth:

Minimum: 22 meters

Maximum: 29 meters

Range in Mean Grain Size: n = 7

Minimum:	2.64 phi	0.16 mm
Maximum:	1.60 phi	0.33 mm
Mean:	2.16 phi	0.22 mm

Range in Thickness:

Minimum:	3 meters	Vibracore and seismic coverage insufficient to isopach
Maximum:		

Estimated Volume	(x 10^6 m^3)	(x 10^6 yd^3)
Minimum:	6.5	8.5
Maximum:	21.8	28.5
Other:		Explanation of value:

Vibracores Penetrating Deposit:

H-7

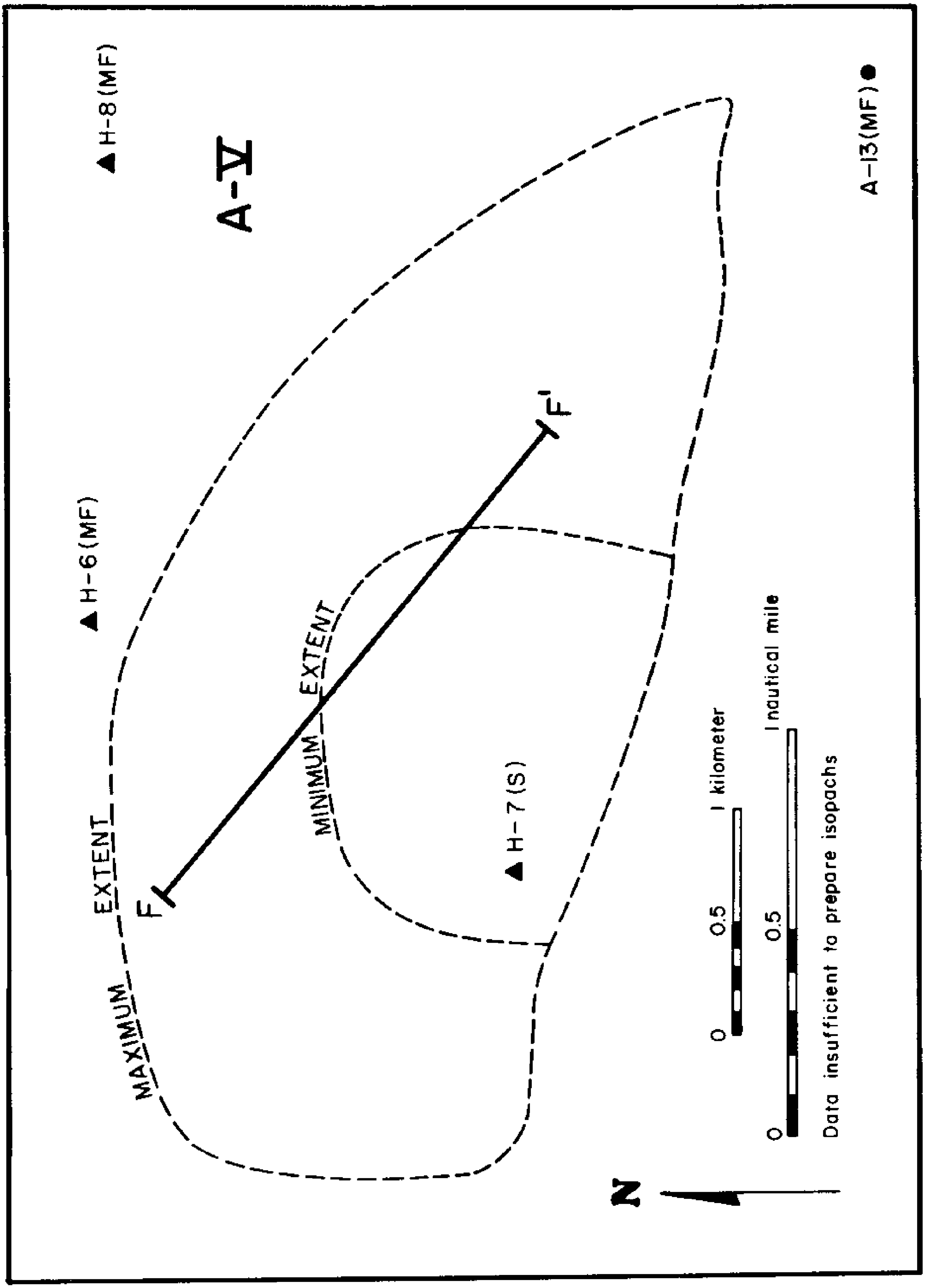


Figure 32. Map of borrow area A-V showing minimum and maximum areal extents with associated vibracore numbers, sand suitability symbols, and line of geologic cross section F-F'.

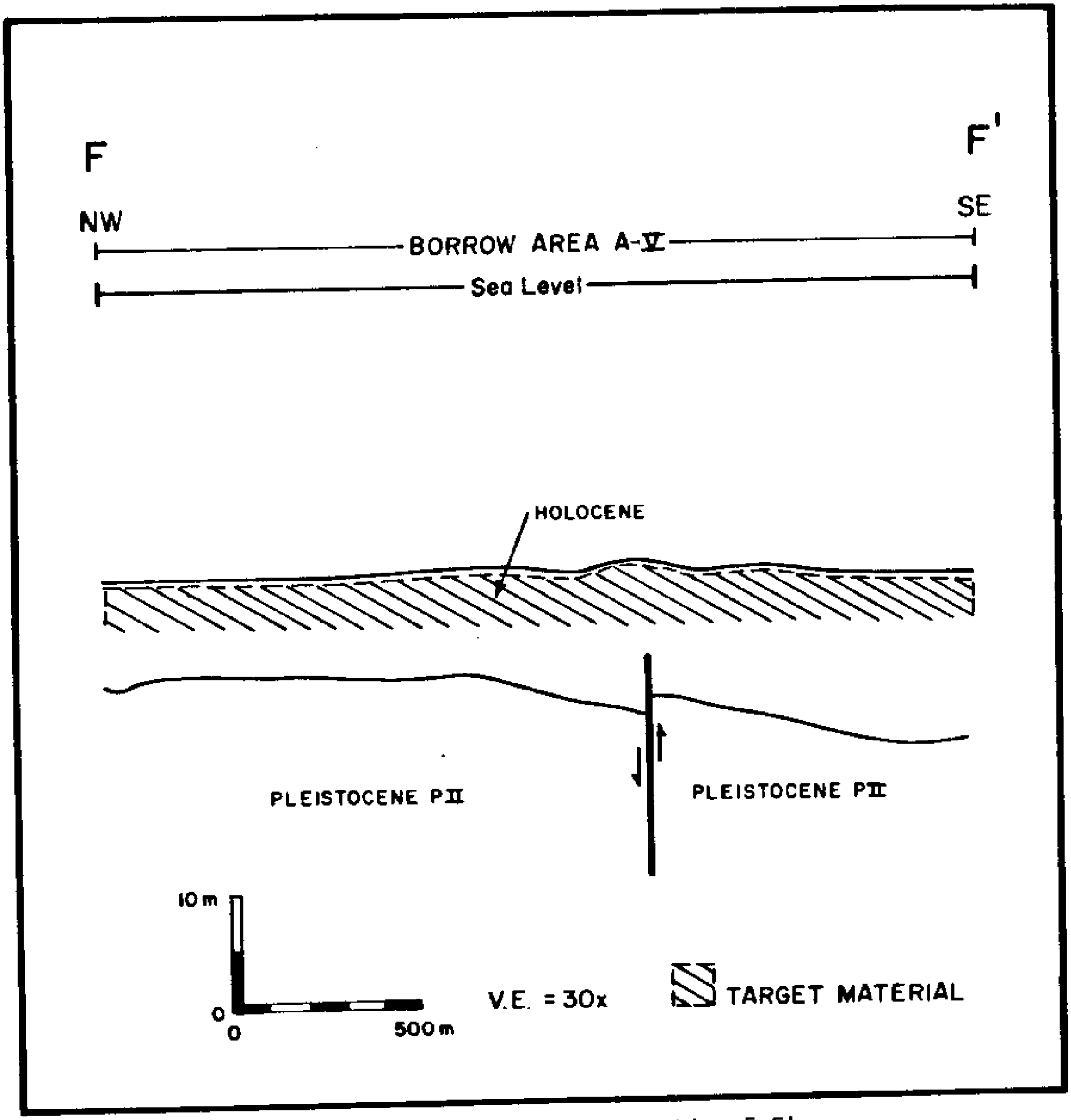


Figure 33. Geologic cross section F-F'.

VIBRACORE LOG

Core number: H-7

Date: 11/81

Total core length (cm): 215

Sheet 1 of 1

Number of core sections: 1

Water depth (ft):

Vertical scale: 1 cm = 25 cm

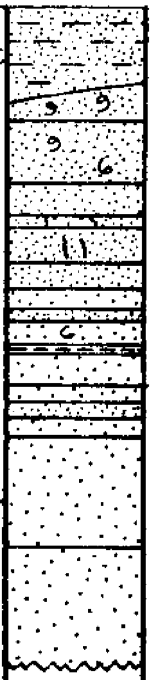
Distance in cm from top of core	Description	Log
0-27	Sand: silty very fine grained; olive gray (5 Y 4/1); micaceous; sparsely fossiliferous; irregular contact 5C°.	
27-39	Sand: fine grained; moderately sorted; medium light gray (N6); fossiliferous; sharp color change below.	
39-58	Sand: fine grained; ranges from very fine to medium sand; moderately sorted; olive gray (5 Y 3/2); sparsely fossiliferous; sharp lower contact.	
58-67	Sand: fine-medium grained; moderately sorted; color range from medium light gray (N6) to olive gray (5 Y 4/1).	
67-72	Sand: medium to coarse grained occurring in the center of the core; the sides are as above; sharp lower contact.	
72-83	Sand: fine to medium grained; moderately to poorly sorted; olive gray (5 Y 3/2); there are vertical stringers colored light olive gray (5 Y 6/1); sharp lower contact.	
83-91	Sand: fine to coarse grained; poorly sorted; olive gray (5 Y 3/2); there are vertical stringers colored light olive gray (5 Y 6/1); sharp lower contact.	
91-100	Sand: medium grained; moderately well sorted; light olive gray (5 Y 5/1); sparse fossils; sharp lower contact.	
100-103	Sand: very fine to fine grained; ranges from very fine to medium sand; moderate to poorly sorted; medium olive gray (N4); abundant biotite; sharp lower contact.	
103-110	Sand: coarse grained; well sorted; light olive gray (5 Y 6/1); sparsely fossiliferous; sharp lower contact.	

Figure 34. Log of vibracore H-7 which is illustrative of the sedimentologic character of borrow area A-V.

Table 13. Summary of potential borrow area A-I.

Type of Deposit:

Undifferentiated Holocene strata

Water Depth:

Minimum: 5.5 meters

Maximum: 49 meters excluding Newport submarine canyon

Range in Mean Grain Size: n = 23

Minimum:	3.32 phi	0.10 mm
Maximum:	1.09 phi	0.47 mm
Mean:	2.53 phi	0.17 mm

Range in Thickness:

Minimum: 2 meters

Maximum: 6 meters

Estimated Volume	(x 10^6 m^3)	(x 10^6 yd^3)
Minimum:	61.6	80.6
Maximum:	102.4	133.9
Other:		Explanation of value:

Vibracores Penetrating Deposit:

A-5; H-2; H-1; A-11

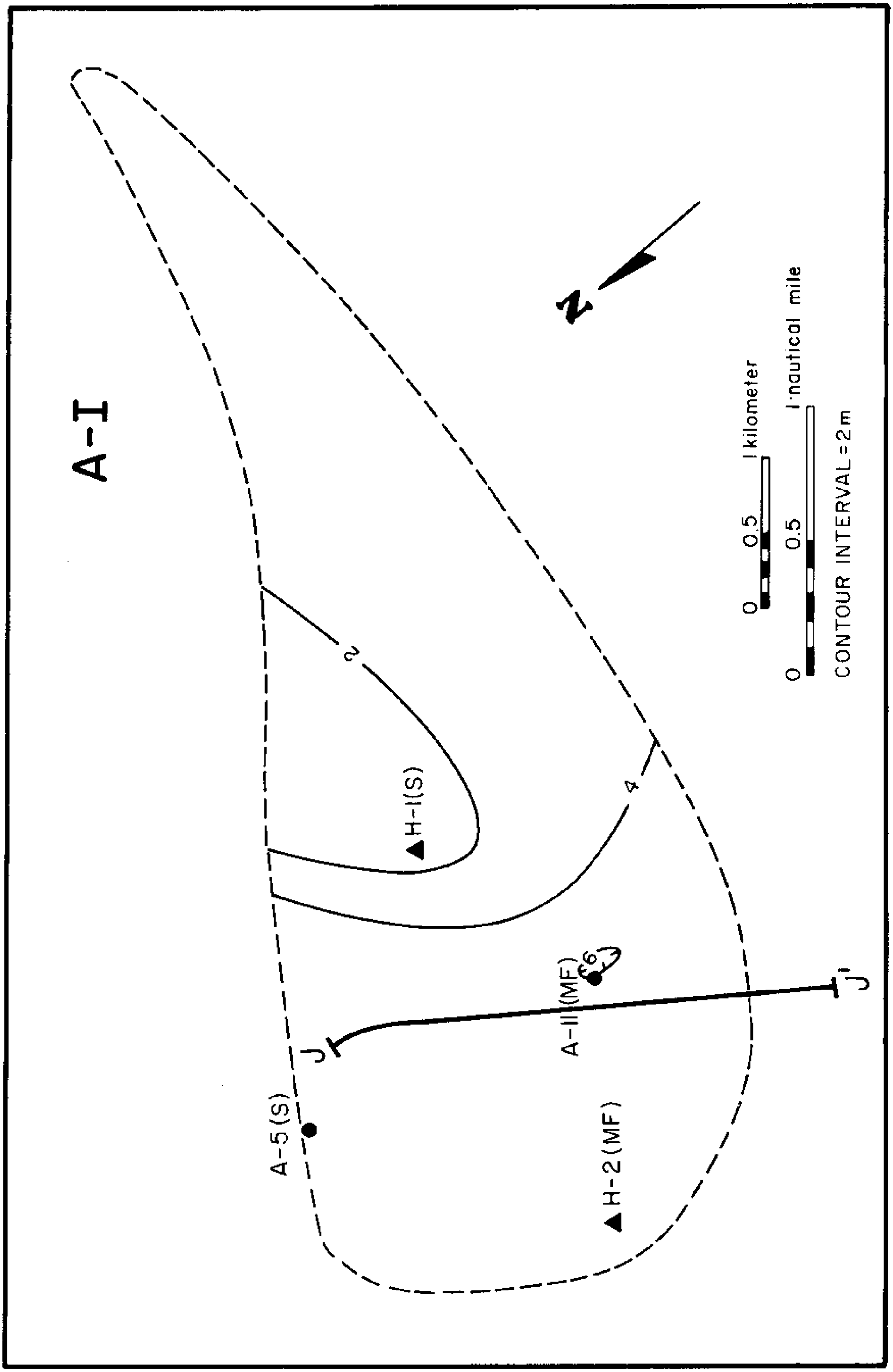


Figure 35. Isopach map of borrow area A-I with associated vibracore numbers, sand suitability symbols, and line of geologic cross section J-J'.

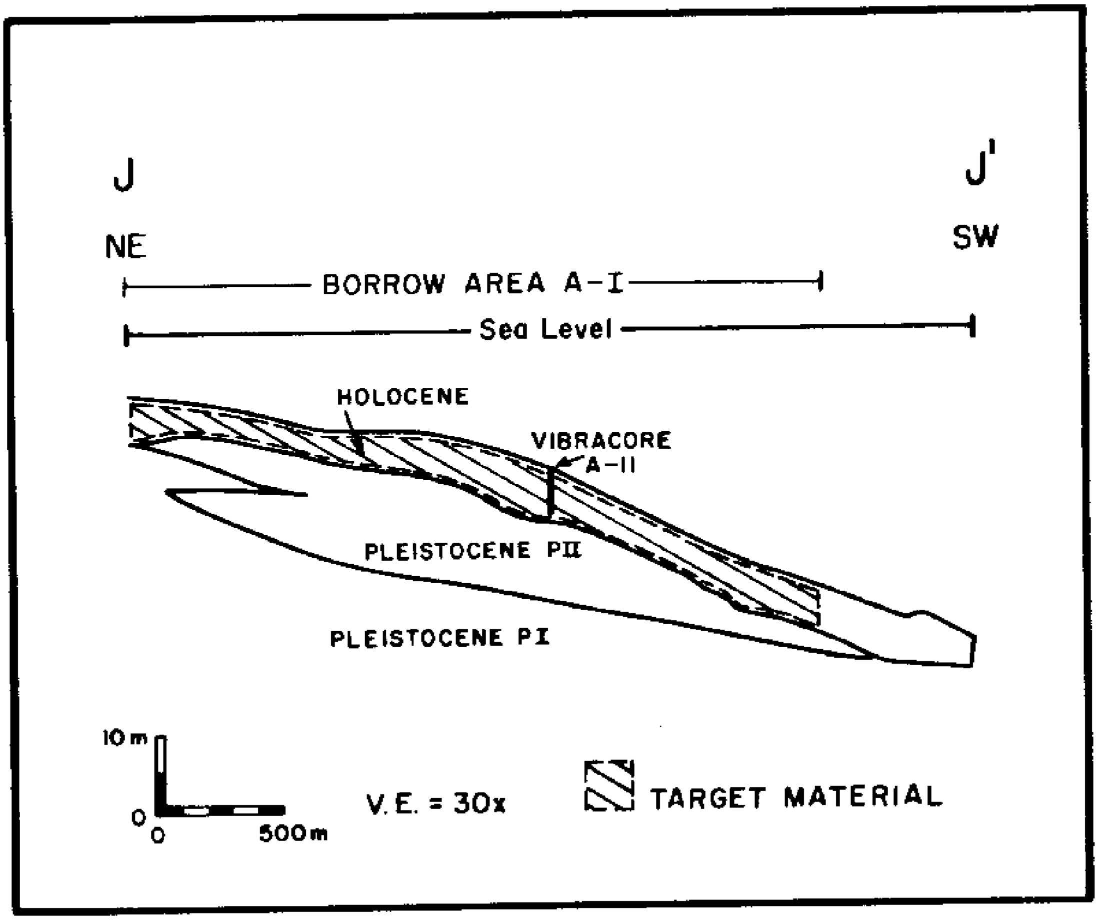


Figure 36. Geologic cross section J-J'.

VIBRACORE LOG

Core number: H-2

Date: 11/81

Total core length (cm): 243

Sheet 1 of 1

Number of core sections: 1

Water depth (ft):

Vertical scale: 1 cm = 25 cm

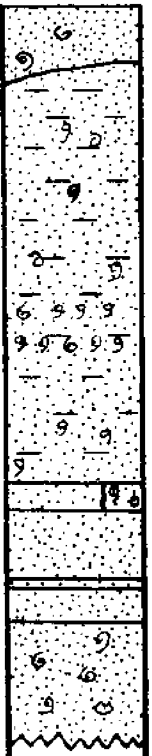
Distance in cm from top of core	Description	Log
0-20	Sand: very fine grained; moderately to well sorted; moderate olive brown (5 Y 4/4); micaceous; slightly fossiliferous; gradational contact.	
20-23	Sand: small pocket of very fossiliferous sediment as above; sharp lower contact.	
23-155	Sand: silty very fine sand; well sorted except for fossil debris; grayish olive (10 Y 4/2); highly micaceous (muscovite); coarse fossil debris confined to 112-115 and 100 cm; sharp lower contact.	
155-163	Sand: as above except on right side of core is a fossiliferous fine sand with a color change to moderate olive brown (5 Y 4/4); sharp lower contact.	
163-187	Sand: very fine grained; moderately well sorted; olive gray (5 Y 3/2); very micaceous (muscovite); fossiliferous.	
187-190	Sand: very fine to fine grained; moderately olive brown (5 Y 4/4); sharp lower contact.	
190-205	Sand: silty very fine grained; olive gray (5 Y 3/2); micaceous; sharp contact.	
205-243	Sand: silty very fine grained; olive gray (5 Y 3/2); micaceous; abundant shell fragments.	

Figure 37. Log of vibracore H-2 which is illustrative of the sedimentologic character of borrow area A-I.

III. DANA POINT AREA, ORANGE COUNTY

The Dana Point segment extends from Dana Point to San Mateo Point (Figure 1). The offshore area southeast of Newport submarine canyon to Dana Point was not sampled because of the narrowness of the shelf, the marked decrease in sediment volume as compared to San Pedro Bay, and the occurrence of numerous kelp stands.

The ten vibracores obtained in this area (D-1 through D-10) were taken during October, 1979 aboard the crane barge Geronimo with Meridian Ocean Systems, Inc., acting as contractor. Vibracore locations for this shelf segment were selected with the aid of a Holocene sediment isopach map prepared under the direction of P. J. Fischer. Locations were chosen where the generally fine-grained Holocene sediment cover was absent or relatively thin. Recovered cores range from 0.20 to 4.35 m in length, and average 2.4 m. Where the Holocene cover is either absent or completely penetrated by the vibracores, dense friable sandstone was encountered. This sandstone is thought to represent the Miocene Vaqueros Formation.

Due to the apparent absence of coarser-grained Pleistocene sand and gravel packages along the Dana Point shelf segment, the only possible source for suitable sand is within the Holocene package. Unfortunately, the character of the Holocene strata in this area is not promising. This sediment typically is an olive-gray, micaceous, silty, very fine- to fine-grained sand. There are laminae of mud and clayey silt expressed as thin darker strata within the vibracores. The finer-grained character of the Holocene sediment in this segment probably reflects the relatively lower-energy, sheltered environment of this inner shelf area (Fischer, and others, 1982).

Although occasional medium-grained sand intervals occur in the vibracores from the Dana Point segment, the average grain-size diameter of the sand

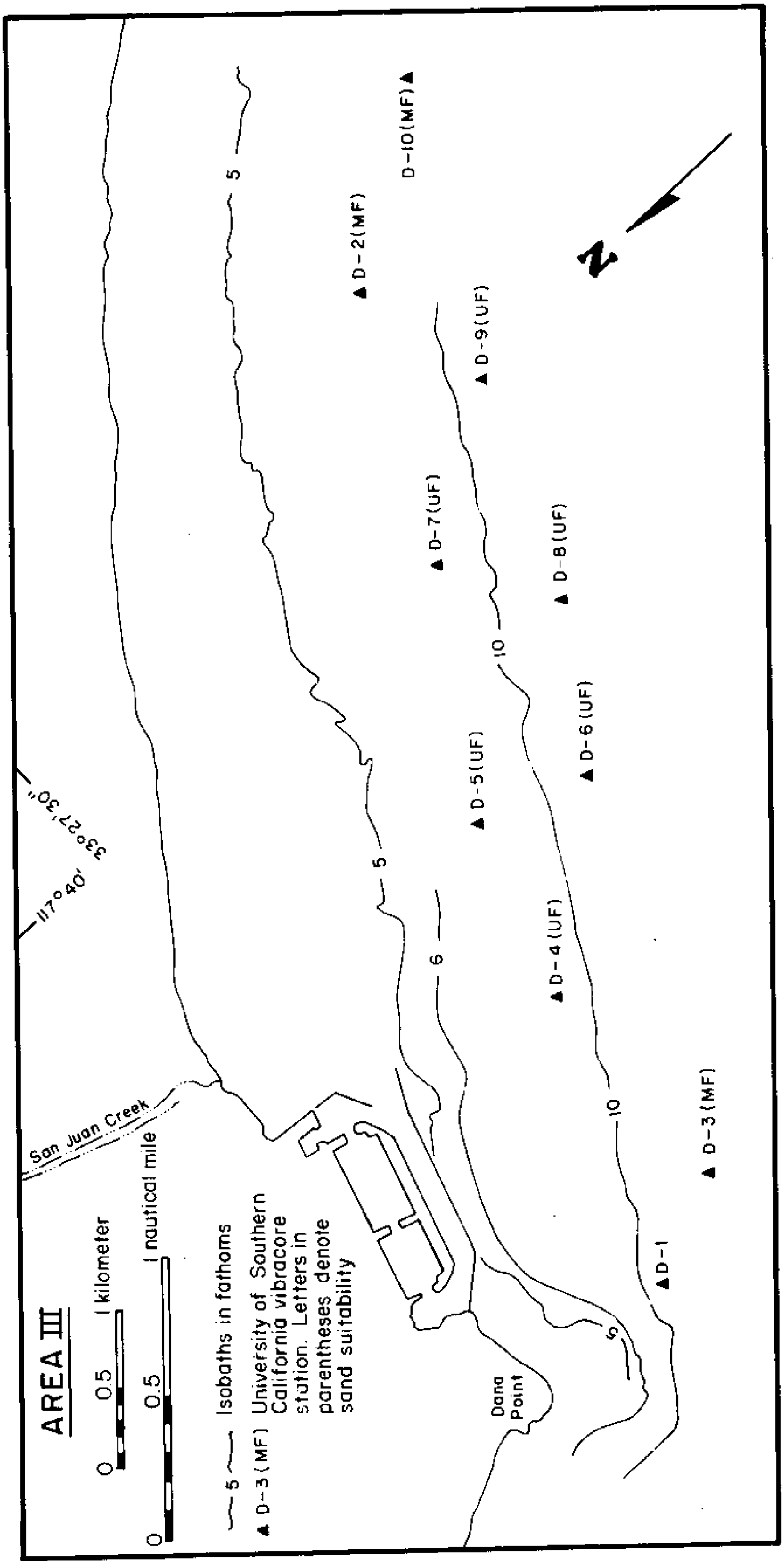


Figure 38. Map of area III showing vibracore locations with associated sand suitability symbols and bathymetry.

fraction of 54 samples is 0.09 mm (3.41 phi), and the phi standard deviation is 0.46. Thus the sand fraction of these samples consists of well-sorted, very fine-grained sand. Although the sand fraction itself falls in the marginally fine category in the sand suitability scale (Fig. 4), it is admixed with an average of 41.5% silt and clay (less than 0.0625 mm in diameter), which renders the entire Holocene package as unsuitably fine. Thus it does not appear that the shelf segment between Dana Point and San Mateo Point will yield sediment deposits suitable for beach restoration and nourishment.

IV. THROUGH VIII., SAN DIEGO COUNTY

Introduction

Study areas IV through VIII are on the continental shelf offshore of San Diego County, California (Fig. 1). These occur in an area approximately 100 km long, which ranges in width from about 17 km offshore of San Diego Bay to less than 1 km at La Jolla, where the Scripps and La Jolla submarine canyons cut close to shore. The shelf break in this area is at an approxiamte depth of 100 m. The shelf is transected by three major submarine canyons namely, the Carlsbad, La Jolla-Scripps, and the Coronado. The coastline is cut by many streams, which play an important role in the nearshore Quaternary depositional history.

The mainland shelf of San Diego County is part of the Peninsular Range province (Reed, 1951; and Jahns, 1954), which extends from the Los Angeles basin well into the Baja California peninsula. The basic stratigraphy of the San Diego County coast consists of a basement complex, upon which Cretaceous, Tertiary and Quaternary strata have been deposited.

The basement complex of the Peninsular Ranges consists of plutonic, metamorphic and volcanic rocks. Granite, granite monzonite, quartz monzonite and granodiorite occur in the Mesozoic Southern California batholith (Jennings, 1977), which is the core of the Peninsular Ranges and accounts for most of the exposed bedrock in San Diego County. Other basement rocks include schist, volcanic and metavolcanic rocks, and relatively small occurrences of Mesozoic basic intrusives, mainly gabbro and dioritic rocks.

Blake (1865), Dall (1898), Fairbanks (1898), Ellis and Lee (1919), Hanna (1926), and Hertlein and Grant (1954) mapped and described the geology of San Diego County. Strand (1962), Rogers (1965) and Jennings (1977) compiled more regional geologic maps that include San Diego County. In more detailed studies, Moyle (1973) and Young (1980) mapped the coastal area from Camp Pendleton to Carlsbad; Wilson (1972) from Carlsbad to Solana Beach; and Kennedy (1969, 1975) and Kennedy and Tan (1977) from Solana Beach to the international border.

A thick sequence of Cretaceous and Tertiary marine and terrestrial strata were deposited on the basement complex in San Diego County. The stratigraphy of the San Diego area has been presented in some detail by Kennedy and Moore (1971a, 1971b), Kennedy (1973), Gastil and Higley (1977), and Kuper and Gastil (1977). Elliot (1973, 1975) published stratigraphic correlation charts for parts of San Diego and Orange Counties. Quaternary marine terraces of the onshore San Diego area have been studied by Kern (1973, 1977), Ku and Kern (1974), Wehmiller and others (1977), and LaJoie and others (1979). Many other studies, too numerous to mention here, have been completed concerning the age relationships, sedimentology and provenance of specific Cretaceous and Cenozoic formations of San Diego County. Most recently, many papers dealing with Cretaceous, Eocene and Miocene strata in San Diego County have been published in volumes edited by Abbott (1979a, 1979b) and Stuart (1979).

The structural geology of onshore San Diego County has been studied by Reed and Hollister (1936), Wilson (1972), Ziony (1973), and Hannan (1975). Artim and Pinckney (1973) and Elliot and Hart (1977) studied the La Nacion fault system in the onshore San Diego Bay area. The onshore Rose Canyon fault has been studied by Kennedy (1975), Gastil and others (1979), and Threet (1979).

Structurally, the San Diego shelf is very complex. For most of its length, it is transected by the Newport-Inglewood-Rose Canyon fault zone, which extends from the southern edge of the Transverse Ranges, through the Los Angeles basin, trends offshore at Newport beach and back onshore at La Jolla, through Rose Canyon and the San Diego Bay and Bight. It is generally agreed that the features associated with the Newport-Inglewood-Rose Canyon fault zone can be accomodated by the right-slip wrench tectonic model of Moody and Hill (1956), Harding (1973), and Wilcox and others (1973), in which the right lateral strike-slip component is accompanied by secondary compressional and tensional components. Various models have been proposed to explain the tectonic setting of this fault zone (Junger, 1976; Greene and others, 1979; Reed and Hollister, 1936; Yerkes and others, 1965; Atwater, 1970; Hill, 1971; and Crouch, 1979).

The geology of the mainland shelf of San Diego County was examined first in studies of the southern California continental borderland by Emery and Shepard (1945) and Emery (1954). Welday and Williams (1975) described shelf sediment for the entire California continental shelf. Stevenson and others (1959) and Wimberly (1964) examined the southern California area: Inman (1953) and Wimberly (1955) examined the La Jolla area: and San Diego Marine Consultants (1959, 1961) examined the area from Mission Beach to the international border. Butcher (1951a, 1951b) and Emery and others (1952) studied sediment from Coronado Bank and the shelf offshore of San Diego. Heavy minerals in southern California shelf sediment have been studied by Azmon (1960) and Rice and others (1976).

Seismic reflection profiling of the offshore San Diego area was initiated in studies by Moore (1957, 1960). Emery (1958) identified terrace-like features related to bottom topography using echo-sounding profiles. Seismic reflection studies by Moore (1966), Vedder and others (1974), Greene and others (1979), Legg (1979), and Legg and Kennedy (1979) encompass the entire continental borderland. Byrd and others (1975), Henry (1976), Henry and others (1976), and Fischer and others (1982) used seismic reflection data to estimate the thickness of unlithified sediment on the San Diego shelf. Young (1980), Ticken (in preparation) and Webb (in preparation) used seismic data in more comprehensive studies of the shelf. White (1969), Moore (1972), Crane (1977), Kennedy and others (1980a, 1980b) and Darigo (in preparation) have mapped the stratigraphy and structure of the shelf and inner borderland of southern San Diego County from seismic information. Darigo (in preparation) is particularly relevant to the present study.

Methods

A methodology similar to that used in Santa Monica and San Pedro Bays was employed to examine the Quaternary stratigaphy and structure of the San Diego shelf; however, geophysical and vibracore coverage is sparse compared to that available for other coastal segments. Therefore, more uncertainity is associated with volumetric and sand suitability estimates for each of the twelve (SD-I through SD-XII) potential borrow areas identified in this area.

The geophysical data consist of approximately 450 km of Uniboom and 3.5 kHz high-resolution seismic profiles as well as side-scan sonar data. These data were taken simultaneously by Woodward Clyde Consultants, under contract to the U. S. Army Coastal Engineering Research Center, aboard the M/V Polaris in October and November, 1979. The Uniboom data provided the major source of information for the present study. Inasmuch as the Uniboom frequency varied from 0.4 to 8.0 kHz, associated limits of resolution range from approximately 4 m to less than 1 m. Most of the data used for the present study has a resolution limit near 1 m. Additional information regarding equipment specifications for the Uniboom and other geophysical systems are available in a report by Woodward Clyde Consultants (1979).

A total of 49 vibracores totalling approximately 122 lineal m were recovered from the San Diego shelf by Ocean Surveys, Inc., under contract from the U. S. Army Coastal Engineering Research Center, during February 1981. The reovered cores range from 0.73 to 5.72 m long, and average 2.84 m. All vibracores were logged and reposited in the Sedimentary Petrology Laboratory at the University of Southern California.

Conventional grain-size analyses were performed on 168 sediment samples selected from the cores, and petrographic modal analyses were performed on a total of 81 samples, of which 53 were from San Diego Bay. More detailed sediment data are provided in the following discussion of each of the San Diego shelf segments. Again, relevant core and sediment sample data are provided in Appendices A through D.

IV. OCEANSIDE AREA, SAN DIEGO COUNTY

Introduction

The Quaternary geologic history of the Oceanside shelf segment (Figs. 1 and 39), like most of nearshore San Diego County, is strongly influenced by the Newport-Inglewood fault zone. Its main component in the offshore Oceanside area is a fault zone approximately 1 km wide, which is continuous with the South Coast fault zone mapped by Greene and others (1979), Legg and Kennedy (1979) and Young (1980). The South Coast fault zone occurs approximately 7 to 8 km offshore of the middle Camp Pendleton area, and about 5 to 6 km offshore of the Santa Margarita River (Young, 1980). From the northwest edge of the present study area (Fig. 39), this fault zone trends southeast to a location 2.4 to 4.3 km offshore of Loma Alta Creek, where it trends south-southeast to just offshore of Aqua Hedionda Lagoon, and then continues to the south. Of secondary importance is a north-trending structural element, which is expressed in the offshore Oceanside area as several discontinuous, subparallel faults extending seaward from Buena Vista and Aqua Hedionda Lagoons. Due to the shallow penetration of the seismic data nearshore, it is difficult to determine whether or not these faults continue onshore; however, they are on trend with several mapped by Moyle (1973) and Young (1980) in the Oceanside-Camp Pendleton area. The faults offshore of Aqua Hedionda Lagoon show the greatest Holocene offset of any faults in the Oceanside area, but do not appear to break the sea floor (Darigo, in preparation). Another set of north-trending faults occurs offshore of Camp Pendleton, and intersects the coast immediately south of the San Onofre Nuclear Power Plant, where it is named the Christianitos fault. Like the onshore faults at Oceanside, the Christianitos fault does not transect Pleistocene terrace deposits (Hunt and Hawkins, 1975). Wilson (1972) identified two

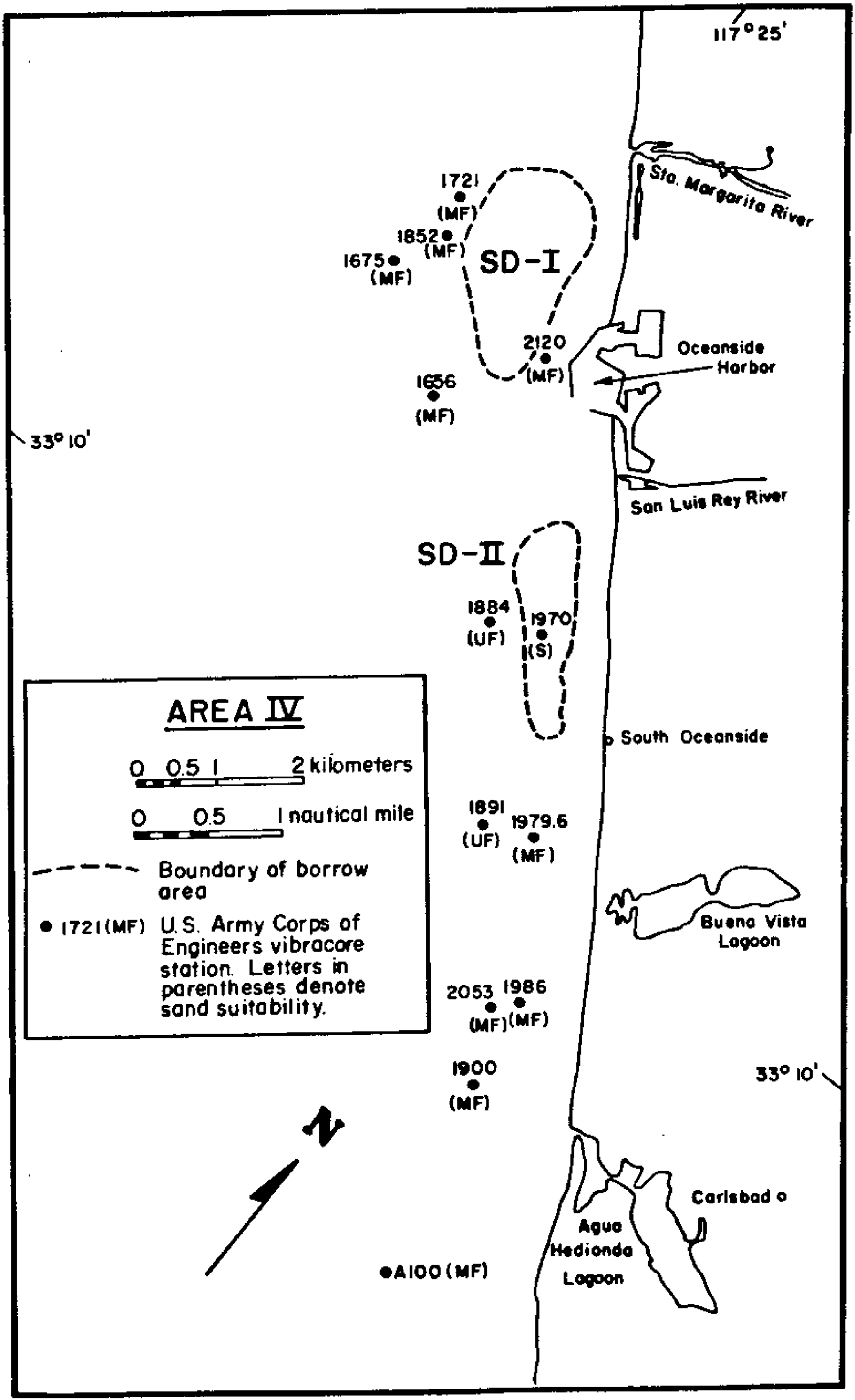


Figure 39. Map of area IV showing locations of borrow areas SD-I and SD-II with associated vibracore numbers and sand suitability symbols.

north-trending faults that intersect the coast in the Leucadia-Encinitas area south of Oceanside that do not cut Pleistocene terrace deposits.

Stratigraphic units occurring both onshore and offshore in the Oceanside segment include the Eocene Santiago Formation, the Miocene San Onofre Breccia and Monterey Formation, the Miocene-Pliocene Capistrano Formation, the Pliocene San Mateo Formation, and various Quaternary deposits. East and south of the Oceanside area, the Tertiary and Quaternary strata are underlain by rocks assigned to the Cretaceous Rosario Group and the Jurassic Santiago Peak Volcanics. Although nomenclature varies, the sedimentary units in the Oceanside area are, in general, equivalent to units described in Orange and southern San Diego Counties.

Quaternary Stratigraphy

Upper Pleistocene Strata

Stratigraphy: The upper Pleistocene stratigraphy and geologic history of the Oceanside segment are discussed thoroughly by Darigo (in preparation).

A complex sequence of Pleistocene terrace, progradational marine, channel and fault-ponded deposits occur offshore of Camp Pendleton (Young, 1980; Darigo, in preparation). Offshore of the southern part of Camp Pendleton, Young (1980) identified a stratigraphic sequence of probable Pleistocene age, which fills a trough between the South Coast fault zone and the shoreline. This sedimentary package consists of four units (A through D), each of which is characterized by its seismic signature and stratigraphic position. All four units occur on the sea floor at varying positions along the edges of the trough, where they are truncated by erosion.

The structural trough, representing a faulted syncline, probably extends into the northern half of the Oceanside segment, where it shallows and merges with the South Coast fault zone. Young's units A and B either wedge-out southward or were eroded by channeling of the Santa Margarita and San Luis Rey Rivers. A seaward-dipping unit with parallel reflectors appears in the northern part of the study area, which may represent Young's unit C.

A progradational marine package overlies a marine abrasion platform, which truncates unit C along the northern edge of the Oceanside segment and Tertiary strata farther south. Young (1980) tentatively correlated this marine unit with unit D, because the two units occur at approximately the same depth near the shelf break (80 to 100 m b.p.s.l.). The abrasional platform is a combination of two terraces with shoreline angles at 46 to 50 and 56 to 59 m b.p.s.l. These two shoreline angles do not occur in the northern part of the Oceanside segment, but do appear further south, and it appears that the shallower terrace is older than the deeper one, as the deeper one truncates the seaward edge of the other.

Pleistocene unit D overlies these terraces in a continuous strip along the Oceanside shelf, and is characterized as a lense-shaped unit with sigmoidal reflectors. According to Mitchum and others (1977), the sigmoidal, progradational configuration suggests continued upbuilding of the topset beds coincident with prograding of the middle segments, which, in turn, implies a relatively low sediment supply, a rapid rise in sea level to permit preservation of topset beds, and a low-energy depositional environment. Sangree and Widmier (1977) suggest that such a configuration implies the occurrence of a shelf-margin, progradational slope environment, which allows for hemipelagic deposition from low velocity currents and some wave or fluvial influence for the shallower zones.

Unit D ranges from 15 m thick in the northern part of the area to 7 m in the southern part. This difference in thickness probably is related to the position of local sediment sources and local tectonic activity

(Young, 1980; Darigo, in preparation). Unit D was deposited before the late Pleistocene sea level low, about 15,000 to 20,000 years ago, which immediately preceded the Holocene transgression (Bloom and others, 1974).

Other offshore Pleistrocene strata on the Oceanside shelf include terrace deposits, fault-ponded sediment, basal gravel deposits, and an estuarine sequence. Two sets of terrace deposits occur north of the study area (Young, 1980). These deposits overly Miocene, Pliocene and Pleistocene unit D strata, but do not extend as far south as Oceanside.

Fault-ponded Pleistocene deposits occasionally occur along the South Coast fault zone, but are difficult to measure because they are either too thick for seismic penetration or are infilled with upwelling gas along the fault zone. One such deposit occurs offshore of Carlsbad, where a down-dropped fault block permitted the accumulation of more than 40 m of Pleistocene strata.

A Pleistocene channel-fill deposit over 40 m thick occurs offshore of Aqua Hedionda Lagoon. It is cut into Eocene strata, and is erosionally truncated on top by the 56 to 59 m b.p.s.l. terrace. This channel may have been related to the Carlsbad submarine canyon, and may have been a pathway for sediment from the Aqua Hedionda river valley during the middle Pleistocene. During the late Pleistocene and Holocene, sediment from Aqua Hedionda was transported south parallel to the coast or funneled through the present Carlsbad submarine canyon.

A Pleistocene sequence containing estuarine, channel and slope wash facies occurs in a strip 700 m wide along the inner shelf between Loma Alta Creek and San Luis Rey River. This unit is parallel to shore from its northern extremity near the Oceanside pier, where it is truncated by later San Luis Rey river channeling, to just offshore of Buena Vista Lagoon, where it abuts against Eocene bedrock due to faulting. The estuarine facies of this sequence generally overlies and grades into channel facies, and together they attain a thickness as much as 25 m. The slope wash facies is from 61 to 122 m wide, as much as 20 m thick, and was constructed against Tertiary bedrock. Internally, the estuarine facies consists of very flat, very continuous, thinly-layered, parallel, high-amplitude reflectors, which are concordant with top and bottom boundaries. According to Sangree and Widmier (1977), high continuity implies stratal continuity over a wide area, and high-amplitude interbedding of strata with distinctly different seismic velocities. In the Oceanside area, this sedimentary package probably represents fluvial strata interbedded with marsh deposits within an overall shelf sequence. This estuary trended parallel to the coast, and probably received sediment from the San Luis Rey River. The mouth of the main channel was halfway between the Oceanside pier and Loma Alta Creek, whereas the coastal marsh probably extended farther south.

The estuarine facies grades laterally and downward into a channel-like facies. This unit contains less continuous, lower amplitude, occasionally chaotic reflectors with small-scale, channel-like reflectors in the upper 5 m. The low continuity and low amplitude reflectors indicate a higher mechanical-energy depositional environment and more homogenerous sediment than occurs in the estuarine facies. The slope wash facies contains discontinuous, low-amplitude reflectors, which prograde from the adjacent bedrock.

The youngest Pleistocene deposits on the Oceanside shelf are basal gravels associated with the floors of the major river valleys. Four of the five major river valleys along the Oceanside coastal segment probably contain basal gravel deposits; namely the Santa Margarita, San Luis Rey, Loma Alta, and Aqua Hedionda valleys. This unit cannot be clearly identified on the available seismic profiles due to limited penetration of the overlying Holocene strata and gradational contacts between Pleistocene and Holocene channel-fill deposits. The extent and configuration of these Pleistocene channels is best described by the distribution of thick Holocene fill shown on the Holocene isopach map prepared in conjunction with this report. The distance a basal gravel deposit extends offshore depends on the shelf width and the position of the shoreline during the pre-Flandrian low sea level stand. It is evident from the Holocene isopach map that the old shoreline trended N. 50° W. as compared to the present trend of approximately N. 35° W. Seismic data offshore of Buena Vista Lagoon show no major channel-fill deposits similar to those of the other major river valleys. The reason for this is not clear, but it may be related to local faulting.

Lithology: Vibracore 1884 probably ceased penetration at the inferred Pleistocene-Holocene boundary, therefore Pleistocene sediment was recovered only from core 1970. This core penetrated 53 cm of the slope wash facies of the upper Pleistocene estuarine sequence, and the recovered sediment is a dusky yellow to grayish black, very micaceous, moderately-sorted, medium-grained sand. The base of the overlying Holocene marine unit contains pebbles and cobbles from 1 to 8 cm in diameter.

Holocene Strata

Stratigraphy: The offshore Holocene depostional history is more simple than that of the Pleistocene. Henry (1976), Fischer and others (1982) and Young (1980) assigned all of the Holocene strata to a marine facies; however, oscillating sea levels during the Holocene and dissecting coastal streams preclude the possiblity that only marine sediment accumulated on the inner shelf during the general Holocene transgression. Therefore Holocene strata are assigned to both marine and nonmarine facies in this report.

The Holocene isopach map shows that the thickest sections occur where pre-existing river valleys were filled during the Holocene transgression. During the transgression, aggradation of the channel-fill sediment occured with rising base level; and there was an adequate sediment supply to the river valleys, because nowhere are they expressed as "starved basins"; instead they are completely filled and, in most places, buried by marine sediment. The thickest section of the Holocene nomarine facies occurs at the coastline; however, seismic data was unable to penetrate it completely. the thickness of Holocene strata near the mouth of the San Luis Rey River is approximately 50 m, and the same may be true for the mouth of the Santa Margarita River. Inasmuch as the available seismic data did not penetrate the entire thickness of channel-fill deposits nearshore, only minimal thicknesses could be plotted on the isopach maps.

The Holocene isopach map suggests that the Santa Margarita, San Luis Rey and Loma Alta river valleys coalesce into one, longshore-trending, estuarine channel. The offshore edge of this channel delimits the offshore limit of the Holocene nonmarine facies. Sediment escaping the estuary would have been resedimented by shelf wave and currents into various marine enviornments or would have washed down the small, unnamed submarine canyon, which transects the shelf in the northwest corner of the study area. If this longshore channel was an estuary, it probably was filled rapidly with the rising sea level, and it most likely contains more homogeneous and coarser-grained sediment than the Pleistocene estuarine sequence preserved in the inner shelf.

The Holocene nonmarine facies contains two types of seismic signatures. The first consists of moderately continuous, moderately high amplitude, thickly-layered, parallel reflectors; and the second consists of low amplitude, occasionally chaotic reflectors, which sometimes occur in small-scale, sloping, concave or channeled configurations. The first type occurs mainly in the lower half of the longshore channel; whereas the second occurs in the upper half of the channel, and represents the entire section of nonmarine strata in stream valleys closer to shore. The second type of signature occurs everywhere north of the San Luis Rey River valley above approximately 20 m b.p.s.l., which implies that by the time the sea had risen to this level, the San Luis Rey and Santa Margarita drainage systems had completely merged into one broad alluvial plain in the present middle to inner shelf areas.

The channel fill extending from Aqua Hedionda Lagoon does not merge with other channel fill to the north, but is incorporated with marine facies trending parallel to shore.

The Holocene marine facies attains a maximum thickness of approximately 20 m in the middle shelf area, and thins to zero in the nearshore area. The marine facies overlies Pleistocene unit D on the middle to outer shelf, the Pleistocene estuarine sequence along the inner shelf between the San Luis Rey River and Loma Alta Creek, and Miocene and Eocene strata in the southern part of the Oceanside segment where no Pleistocene strata exist. Darigo (in preparation) identified at least five terraces and associated shoreline angles within the Holocene marine package on the Oceanside shelf. These terraces occur at 63 to 70, 42 to 46, 39 to 45, 30 to 36, and 24 to 27 m b.p.s.l., and represent standstills or slight oscillations during the overall Holocene transgression. The terraces usually are overlain by marine strata, which generally onlap across its landward edge.

Internally, the marine facies contains gradually prograding or concordant reflectors, which are low amplitude, continuous and parallel. In certain of the thicker localities, the marine facies appears to have been deposited in several episodic pulses of prograding or concordant layers. The depositional pulses sometimes are separated by a slightly stronger reflector, perhaps a coarser-grained layer deposited during a stillstand or slight fall of sea level. The uppermost reflectors of the marine facies are concordant with the sea floor. This concordance indicates continued aggradation, and the upper parallel strata would only be preserved in an environment with low sediment supply and relatively rapid sea level rise and/or basinal subsidence.

Lithology: Of the thirteen vibracores recovered in the Oceanside segment, seven cores ranging from 2.0 to 4.8 m long penetrated only strata assigned to the Holocene marine package (A100, 1656, 1675, 1852, 1884, 1891, and 1900). This facies is characteristic of much of the San Diego County shelf, and consists of olive gray to olive black, micaceous, moderately well- to well-sorted, very fine- to fine-grained sand with occasional shell fragments. Four of these seven cores stopped penetrating where they encountered a more indurated or coarser-grained unit below: cores 1656 and 1852 stopped at the boundary with the nonmarine Holocene facies; core 1884 stopped at the late Pleistocene estuarine unit; and core 1900 at Eocene bedrock.

Three cores penetrated the Holocene nonmarine facies. Cores 1721 and 2120 passed through a thin marine cover in the northern Oceanside area, and penetrated 16 and 30 cm, respectively of the Holocene channel-fill facies. These nonmarine strata consist of olive gray, poorly-sorted conglomerate with grain sizes ranging from silt to cobbles, but predominatly are composed of sand and gravel with some gravel-size shell fragments. Core 1979.6 penetrated the Holocene nomarine facies offshore of Loma Alta Creek. After passing through an upper unit of marine sediment and a middle nonmarine sand unit, the core entered a lower olive to light gray, moderately- to well-sorted, very fine- to fine-grained sand unit. It is possible that this core represents the intercalation of a channel-fill with typical Holocene marine strata.

Two vibracores in the southern Oceanside area (1986 and 2053) penetrated the Eocene Santiago Formation, and core 1900 probably stopped penetration at the contact between Holocene and Eocene strata.

Compositional data for the Oceanside sediment samples are listed in Table 14. The upper Pleistocene and Holocene nonmarine samples may be classified as feldspathic litharenite, whereas the Holocene marine samples range from feldspathic litharenite to lithic arkose (McBride, 1963).

Potential Sand and Gravel Resources

Potential Borrow Area SD-I

Two potential borrow areas (SD-I and SD-II) have been located on the Oceanside shelf. Borrow area SD-I occurs between the <6 and 20 m isobaths in an area extending southward from the mouth of the Santa Margarita River to Oceanside Harbor (Table 15, Figs. 39 and 40). The target material at this locality is the Holocene nonmarine unit; however, Pleistocene basal gravel deposits occur beneath these strata (Fig. 41). Vibracores 1721 and 2120 (Fig. 40) penetrated this sedimentary unit, but these areas could not be included in SD-I because of excessive fine-grained cover. Seismic penetration is poor in this area, therefore the thicknesses shown on the isopach map (Fig. 40) must be considered minimal. The maximum volume of suitable sand for SD-I is estimated at 24.9×10^6 m^3.

Potential Borrow Area SD-II

Potential borrow area SD-II occurs between the <5 and 10 m isobaths between the mouth of San Luis Rey River and South Oceanside (Table 16, Figs. 39 and 42). Site SD-II is approximately the same as area VI identified by Ocean Surveys, Inc. (1981); however, the limits of this potential borrow area

Table 14. Summary of lithologic composition of sand from samples recovered from the Oceanside area.

LITHOLOGIC COMPOSITION	UPPER PLEISTOCENE n = 1 Mean %	HOLOCENE NONMARINE n = 3 Mean %	HOLOCENE MARINE n = 5 Mean %
Monocrystalline Grains			
Nonundulose Quartz	19.7	11.2	7.4
Undulose Quartz	16.7	8.9	5.7
Plagioclase Feldspar	18.0	3.8	4.8
Potassium Feldspar	4.9	4.3	2.4
Pyroxene	0.3	0.1	0.1
Amphibole	2.0	0.1	0.6
Biotite	1.6	6.6	32.5
Epidote	0.0	0.0	0.0
Sphene	0.0	0.0	0.0
Garnet	0.0	0.0	0.2
Magnetite-Ilmenite	0.0	0.1	1.3
Polycrystalline Grains			
Quartz with 2-3 subunits	6.6	7.8	2.6
Quartz with >3 subunits	2.3	3.8	1.7
Plutonic Rock	27.5	11.0	8.6
Metamorphic Rock	0.0	0.2	0.1
Volcanic Rock	0.0	0.1	0.0
Siliciclastic Rock	0.0	0.3	0.0
Intraclastic Grains	0.0	0.7	0.3
Allochemical Constituents	0.0	31.5	29.4
Microcrystalline Quartz	0.3	3.0	2.0

Table 15. Summary of potential borrow area SD-I.

Type of Deposit:

Holocene nonmarine deposits underlain by Pleistocene gravel

Water Depth:

Minimum: <5 meters

Maximum: 13 meters

Range in Mean Grain Size: No samples recovered

Minimum: phi mm

Maximum: phi mm

Mean: phi mm

Range in Thickness:

Minimum: <6 meters

Maximum: 20 meters

Estimated Volume (x 10^6 m^3)		(x 10^6 yd^3)
Minimum:		
Maximum:	24.9	32.6
Other:		Explanation of value:

Vibracores Penetrating Deposit:

None

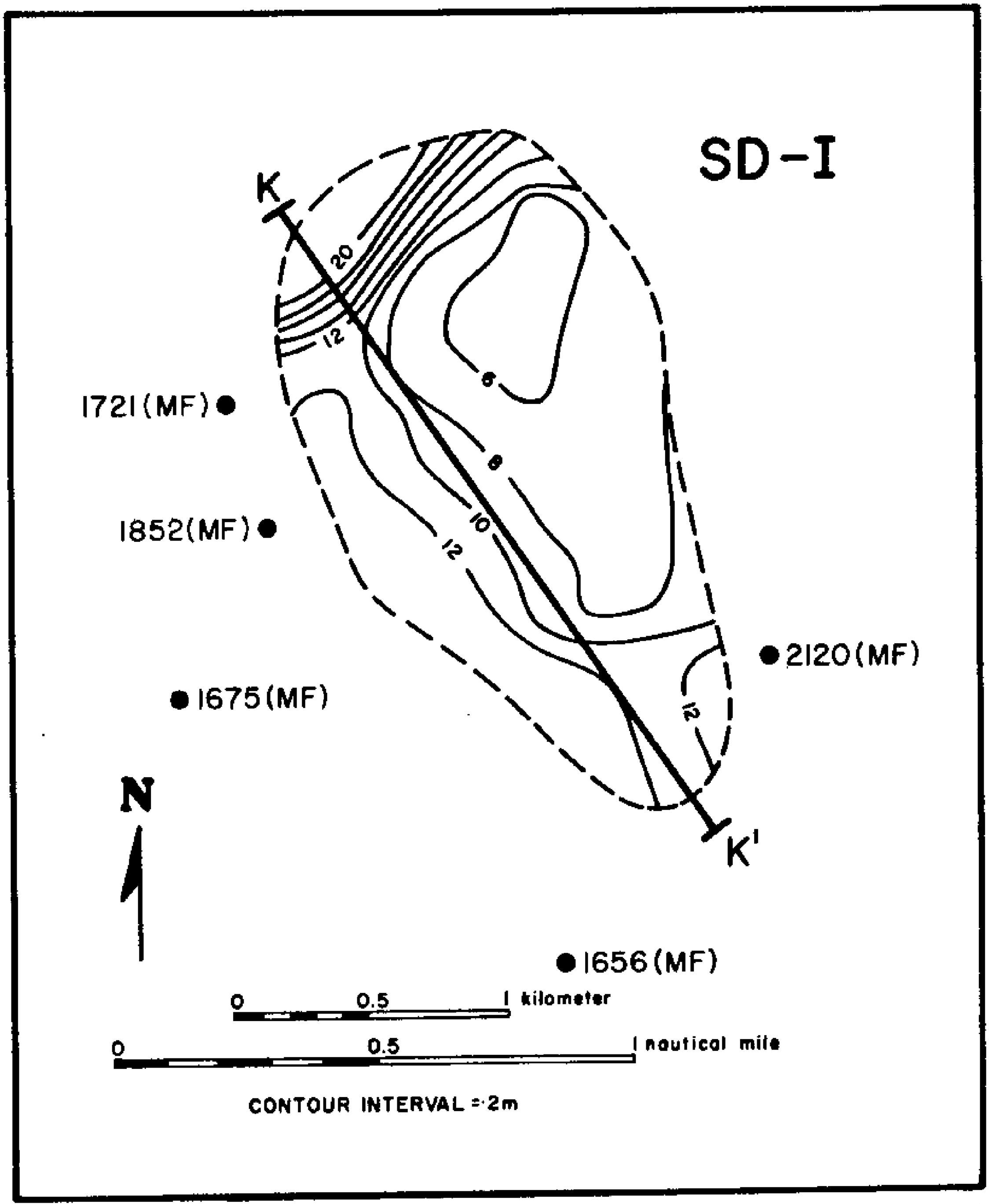


Figure 40. Isopach map of borrow area SD-I with associated vibracore numbers, sand suitability symbols, and line of geologic cross section K-K'.

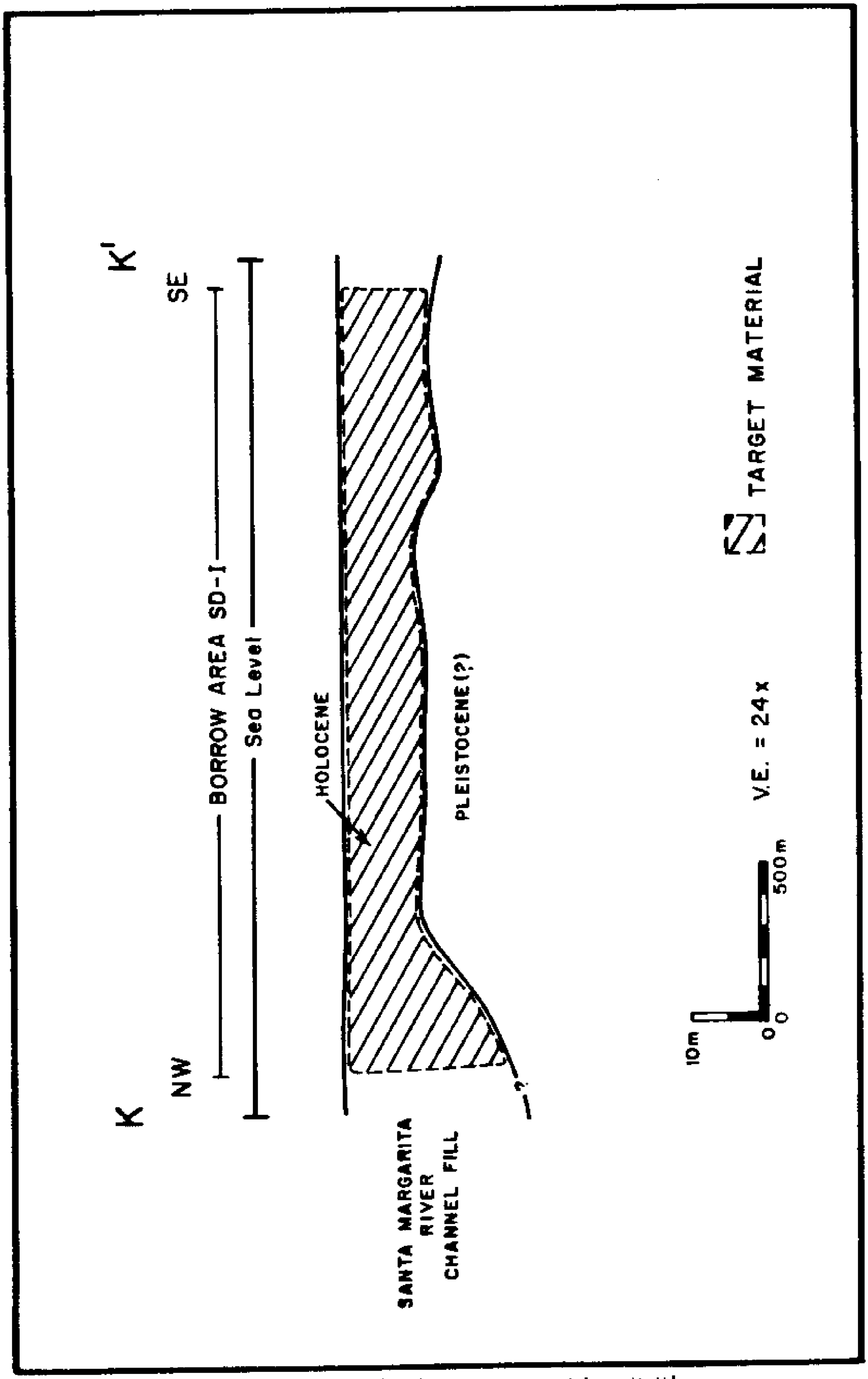


Figure 41. Geologic cross section K-K'.

Table 16. Summary of potential borrow area SD-II.

Type of Deposit:

Slope-wash facies of Pleistocene estuarine sequence, and Holocene channel fill along the northern boundary

Water Depth:

Minimum: <5 meters

Maximum: 10 meters

Range in Mean Grain Size: n = 2

Minimum:	2.65 phi	0.16 mm
Maximum:	1.18 phi	0.44 mm
Mean:	1.74 phi	0.30 mm

Range in Thickness:

Minimum: 0 meters

Maximum: 22 meters

Estimated Volume	(x 10^6 m^3)	(x 10^6 yd^3)
Minimum:		
Maximum:	20.7	27.1
Other:		Explanation of value:

Vibracores Penetrating Deposit:

1970

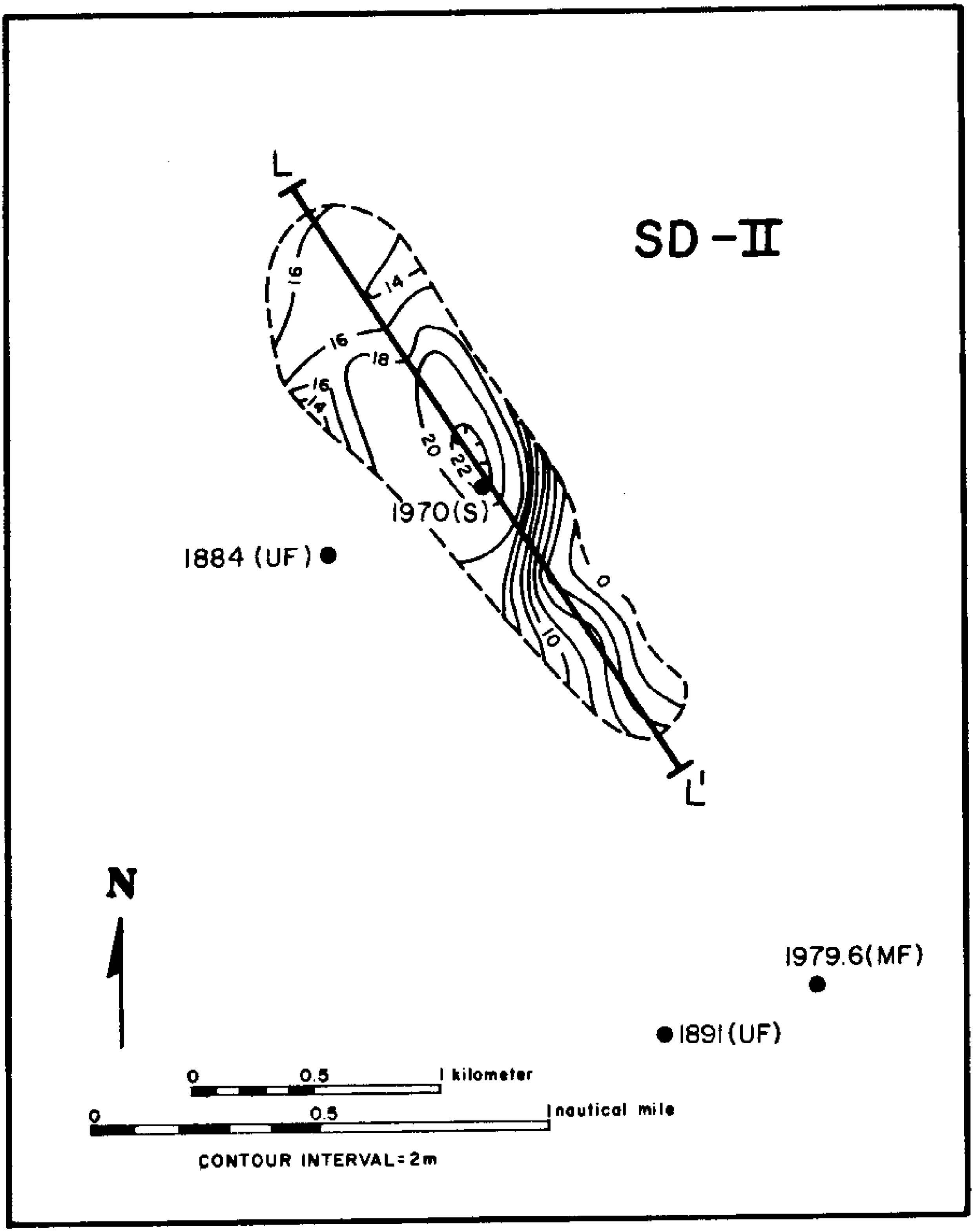


Figure 42. Isopach map of borrow area SD-II with associated vibracore numbers, sand suitability symbols, and line of geologic cross section L-L'.

have been extended both to the north and south. The principal target material is the slope wash facies of the Pleistocene estuarine sequence, which was penetrated by vibracore 1970 (Figs. 43 and 44). Along the northern margin of this site, where the San Luis Rey offshore channel cuts this estuarine sequence, the target is Holocene channel fill. A maximum of 20.7 x 10^6 m^3 of suitable sand is estimated to occur in SD-II.

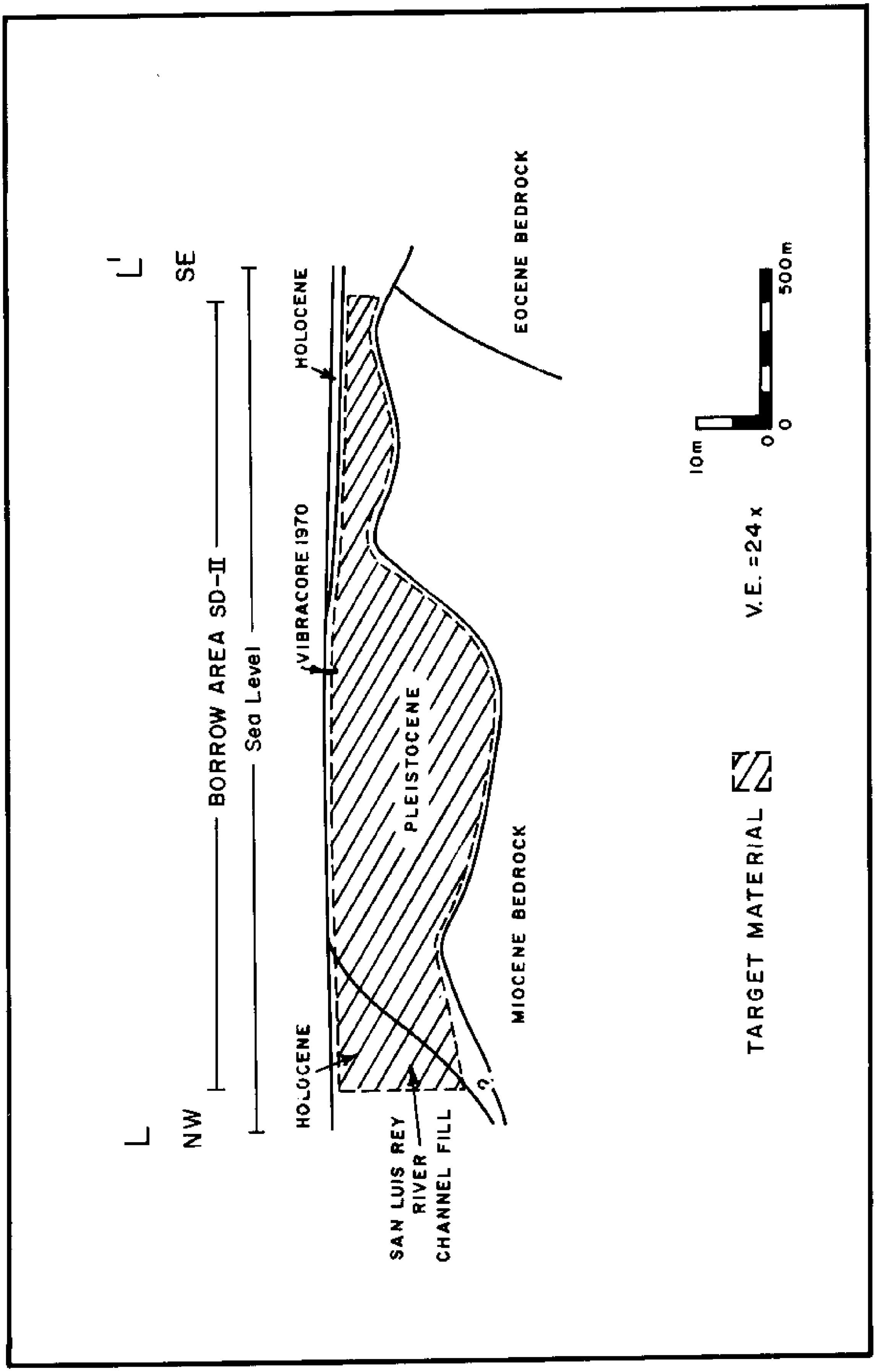


Figure 43. Geologic cross section L-L'.

VIBRACORE LOG

Core number: 1970

Date: 2/81

Total core length (cm): 93

Sheet 1 of 1

Number of core sections: 1

Water depth (ft): 45

Vertical scale: 1 cm = 25 cm

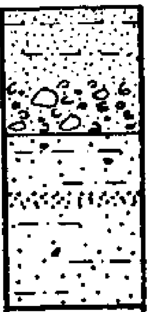
Distance in cm from top of core	Description	Log
0-40	Sand: very fine grained, ranges from silt to fine sand; well sorted: olive gray (5 Y 3/2); sparse shell fragments; apparently massive with interval 24-40 cm. containing fine sand to gravel with abundant shell fragments and occasional whole gastropod and pelecypod shells, pebbles and cobbles (1-8 cm. dia.); very poorly sorted; sharp lower contact.	
40-93	Sand: medium grained, ranges from silt to gravel; moderately sorted; dusky yellow (5 Y 6/4) with bands of grayish black (N2) from 78-93 cm.; predominantly massive with a bed of very coarse sand from 60-65 cm.; very micaceous; rare shell fragments.	

Figure 44. Log of vibracore 1970 which is illustrative of the sedimentologic character of borrow area SD-II.

V. OCEANSIDE TO LA JOLLA AREA, SAN DIEGO COUNTY

Introduction

The seismic and vibracore data between Oceanside and La Jolla are very sparse (Fig. 45), and were taken to provide transitional coverage between these two more thoroughly studied areas. Only one continuous trackline was taken between Oceanside and La Jolla, and it approximately follows the 15 m isobath parallel to the coastline. Having only one profile precludes the preparation of isopach and structural contour maps, thus the following is a brief discussion of the structural geology and stratigraphy between the seismic trackline and the coast.

The bedrock along the coast from Carlsbad to the Rose Canyon fault in the La Jolla area is entirely Eocene. Maps of the coastal area (Wilson, 1972; Kennedy, 1975) indicate that the Eocene strata generally trend north and dip eastward from 2° to 8°. In faulted areas, the strike of the Eocene strata varies greatly, and dips increase from 10° to 50°. Along the seismic trackline, the Eocene strata appear to be horizontal or dip slightly southward, but this is undoubtedly due to apparent dips associated with the generally eastward dip mapped on land.

Faults that intersect the coast include a group of four unnamed faults immediately south of Batiquitos Lagoon (Wilson, 1972), an unnamed fault at the northern edge of Soledad Valley, and two strands of the Carmel Valley fault in Torrey Pines Park (Kennedy, 1975). Of these, only the northernmost set of faults and the Carmel Valley fault occur on the offshore seismic trackline. The faults south of Batiquitos Lagoon may represent an older segment of the Rose Canyon fault zone, which was later abandoned and transected by a younger offshore branch. If the Bataquitos faults were extended southward from the coast, through the disturbed zone on the obtained seismic profile, and beyond,

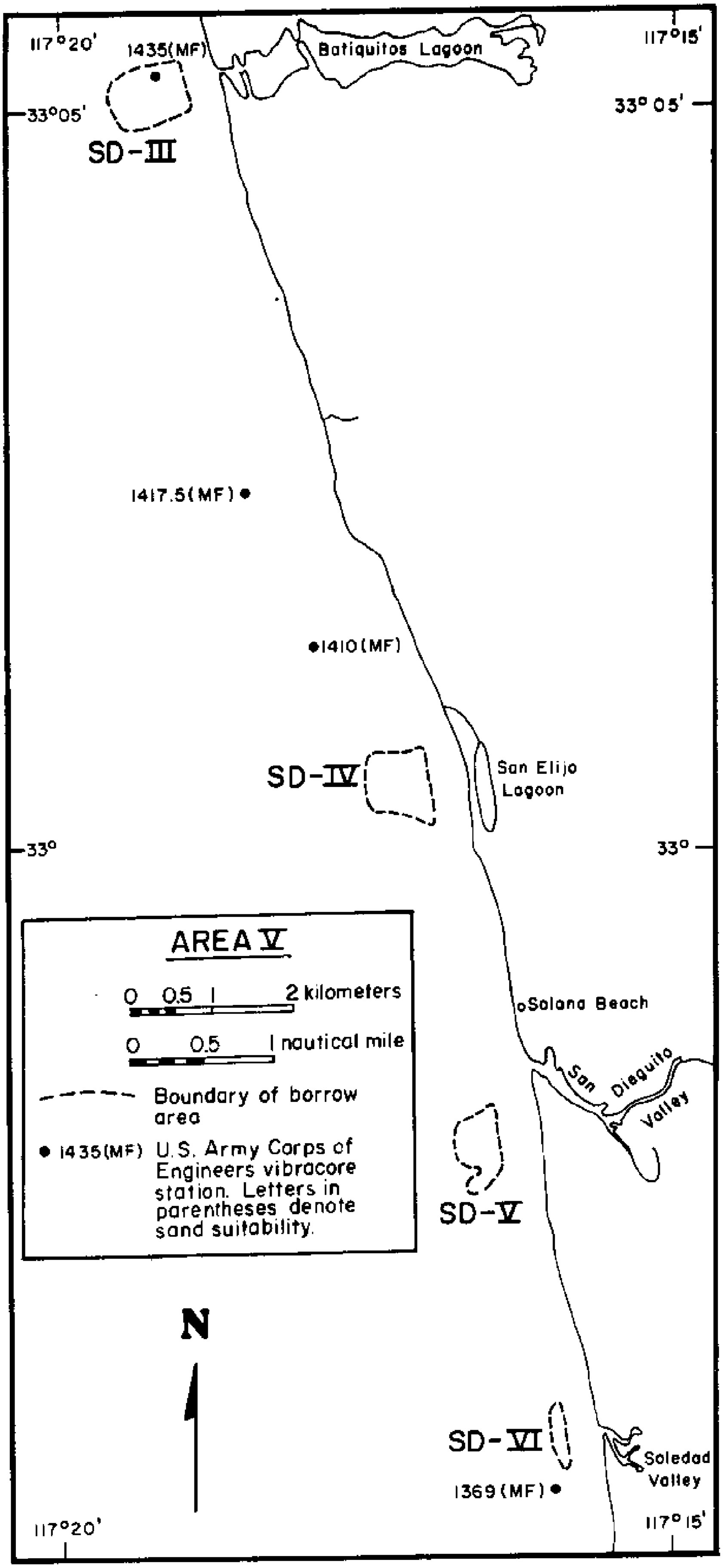


Figure 45. Map of area V showing locations of borrow areas SD-III through SD-VI with associated vibracore numbers and sand suitability symbols.

they would intersect the north-northwest trending Rose Canyon fault zone approximately 45 km offshore of Solana Beach. The Rose Canyon fault zone has been mapped offshore by Moore (1972), Byrd and others (1975), and Darigo (in preparation).

The two strands of the Carmel Valley fault intersect the coast 1.8 and 2.1 km south of the southern edge of Soledad Valley. Kennedy (1975) shows the fault trending northeast and extending inland for about 4 km; however, at the coast it trends nearly east. Three possible faults occur offshore in the vicinity of the Carmel Valley fault, which are on trend with the coastal strike of this fault. Thus it is possible that the Carmel Valley fault extends offshore in this area.

Examination of the seismic profile indicates the presence of several folds, some of which may be continuous with onshore structures (Darigo, in preparation).

Quaternary Stratigraphy

Holocene Strata

Stratigraphy: Only two major stratigraphic units are present on the narrow shelf between Carlsbad and La Jolla; namely, Eocene bedrock and Holocene strata. A thin layer of Pleistocene basal gravel may be present in the offshore channels associated with Batiquitos Lagoon, San Elijo Lagoon, San Dieguito Valley and Soledad Valley. The coastal geology from Carlsbad to Solana Beach has been mapped by Wilson (1972), and south of Solana Beach by Kennedy (1975). The Eocene units that are exposed in the sea cliffs include, from north to south, Santiago Formation Member B, the Torrey Sandstone, the Del Mar Formation, the Ardnath Shale, and the Scripps Formation. The last four units are assigned to the La Jolla Group.

Offshore Holocene strata consist of nonmarine channel fill deposits, which lie seaward of the four major sloughs, and a continuous cover of very fine-grained, marine sand. The marine cover overlies Eocene and nonmarine Holocene deposits, and isopach maps for the marine strata have been prepared by Henry (1976) and Fischer and others (1982). The Holocene marine package is as much as 8 m thick, and the thickest part parallels the coastline from 1.2 to 2 km from shore. In a landward direction, it thins to zero from 0.3 to 1.5 km from shore; and in a seaward direction, it thins to zero from 2.5 to 4 km from shore. Immediately north of Scripps submarine canyon, the Holocene marine unit increases in thickness to a maximum of 15 m where it occurs over marine terraces. This unit is characterized by very parallel, continuous reflectors, which infill erosional vacuities within Eocene strata and are conformable to the sea floor.

The Holocene marine cover is underlain by a thicker nonmarine Holocene component at four localities. These nonmarine deposits infill channels, which are offshore extensions of Batiquitos Lagoon, San Elijo Lagoon, San Dieguito Valley and Soledad Valley. Detection of the channel boundaries was facilitated by the side-scan sonar data, which show an abrupt change in surface texture from rough to smooth, i.e. from Eocene bedrock to Holocene strata. The nonmarine strata are characterized by discontinuous, weak reflectors, or a generally transparent signature compared to the Eocene bedrock. The maximum thickness of the channel fill deposits cannot be determined from the available seismic data, because of the transparency of its signature and multiple interference. However, it is estimated to be at least 25 m thick at some localities.

Lithology: Five vibracores, ranging from 0.7 to 2.9 m long, were recovered in the Oceanside-La Jolla coastal segment. All vibracores, except 1435, encountered olive black to olive gray, fossiliferous, moderately well-sorted, very fine- to fine-grained, marine sand. Core 1435 penetrated 65 cm of similar sediment, which was underlain by at least 8 cm of olive gray, medium-grained sand and gravel. Although seismic coverage is meager in the vicinity of vibracore 1435, this coarse-grained sediment is considered to be a channel fill deposit, particularly as it occurs directly offshore of Batiquitos Lagoon (Fig. 45).

Compositional data for sand samples recovered from the Oceanside-La Jolla segment are listed in Table 17. All of the samples examined petrographically are assigned to the Holocene marine unit, and range compositionally from litharenite to feldspathic litharenite (McBride, 1963).

Potential Sand and Gravel Resources

Holocene channel fill deposits are considered the only suitable target material in the Oceanside-La Jolla coastal segment (Fig. 45). The Eocene strata are too indurated, and the Holocene marine strata are too fine-grained. The four sites delimited in this area are discussed collectively due to their similarity in geologic setting and target materials. At each of the four potential borrow areas, the channel fill deposits are overlain by less than 1 m of the Holocene marine unit. The seaward edge of each borrow area was taken as the position of the 1 m isopach for the Holocene marine unit (Henry, 1976; Fischer and others, 1982). Seaward of this isopach, the Holcene marine unit is undesirably thick.

Potential borrow area SD-III (Table 18, Figs. 46, 47 and 48) occurs offshore of Batiquitos Lagoon, and contains no more than 12.6 x 10^6 m^3 of suitable sand. Borrow area SD-IV (Table 19, Figs. 47 and 49) is offshore of San Elijo Lagoon, and contains a maximum of 9.5 x 10^6 m^3 of suitable material. Borrow area SD-V (Table 20, Figs. 47 and 50) lies offshore of San Dieguito

Table 17. Summary of lithologic composition of sand from samples recovered from the Oceanside-La Jolla area.

LITHOLOGIC COMPOSITION	HOLOCENE MARINE n = 6 Mean %
Monocrystalline Grains	
Nonundulose Quartz	18.4
Undulose Quartz	7.5
Plagioclase Feldspar	2.3
Potassium Feldspar	3.2
Pyroxene	0.3
Amphibole	0.2
Biotite	21.9
Epidote	0.0
Sphene	0.1
Garnet	0.0
Magnetite-Ilmenite	0.8
Polycrystalline Grains	
Quartz with 2-3 subunits	3.7
Quartz with >3 subunits	1.4
Plutonic Rock	10.4
Metamorphic Rock	0.0
Volcanic Rock	0.0
Siliciclastic Rock	0.6
Intraclastic Grains	0.7
Allochemical Constituents	26.6
Microcrystalline Quartz	1.1

Table 18. Summary of potential borrow area SD-III.

Type of Deposit:

Holocene channel fill deposits

Water Depth:

Minimum: 4 meters

Maximum: 22 meters

Range in Mean Grain Size: n = 1

Minimum:	2.73 phi	0.15 mm
Maximum:	2.73 phi	0.15 mm
Mean:	2.73 phi	0.15 mm

Range in Thickness:

Minimum: 0 meters

Maximum: 20 meters

Estimated Volume	(x 10^6 m^3)	(x 10^6 yd^3)
Minimum:		
Maximum:	12.6	16.5
Other:		Explanation of value:

Vibracores Penetrating Deposit:

1435

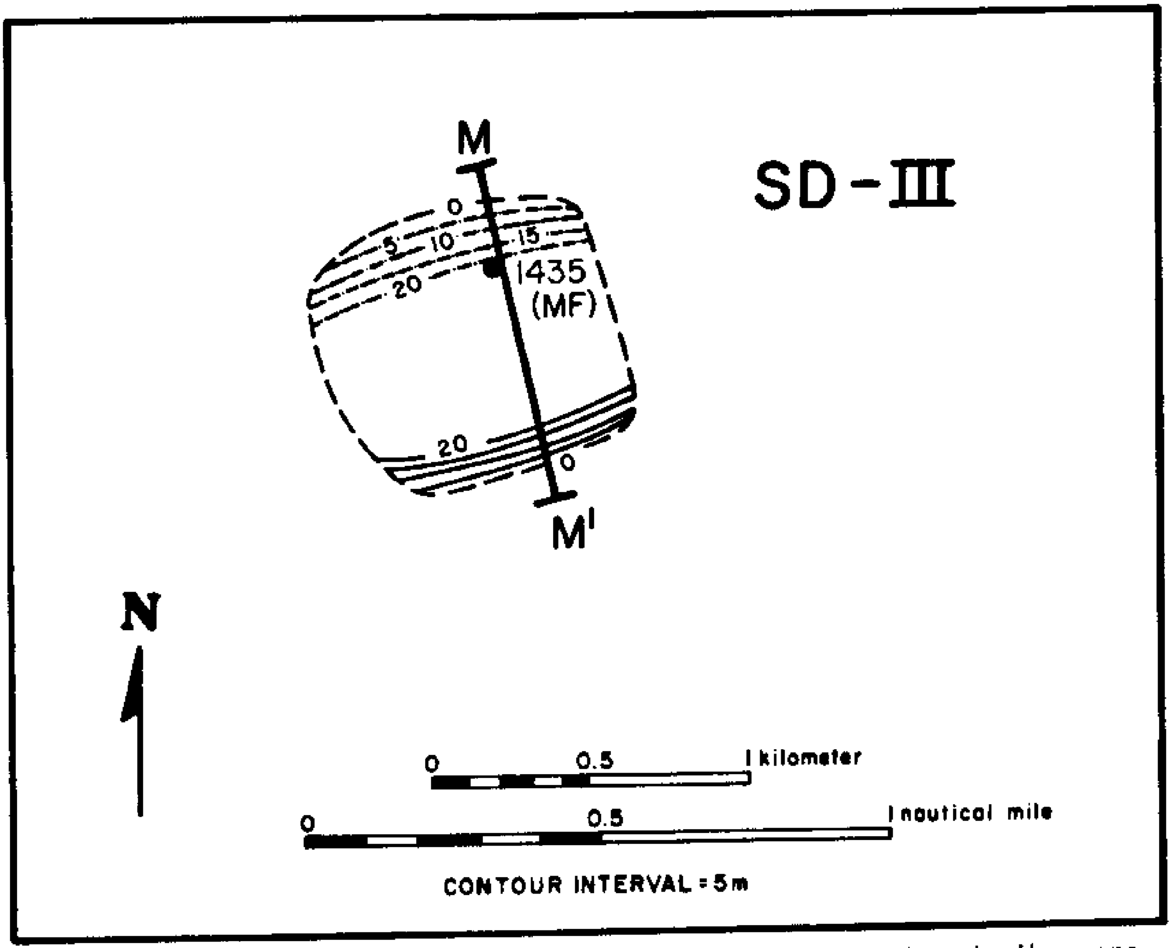


Figure 46. Isopach map of borrow area SD-III with associated vibracore number, sand suitability symbol, and line of geologic cross section M-M'.

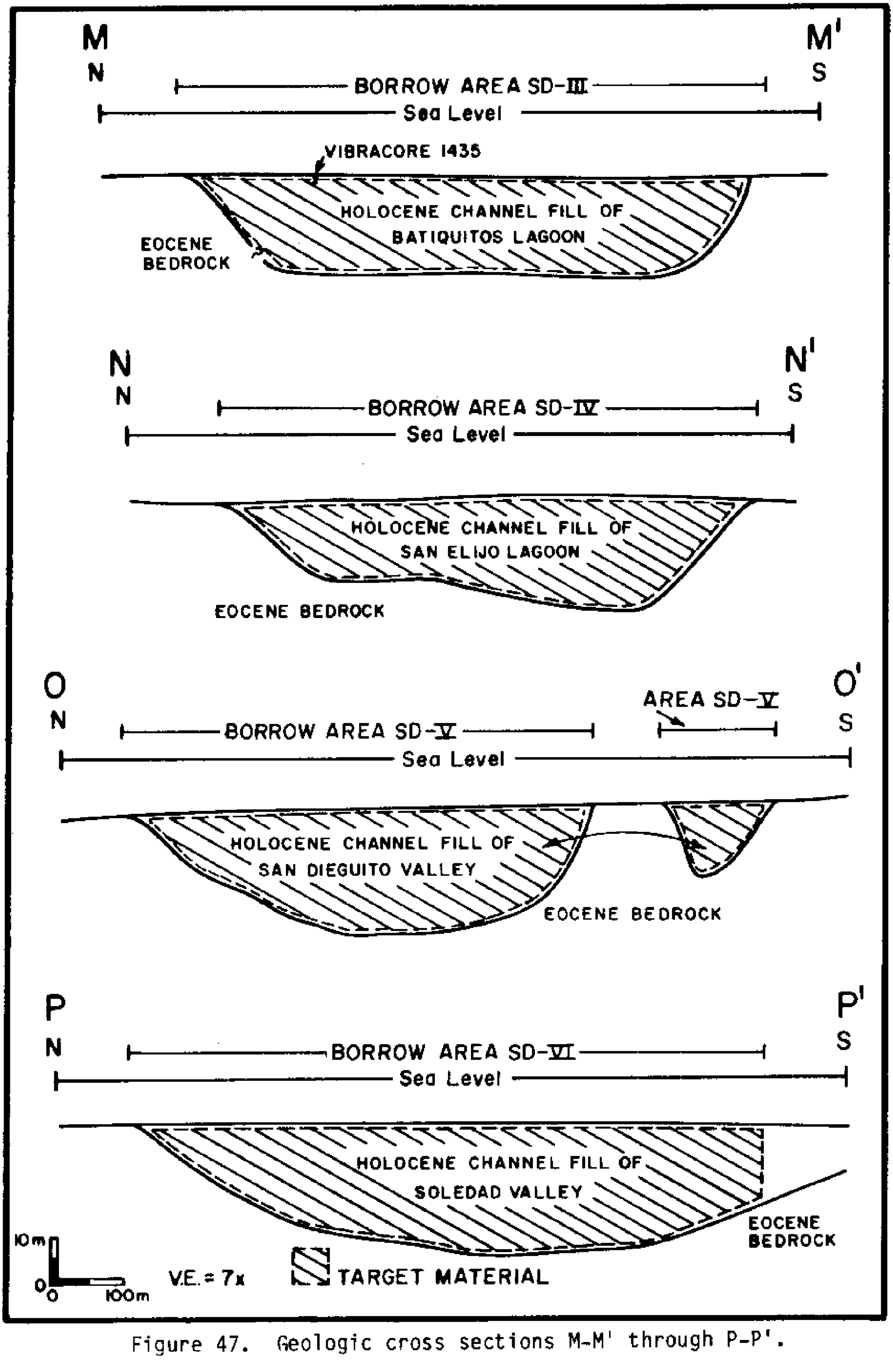


Figure 47. Geologic cross sections M-M' through P-P'.

VIBRACORE LOG

Core number: 1435

Date: 2/81

Total core length (cm): 73

Sheet 1 of 1

Number of core sections: 1

Water depth (ft): 42

Vertical scale: 1 cm = 25 cm

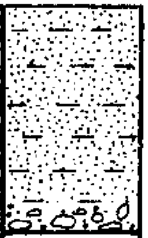
Distance in cm from top of core	Description	Log
0-73	Sand: very fine grained, ranges from silt to fine sand from 0-65 cm., moderately well sorted; medium sand to gravels from 65-73 cm. with abundant clasts (1-5 cm. dia.), poorly sorted; olive gray (5 Y 4/1) grading to olive black (5 Y 2/1); apparently massive; highly micaceous grading downward to slightly micaceous.	

Figure 48. Log of vibracore 1435 which is illustrative of the sedimentologic character of borrow area SD-III.

Table 19. Summary of potential borrow area SD-IV.

Type of Deposit:

Holocene channel fill deposits

Water Depth:

Minimum: 6 meters

Maximum: 18 meters

Range in Mean Grain Size: No samples recovered

Minimum: phi mm

Maximum: phi mm

Mean: phi mm

Range in Thickness:

Minimum: 0 meters

Maximum: 23 meters

Estimated Volume (x 10^6 m^3) (x 10^6 yd^3)

Minimum:

Maximum: 9.5 12.4

Other: Explanation of value:

Vibracores Penetrating Deposit:

None

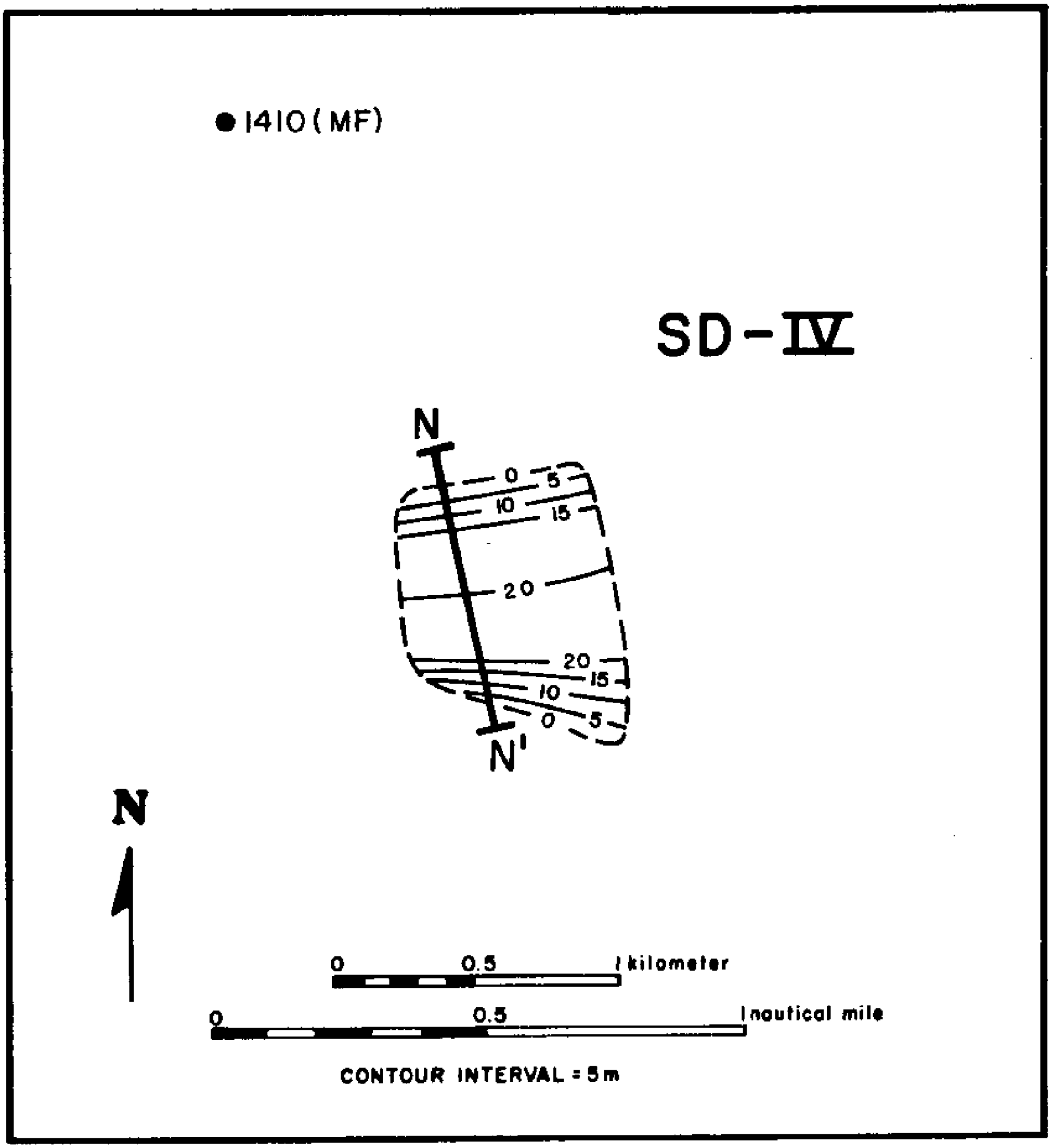


Figure 49. Isopach map of borrow area SD-IV with associated vibracore number, sand suitability symbol, and line of geologic cross section N-N'.

Table 20. Summary of potential borrow area SD-V.

Type of Deposit:

Holocene channel fill deposits

Water Depth:

Minimum:	6 meters
Maximum:	17 meters

Range in Mean Grain Size: No samples recovered

Minimum:	phi	mm
Maximum:	phi	mm
Mean:	phi	mm

Range in Thickness:

Minimum:	0 meters
Maximum:	25 meters

Estimated Volume	(x 10^6 m^3)	(x 10^6 yd^3)
Minimum:		
Maximum:	7.9	10.3
Other:		Explanation of value:

Vibracores Penetrating Deposit:

None

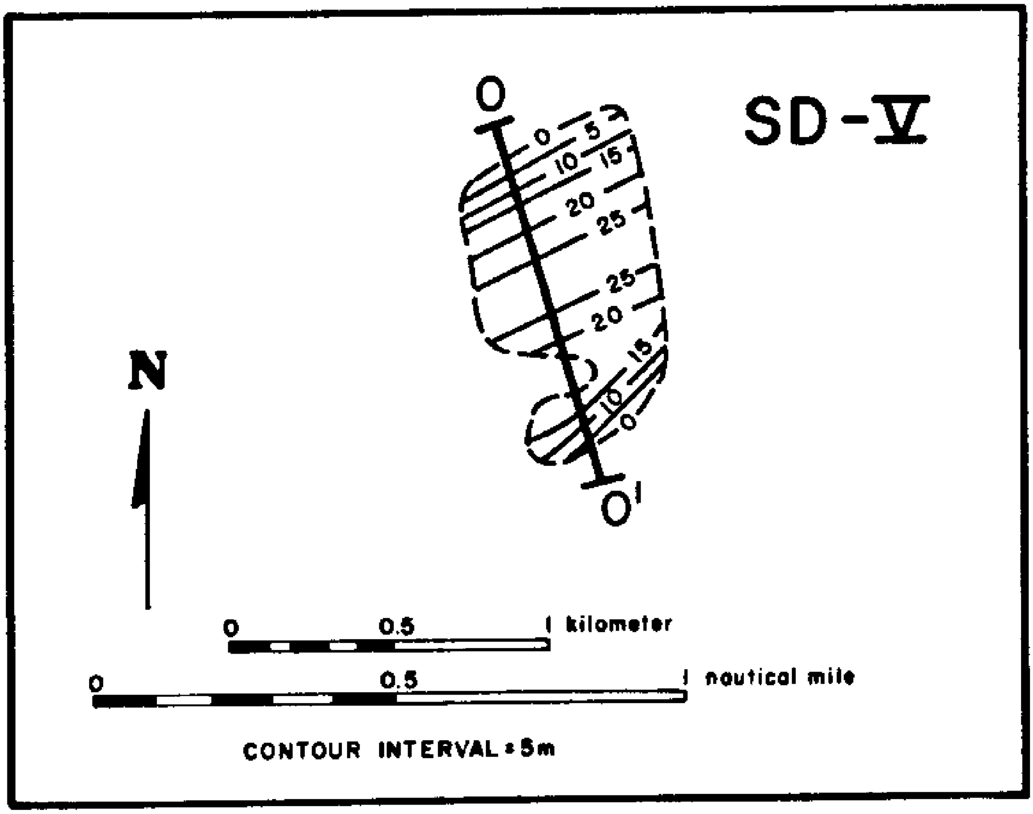


Figure 50. Isopach map of borrow area SD-V with line of geologic cross section O-O'.

Valley, and contains at most 7.9 x 10^6 m^3 of suitable sand. Potential borrow area SD-VI (Table 21, Figs. 47 and 51 occurs offshore of Soledad Valley, and contains a maximum of 2.2 x 10^6 m^3 of target material. Potential borrow area SD-VI is approximately equivalent to Area IV of Ocean Survey, Inc. (1981); however, Area IV includes the position of vibracore 1369, where the thickness of the Holocene marine unit is prohibitive.

Table 21. Summary of potential borrow area SD-VI.

Type of Deposit:

Holocene channel fill deposits

Water Depth:

Minimum: 6 meters

Maximum: 12 meters

Range in Mean Grain Size: No samples recovered

Minimum:	phi	mm
Maximum:	phi	mm
Mean:	phi	mm

Range in Thickness:

Minimum: 0 meters

Maximum: 26 meters

Estimated Volume	(x 10^6 m^3)	(x 10^6 yd^3)
Minimum:		
Maximum:	2.2	2.9
Other:		Explanation of value:

Vibracores Penetrating Deposit:

None

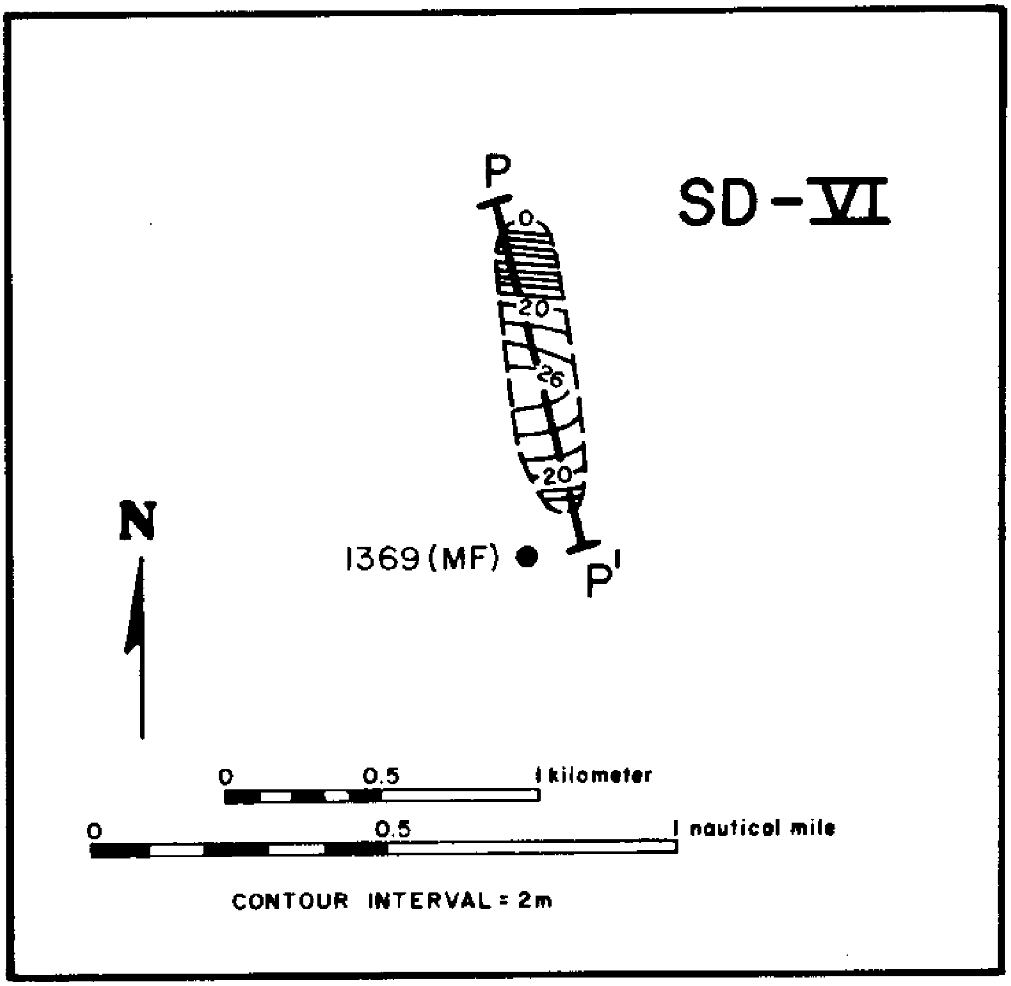


Figure 51. Isopach map of borrow area SD-VI with associated vibracore number, sand suitability symbol, and line of geologic cross section P-P'.

VI. LA JOLLA AREA, SAN DIEGO COUNTY

Introduction

Due to the presence of a major submarine canyon, fault zone, and oceanographic institution all within La Jolla Bay, this area has been studied more thoroughly than any other discussed in this paper (Fig. 52). Nearly every geological aspect of La Jolla Bay, i.e. canyon formation, stratigraphy, and sediment transport and deposition, is affected by the structure of the area. The Rose Canyon fault zone trends offshore from the east side of Mount Soledad, and separates into north-northwesterly and west-northwesterly trending fault sets. The Rose Canyon fault zone has been studied onshore in the La Jolla area by Moore and Kennedy (1970), Peterson (1970), Kennedy (1975), Gastil and others (1979), and Threet (1979); and offshore by Moore (1972), Greene and others (1979), Kennedy and others (1980a, 1980b), and Webb (in preparation). Regionally, it is part of a major structural zone extending from the Los Angeles basin into Baja California, which includes the Newport-Inglewood and South Coast fault zones. Offshore seismic studies by Kennedy and others (1980a, 1980b) identify the faults of La Jolla Bay as part of this major Quaternary deformational zone. The Rose Canyon fault zone is a highly complex network of faults, which can be grouped into three distinct sets named the eastern, central and western subzones. The individual subzones range from less than 1 to 5 km wide, and together they are approximately 15 km wide. Kennedy and others (1980a, 1980b) and Darigo (in preparation) discuss the Rose Canyon fault zone in considerable detail.

Rocks which have been dredged from La Jolla submarine canyon (Emery and Shepard, 1945) and extrapolations from onshore geology (Kennedy, 1975) indicate that the accoustic basement in the offshore La Jolla area consists of the Cretaceous Point Loma Formation south of the submarine canyon; and Eocene

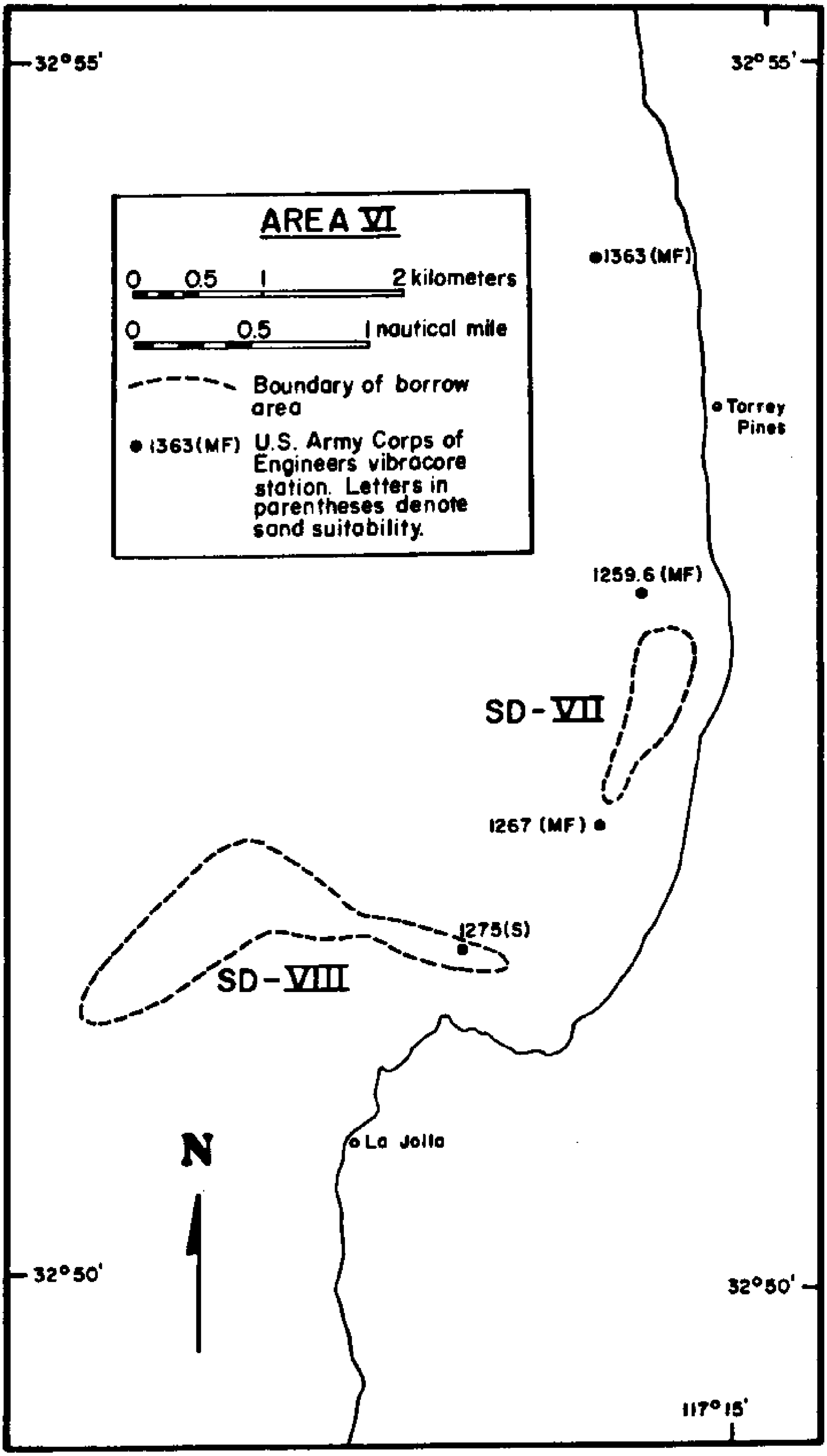


Figure 52. Map of area VI showing location of borrow areas SD-VII and SD-VIII with associated vibracore numbers and sand suitability symbols.

strata, most likely the Ardnath Shale, on the north side. The contact between Cretaceous and Eocene strata probably follows La Jolla Canyon to the onshore Rose Canyon fault, but its exact location is unknown, because the canyon floor is locally covered with sediment (Shepard, 1973), and is beyond available seismic resolution.

Quaternary Stratigraphy

Upper Pleistocene Strata

Stratigraphy: Pleistocene strata in the La Jolla area include possible Bay Point Formation, marine terrace deposits, fault-ponded sediment, and prograded shelf-slope deposits. These four stratal types have distinctly different seismic characteristics and are not usually laterally continuous with one another; therefore there is little available evidence to make age assignments for these units. However, their stratigraphic position, usually beneath an erosional unconformity or depositional hiatus overlain by Holocene strata, justifies a separate description for these strata. If these units are unlithified, they were probably deposited near to the initiation of the Flandrian transgression.

The Bay Point Formation may appear offshore in a small area near Scripps pier. It is characterized seismically by discontinuous, non-parallel, slope-like reflectors. It is interrupted by the head of Scripps canyon to the north, and it is laterally adjacent to Holocene marine strata to the south. The Bay Point Formation crops out along the coast for a distance of approximately 700 m near the offshore deposits (Kennedy, 1975). The shoreline angle of the Nestor terrace, which is included in the Bay Point Formation, occurs 5 m above sea level just north of Scripps pier (Kern, 1977). The Bay Point Formation in this area overlies Eocene strata and consists of thin, marine and terrestrial deposits on top of this terrace.

The fact that all offshore remnants of the Nestor erosional platform would have been destroyed by present sea level argues against these offshore deposits being assigned to the Bay Point Formation. However, the base of the offshore deposits in question occurs at approximately 13 to 15 m b.p.s.l., which correlates well with the expected location and depth of the younger Bird Rock terrace, which is also included in the Bay Point Formation.

Offshore of the Bay Point deposits, Quaternary strata were depoisited on a series of step-like abrasion platforms, any or all of which may have been cut during the Pleistocene. Three shoreline angles can be identified in the La Jolla area, which are approximately 38 to 45, 50 to 56, and 57 to 65 m b.p.s.l. The 38 to 45 and 57 to 65 m terraces are present throughout the La Jolla area, whereas the 50 to 56 m terrace is absent south of La Jolla Canyon. The 38 to 45 and 57 to 65 m terraces probably are equivalent to those mapped by Henry (1976) at depths of 43 to 49 and 52 to 69 m b.p.s.l., respectively.

The deposits immediately overlying the terraces are usually charcterized by either: (1) strong, closely-spaced, locally continuous, parallel, slightly seaward-dipping reflectors, which suggest inhomogeneous nonmarine deposits; or (2) weak, horizontal reflectors, which suggest homogeneous marine deposits. The 38 to 45 m shoreline angle and terrace is generally overlain by thin, nonmarine strata. The 57 to 65 m terrace is overlain by marine strata. The 50 to 56 m terrace is overlain by marine strata north of the Salk fault, and is overlain by nonmarine strata farther south, where it is difficult to distinguish as a separate terrace. The geologic history of these terraces and associated deposits is discussed thoroughly by Darigo (in preparation).

The Pleistocene slope deposits display weak, continuous, parallel reflectors, which dip toward La Jolla Canyon and aggrade so that the thickest part occurs over the shelf edge. These strata overlie Cretaceous rock, and are erosionally truncated on top. The seismic character of this unit and its location at the shelf edge indicate that it is probably a homogeneous deposit of silt to very fine-grained sand. It is overlain by a similar, less steeply-dipping, prograded shelf edge deposit. There is no available evidence to assign a Pleistocene rather than Holocene age for the lower deposit, but it is included here for the sake of delineating the two stratigraphic packages.

Fault-ponded strata north of La Jolla Canyon occur in depressions associated with strike-slip faulting in the central subzone. The seismic character of these strata include (1) chaotic, discontinuous reflectors, and (2) steeply-dipping, parallel reflectors. Both types of reflectors suggest rapid deposition of homogeneous sediment. Occasionally, strong, channel-like reflectors and strong, discontinuous, slightly-dipping reflectors occur, which are suggestive of talus and/or slump deposits. Similar ponded strata have been identified in the main strike-slip portion of the Rose Canyon fault zone as far north as Camp Pendleton (Moore, 1972).

Lithology: No late Pleistocene sediment was recovered from the vibracores taken in the La Jolla area.

Holocene Strata

Stratigraphy: Throughout most of the La Jolla shelf, Holocene strata overlie Cretaceous or Eocene bedrock. Where late Pleistocene deposits occur on the shelf, there usually is no obvious widespread unconformity separating the two units. Instead, the late Pleistocene and Holocene units are separated by a change in seismic character and internal geometry. The Holocene isopach map prepared for this study is similar with those prepared by Byrd and others (1975), Henry (1976), Fischer and others (1982), and Webb (in preparation), except that, in some areas, other studies may include the strata here considered late Pleistocene. Due to more limited seismic coverage, past studies have not included the thick, prograded, shelf edge deposit south of

La Jolla Canyon.

The Holocene strata are characterized by rather weak, parallel, very continuous reflectors, which are concordant with the sea floor. The reflectors at the base of the Holocene are concordant with the underlying surface at middle shelf depths and onlap over bedrock surfaces nearshore. Holocene deposits either thin to zero or prograde over the shelf edge. Holocene deposits on the floor and heads of the canyons (Shepard, 1951, 1973; Chamberlain, 1960, 1964; and Dill, 1964, 1969) cannot be delineated by the seismic data used for this study.

The Holocene isopach map indicates that the sediment packages approximately parallel the present coastline with various submerged shoreline angles. North and south of the submarine canyons, thicker Holocene stratigraphic sections occur over the 38 to 45 m terrace. Two very thick and homogeneous Holocene deposits occur in the La Jolla area: one between the two heads of the submarine canyons, and the other farther offshore on the south slope of La Jolla Canyon. Although the thickest Holocene sections on the San Diego shelf usually are associated with fluvial sedimentation, this may be only partially true for these thick intercanyon deposits. A nearshore channel extends to approximately 20 m b.p.s.l. and is covered with 7 to 8 m of Holocene marine deposits, thus these thick intercanyon packages must be at least partially related to marine processes.

Divers report that the thick section on the intercanyon shelf is most silt (Webb, personal communication), and samples taken near the 50 m isobath, which is over the thickest part of the deposit, have a median diameter of silt (Shepard and Inman, 1951). Several past studies have attributed these sediment build-ups to wave transport as controlled by the unusual bottom topography (Shepard and Inman, 1950, 1951; Inman, 1953; and Henry, 1976).

Whereas the Holocene strata north of the submarine canyons and on the intercanyon shelf probably were delivered by longshore currents from the north, the thick prograded section south of the canyon suggests longshore sediment transport from the south. Inasmuch as no appreciable amount of sediment bypasses Point La Jolla and the head of La Jolla submarine canyon (Shepard and Inman, 1951; Inman, 1953), sediment transported in a northward-flowing longshore current along Point Loma Peninsula, Mission Beach and Mt. Soledad would continue northward at Point La Jolla rather than curving toward La Jolla. Shelf sediment transport ends where the seafloor dips toward La Jolla submarine canyon. Here the sediment accumulates as the northward-prograding stratigraphic sequence at the shelf break. The unconformity between the two progradational units probably formed by a standstill or slight lowering of sea level during the Flandrian transgression, perhaps the same one that formed the 57 to 65 m terrace in the La Jolla area and the 58 m terrace in Santa Monica Bay (Osborne and others, 1980; and Nardin and others, 1981). The oceanographic conditions that permitted the formation of this progradational wedge must have existed since at least the start of the Flandrian transgression.

Lithology: Core 1275 was taken offshore of Point La Jolla and 2.37 m of Holocene sediment was recovered. The yellowish brown to grayish orange, moderately-sorted, massive, medium-grained sand at the top in this core is represented by moderately strong, thinly-layered reflectors. This unit is underlain by medium gray, fossiliferous, moderately well-sorted, fine-grained sand, characterized by chaotic, weak, discontinuous reflectors. The upper medium sand unit extends landward to the edge of La Jolla submarine canyon. Offshore it is either interrupted by exposures of Cretaceous bedrock or grades into finer-grained sediment at about the 50 m isobath. Shepard (1951) and

Table 22. Summary of lithologic composition of sand from samples recovered from the La Jolla area.

LITHOLOGIC COMPOSITION	HOLOCENE VERY-FINE MARINE n = 2 Mean %	HOLOCENE MEDIUM MARINE n = 2 Mean %
Monocrystalline Grains		
Nonundulose Quartz	8.8	20.7
Undulose Quartz	4.1	10.4
Plagioclase Feldspar	3.3	10.8
Potassium Feldspar	2.5	10.1
Pyroxene	0.0	0.0
Amphibole	0.2	0.0
Biotite	19.3	3.5
Epidote	0.0	0.0
Sphene	0.2	0.0
Garnet	0.0	0.0
Magnetite-Ilmenite	0.2	0.0
Polycrystalline Grains		
Quartz with 2-3 subunits	1.0	4.3
Quartz with >3 subunits	0.2	4.8
Plutonic Rock	5.4	22.8
Metamorphic Rock	0.5	0.0
Volcanic Rock	0.5	0.0
Siliciclastic Rock	6.1	0.0
Intraclastic Grains	3.1	0.3
Allochemical Constituents	34.2	11.2
Microcrystalline Quartz	11.2	1.3

Inman (1953) reported that shelf sediment south of La Jolla is coarser-grained and better rounded than sediment north of the canyon, thus suggesting a different source. The medium-grained sand unit is compositionally distinct (Table 22). The stratigraphic position of the medium-grained sand unit and perhaps its compositional distinctiveness may indicate that this sediment has only recently aggraded to the height of exposed Cretaceous bedrock, which brought these strata into the full force of the existing wave and current regime. Associated hydraulic sorting by grain size, specific gravity and shape might explain the observed differences. It also is possible that erosion of the Cretaceous strata south of La Jolla submarine canyon served as a local sediment source for this unit.

Vibracore 1267 was located on the intercanyon shelf approximately 0.67 km offshore, at a water depth of 19 m. A total of 1.98 m of medium dark gray, sparsely fossiliferous, moderately- to well-sorted, very fine- to fine-grained sand was recovered. This sediment overlies a Holocene channel deposit at least 8 m thick, which occurs as a seaward extension of the re-entrant between Mount Soledad and the Eocene bluffs to the north.

Vibracore 1259.6 was taken on the shelf north of Scripps submarine canyon, and 1.83 m of olive black to medium gray, fossiliferous, slightly micaceous, moderately well-sorted, very fine-grained sand was recovered. This core shows closely-spaced, continuous, parallel reflectors at the surface overlying relatively strong, discontinuous reflectors. The surface reflectors may be a response to a concentrated pebble layer from 37 to 56 cm in the core, whereas the underlying chaotic signature is interpreted as Eocene bedrock, which the core does not penetrate.

Compositional data for the four sediment samples from the La Jolla area are listed in Table 22. All samples are classified as feldspathic litharenite (McBride, 1963).

Potential Sand and Gravel Resources

Potential Borrow Area SD-VII

Two potential borrow areas (SD-VII and SD-VIII) occur in La Jolla Bay. Deposits considered to be potential target material include Pleistocene terrace deposits, canyon fill at the head of Scripps submarine canyon, and the Holocene medium-grained sand unit.

Borrow area SD-VII occurs on the inner shelf immediately north of Scripps pier (Table 23, Figs. 52 and 53), between the 11 and 70 m isobaths. The target material mainly consists of coarse-grained strata in the head of Scripps submarine canyon, with minor amounts of Pleistocene terrace and Holocene marine, medium-grained sand deposits (Fig. 54). The nearshore boundary of SD-VII is the 11 m isobath. The north, south and west boundaries are defined by the 1 m limiting thickness of fine-grained Holocene cover. No vibracores were attempted at this borrow area, and it is estimated to contain at most 2.4 x 10^6 m^3 of suitable material.

Potential Borrow Area SD-VIII

Potential borrow area SD-VIII is located northwest of La Jolla and south of La Jolla submarine canyon (Table 24, Figs. 52 and 55), between the 13 and 60 m isobaths. The selection of SD-VIII is based on the Holocene marine, medium-grained sand unit encountered in vibracore 1275 (Figs. 54 and 56). The lower fine-grained sand unit is included in the maximum volumetric estimate of 3.8 x 10^6 m^3 for this site, because it still may be in the marginally fine range of sand suitability. The southern limit of SD-VIII occurs where the Holocene unit abuts against submarine Cretaceous exposures, and the eastern end terminates at the La Jolla submarine canyon. The northern and western boundaries are approximately located at the position of change between the

Table 23. Summary of potential borrow area SD-VII.

Type of Deposit:

Coarse-grained strata in the head of Scripps submarine canyon, with minor amounts of Pleistocene terrace and Holocene marine, medium-grained sand deposits

Water Depth:

Minimum: 11 meters

Maximum: 70 meters

Range in Mean Grain Size: No samples recovered

Minimum:	phi	mm
Maximum:	phi	mm
Mean:	phi	mm

Range in Thickness:

Minimum: 0 meters

Maximum: 8 meters

Estimated Volume (x 10^6 m^3)		(x 10^6 yd^3)
Minimum:		
Maximum:	2.4	3.1
Other:		Explanation of value:

Vibracores Penetrating Deposit:

None

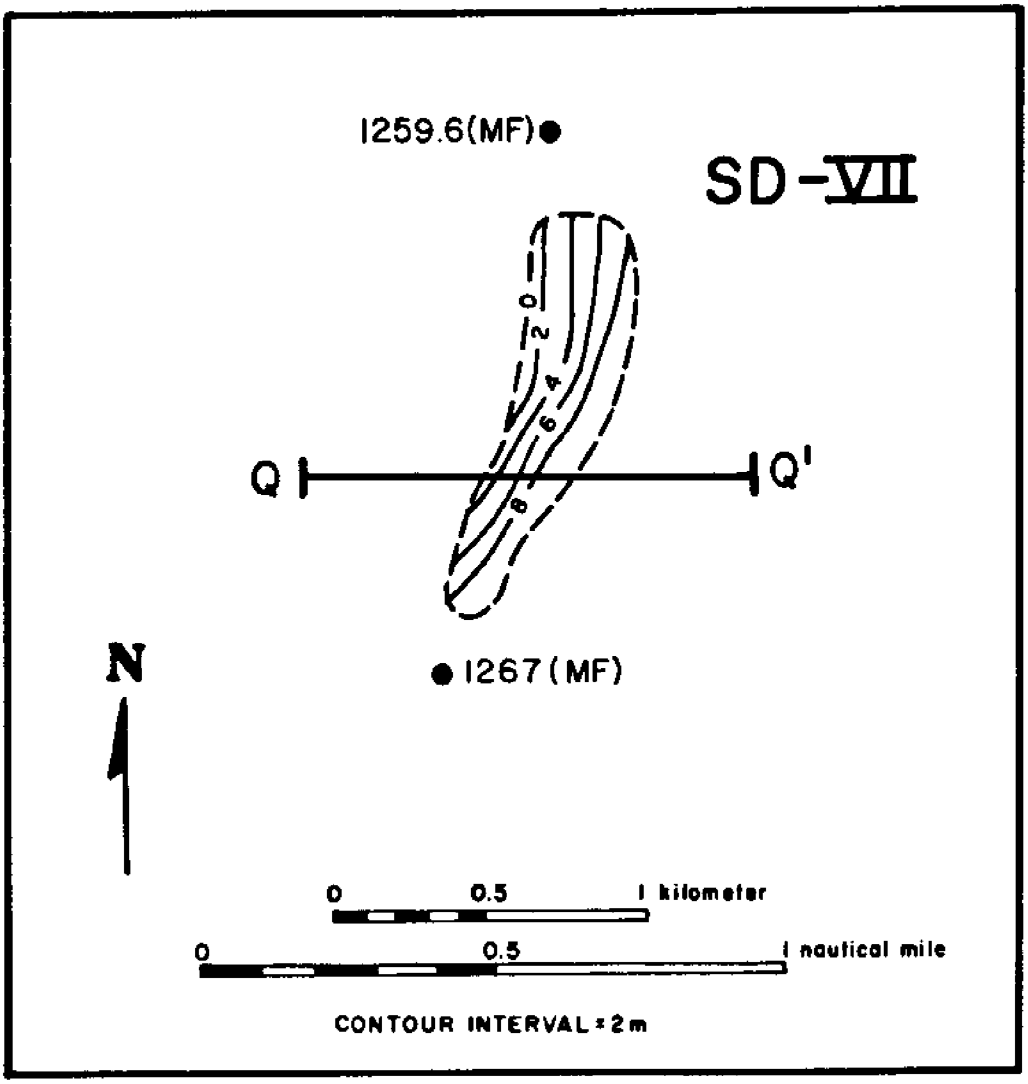


Figure 53. Isopach map of borrow area SD-VII with associated vibracore numbers, sand suitability symbols, and line of geologic cross section Q-Q'.

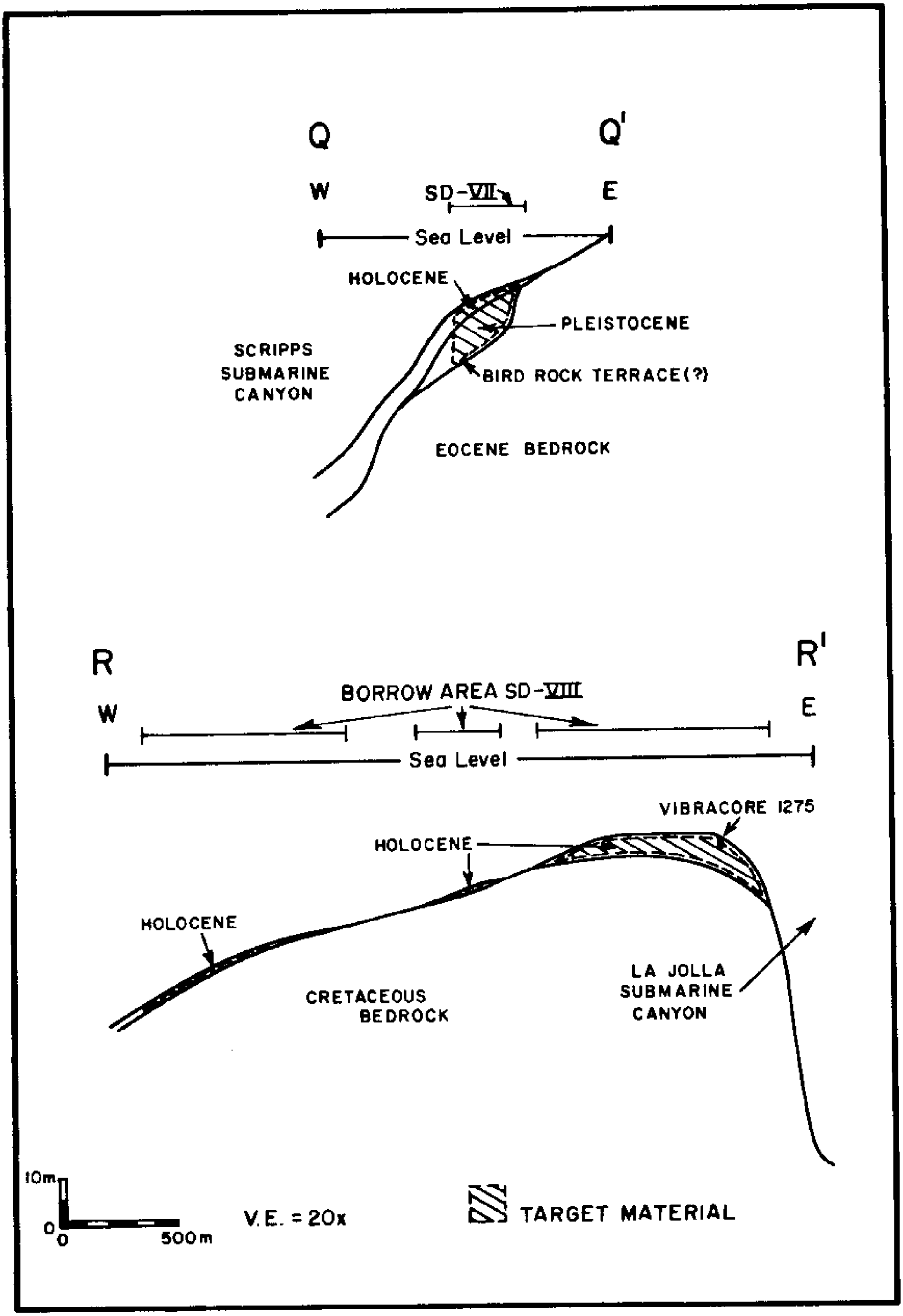


Figure 54. Geologic cross section Q-Q' and R-R'.

Table 24. Summary of potential borrow area SD-VIII.

Type of Deposit:

Holocene marine, medium-grained sand deposits

Water Depth:

Minimum:	13 meters
Maximum:	60 meters

Range in Mean Grain Size: n = 3

Minimum:	2.18 phi	0.22 mm
Maximum:	1.32 phi	0.40 mm
Mean:	1.77 phi	0.29 mm

Range in Thickness:

Minimum:	0 meters
Maximum:	8 meters

Estimated Volume	(x 10^6 m^3)	(x 10^6 yd^3)
Minimum:		
Maximum:	3.8	5.0
Other:		Explanation of value:

Vibracores Penetrating Deposit:

1275

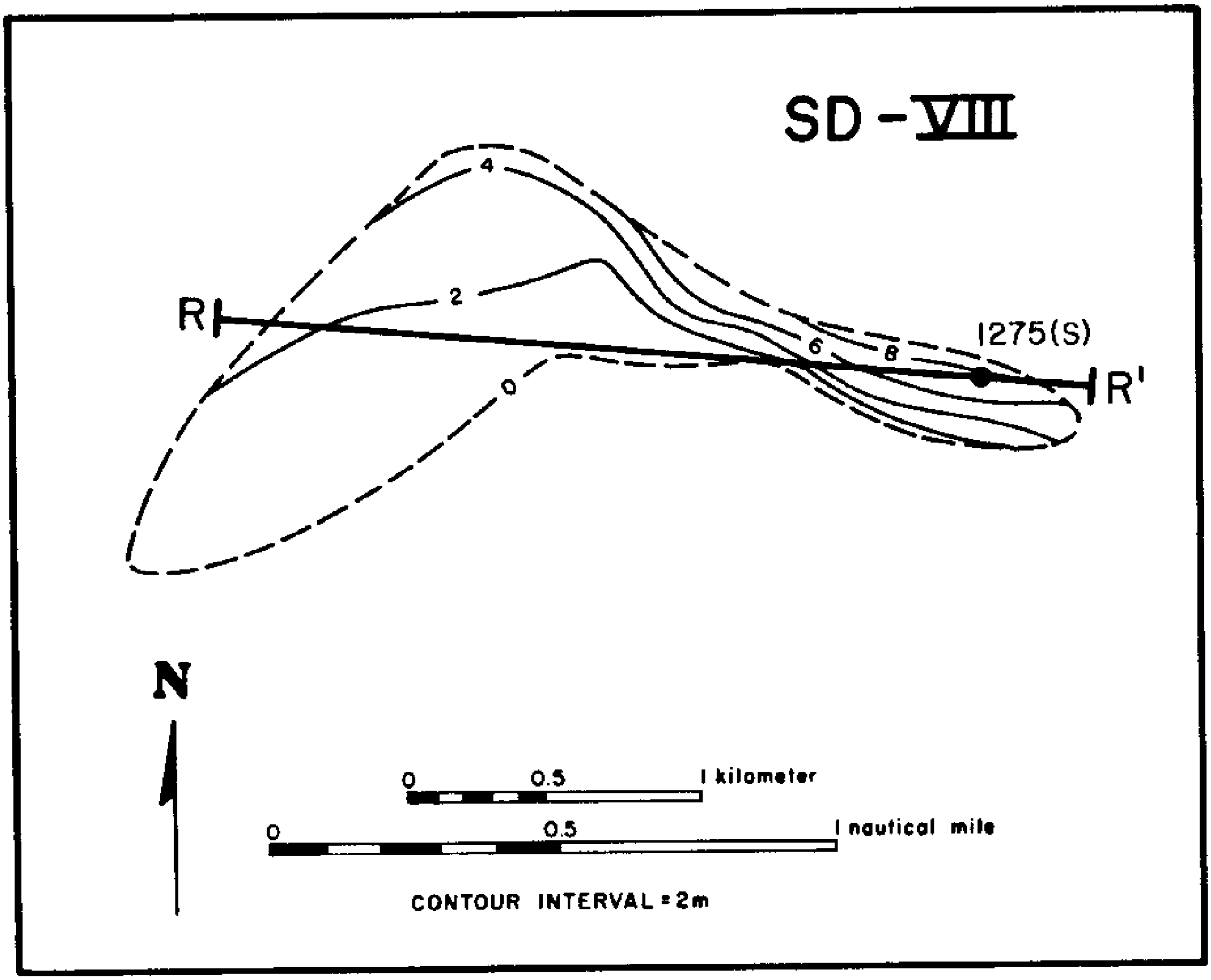


Figure 55. Isopach map of borrow area SD-VIII with associated vibracore number, sand suitability symbol, and line of geologic cross section R-R'.

VIBRACORE LOG

Core number: 1275

Date: 2/81

Total core length (cm): 237

Sheet 1 of 1

Number of core sections: 1

Water depth (ft): 70

Vertical scale: 1 cm = 25 cm

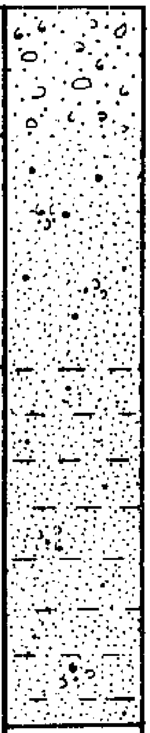
Distance in cm from top of core	Description	Log
0-42	Sand: medium grained, ranges from very fine to coarse sand with occasional large pebbles; moderately sorted; moderate yellowish brown (10 YR 5/4) intermixed with grayish orange (10 YR 7/4); apparently massive; micaceous; abundant coarse sand to gravel size shell fragments; gradational lower contact.	
42-120	Sand: fine grained, ranges from very fine to coarse sand; moderately well sorted; medium gray (N5); apparently massive; sparse shell fragments; micaceous; occasional pockets of very coarse sand and gravels and coarse sand and gravel size shell fragments; no lower contact.	
120-237	Sand: same as above interval 42-120 cm. but ranges from silt to very coarse sand and is moderately sorted.	

Figure 56. Log of vibracore 1275 which is illustrative of the sedimentologic character of borrow area SD-VIII.

type of reflectors characteristic of core 1275 and the parallel, continuous, weak reflectors characteristic of the Holocene very fine-grained marine unit.

VII. MISSION BEACH AREA, SAN DIEGO COUNTY

Introduction

The controlling structure in the Mission Beach area (Fig. 57) is an east-trending syncline, which merges to the east with the Pacific Beach syncline. Two normal faults may transect this syncline on its north flank near False Point (Beagles, 1963; and Kennedy, 1975) and on its south flank near the southern edge of Mission Bay (White, 1969), but these faults are not clearly expressed on the seismic profiles used for the present paper. According to Kennedy and others (1980a), the Mission Beach area is a regional low, which lies between two structural highs, namely Point Loma and Mount Soledad. This structural low formed in response to tensional forces associated with the Rose Canyon fault zone. Although the geologic history of Mission Bay reflects two major events, (1) the deposition and tilting of Cretaceous and Tertiary strata and (2) the erosion and sedimentologic filling of the San Diego River valley or ancient Mission Bay, Darigo (in preparation) suggests that the Mission Bay depression formed concurrently with deposition and folding of the Tertiary strata.

The geology offshore of Mission Beach is influenced greatly by an extension of the Pacific Beach syncline and the San Diego River valley. Of the five shore-normal seismic lines taken offshore of Mission Beach, the middle three are dominated by cutting, filling and reorientation of the ancient San Diego river valley, whereas Cretaceous and Tertiary bedrock is exposed along the most northern and southern tracklines.

Quaternary Stratigraphy

Stratigraphy

Quaternary strata overlie deformed and truncated Cretaceous and Tertiary bedrock in the ancient Mission Beach embayment. The maximum thickness of the Quaternary sediment package occurs deeper than the limit of available seismic

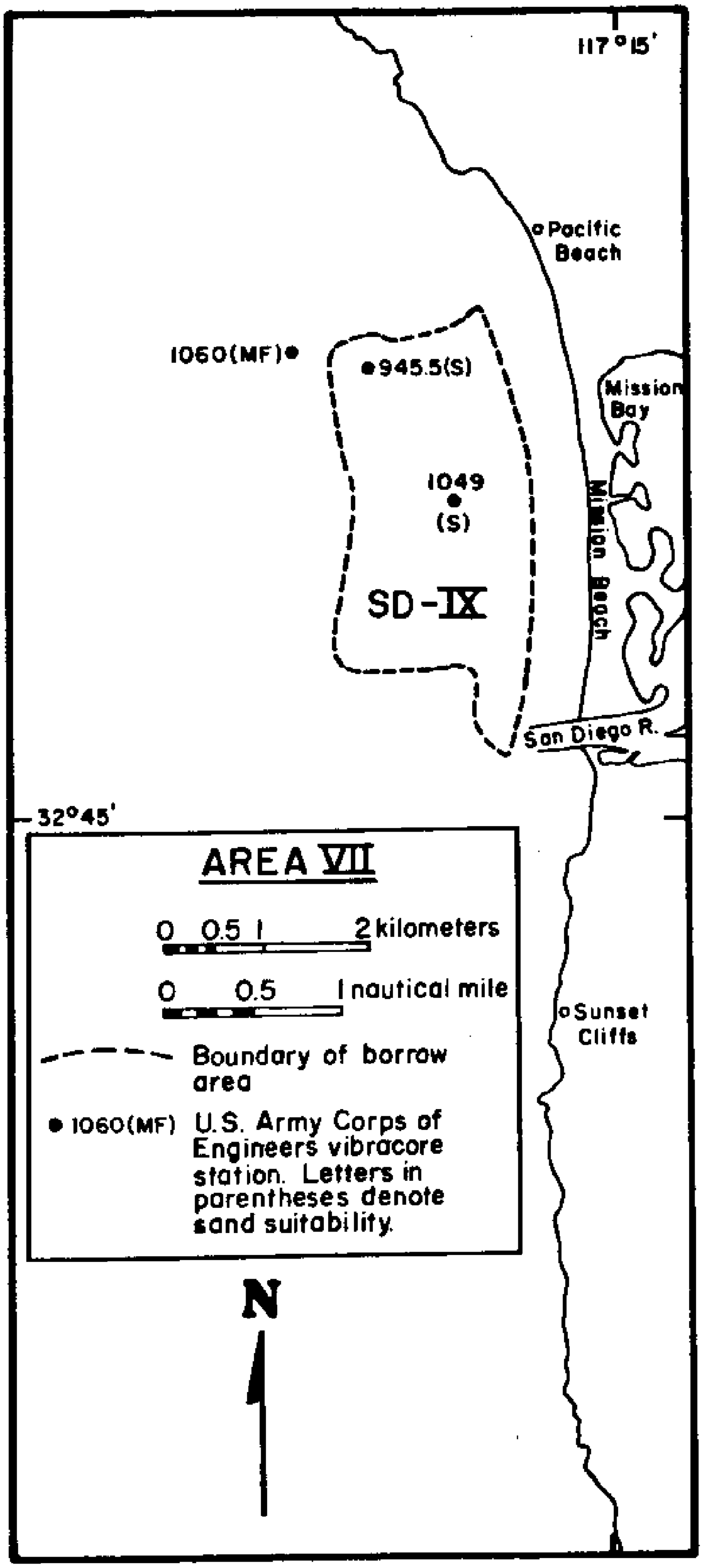


Figure. 57. Map of area VII showing location of borrow area SD-IX with associated vibracore numbers and sand suitability symbols.

penetration. The deepest erosional surfaces that can be detected are at 43 m b.p.s.l. in the nearshore area and 48 m b.p.s.l. farther offshore. It is not known whether the lithologic unit beneath this erosional surface is Cretaceous and/or Tertiary bedrock or Quaternary fill. To the north, the unit above this unconformity is characterized by uneven, discontinuous, and occasionally sloping reflectors, which are not continuous with the parallel reflectors of the Tertiary rock farther north. Thus, the undefined unit may be tentatively assigned to the Quaternary sediment package.

There is little evidence to accurately define the position of the boundary between Pleistocene and Holocene units in this area. Henry (1976) and Fischer and others (1982) prepared isopach maps for an area near the offshore boundary of this study which show Holocene thicknesses from 6 to 7 m. This position corresponds to an unconformity that truncates Cretaceous and Tertiary rocks to the north, but becomes unrecognizable within the indistinct parallel reflectors characteristic of the middle of the embayment. Although this unconformity seems to be a good choice for the Pleistocene-Holocene boundary on the basis of cross-cutting relationships, it is possible that the base of the Holocene dips into the middle of the embayment to connect with an uneven, though very distinct reflector at about 48 m b.p.s.l. This reflector is covered by approximately 34 m of sediment, which is characterized by parallel, continuous, flat-lying reflectors. Using data from Kennedy (1975) and Kennedy and Peterson (1975), Darigo (in preparation) determined the onshore position for the contact between Pleistocene and Holocene fluvial deposits and extrapolated this position offshore assuming a constant gradient. Although the slope changes from approximately 0.23° in the upper part of Mission Valley to about 0.15° in the lower part, the offshore extrapolation using the 0.15° value correlates with the reflector at 41 to 48 m b.p.s.l. in every available seismic line. Therefore this reflector was used to define the Pleistocene-Holocene boundary, and is the basis for the Holocene isopach map prepared for this report.

Areas of zero Holocene thickness north and south of the main channel are sites of Cretaceous sea floor exposures, and associated heavy kelp concentrations may be identified on the seismic data, side-scan sonar data, and aerial photographs studied by Hamilton (1980). The thickness and structural contours indicated the trend of an ancient river valley in the southern part of the study area, whereas a less pronounced re-entrant occurs farther offshore and to the north. The thickest channel section follows the northern side of the channel, and is a seaward extension of the meandering channel described by Ellis and Lee (1919). Prior to the Holocene transgression, the main channel ran along the southern edge of Mission Bay, made a slight jog to the northwest at the present mouth of the Entrance Channel, and turned west again. This pathway was controlled on the south by the presence of Cretaceous outcrops, which formed steep river bluffs.

North of the main channel, Holocene valley fill drapes over what may be Pleistocene stream terrace deposits. These terrace deposits show uneven, discontinuous reflectors and low-relief channeling on the seismic profiles. They may be similar to those that occur upstream, which consist of poorly-lithified, conglomeratic sand, occurring locally as thin veneer along drainage courses (Kennedy, 1975; and Kennedy and Peterson, 1975).

The Pleistocene Bay Point Formation and marine terrace deposits occur beneath the Pleistocene stream terrace deposits. The Bay Point Formation cannot be identified with certainity on the seismic records, but its presence is assumed on the basis of unidentified space between the Holocene marine and nonmarine cover, the Cretaceous and Tertiary units that dip under the embayment, and the marine terraces which lie laterally to the southwest. The Bay Point Formation is a poorly-lithified, lagoonal and nonmarine sandstone (Kennedy, 1975), which was deposited during a marine regression at the end of a late Pleistocene interglacial period, perhaps 100,000 years b. p. (Kern, 1971).

Three shoreline angles, at 39 to 40, 34, and 25 to 29 m b.p.s.l., and their associated marine terraces occur between the main channel and the Bay Point deposits. Associated strata are characterized on the seismic data by three components: (1) a strong, basal reflector representing an ancient cliff face and wave-cut terrace; (2) overlying uneven, discontinuous reflectors, representing nonmarine strata filling the vertex of the shoreline angle; and (3) flat-lying, continuous reflectors, representing overlying marine strata. The middle terrace (34 m b.p.s.l.) is interpreted here as late Pleistocene, which may have formed during the deposition of the Bay Point Formation to the northeast. The other two terraces are thought to be Holocene. The 39 to 30 m terrace probably was cut during the same sea level oscillation about 11,000 years ago, which cut the 38 to 45 m terrace in La Jolla Bay and the 39 to 45 m terrace offshore of Oceanside. The 25 to 29 m terrace probably correlates with the 24 to 27 m terrace in the Oceanside area and a 24 m terrace in Santa Monica Bay (Osborne and others, 1980; Nardin and others, 1981). Nardin and others (1981) propose that the 24 m terrace was cut during a minor high sea level stand about 12,000 years ago, which was followed by a drop in sea level to 46 m b.p.s.l., which is the same oscillation that formed the 39 to 40 m terrace of the Mission Beach area and similar terraces along the San Diego County shelf. Therefore the 39 to 40 m terrace is younger than the 25 to 29 m terrace.

Lithology

Three vibracores (945.5, 1049, and 1060) were taken in the Mission Beach area, which penetrated from 1.51 to 2.16 m of Holocene strata. All three have a top layer of very fine-grained sand, and terminate in a basal layer ranging from fine- to coarse-grained sand with occasional gravel-size shell fragments and lithoclasts. Inasmuch as the vibracores stopped penetrating at nearly the same depth, this position may represent a contact between unlithified and more lithified strata, and/or between finer-grained and more conglomeratic strata. A relatively strong seismic reflector occurs approximately 1.5 m below the sea floor in this area, which appears to be correlative with this surface.

The top layer of olive-gray, moderately-sorted, fine- to very fine-grained sand is typical of the Holocene cover ubiquitous to much of the San Diego County shelf. The underlying unit consists of dark gray to dusky yellow, fossiliferous, poorly-to moderately-sorted, apparently massive, medium-to coarse-grained sand. This coarse-grained sediment probably was derived from the San Diego River, and is considered nonmarine. Prior to the deposition of the upper, very fine-grained sand unit, sea level may have been slightly lower, which would allow more of the sediment from Mission Valley to reach the shelf. This would explain the observed change in grain size as well as the occurrence of thicker sections of very fine-grained sand offshore of coastal areas with no fluvial outlets. Today, very little fluvial sediment reaches the shelf (Norris, 1964), as it is deposited in associated estuaries.

Compositional data for three Holocene nonmarine and three Holocene marine samples from the Mission Beach area are listed in Table 25. All six samples are classified as feldspathic litharenite (McBride, 1963).

Table 25. Summary of lithologic composition of sand from samples recovered from the Mission Beach Area.

LITHOLOGIC COMPOSITION	HOLOCENE NONMARINE n = 3 Mean %	HOLOCENE MARINE n = 4 Mean %
<u>Monocrystalline Grains</u>		
Nonundulose Quartz	30.0	25.3
Undulose Quartz	12.5	13.9
Plagioclase Feldspar	17.7	16.7
Potassium Feldspar	6.7	6.1
Pyroxene	0.0	0.2
Amphibole	0.7	1.0
Biotite	0.5	1.3
Epidote	0.0	0.0
Sphene	0.0	0.0
Garnet	0.0	0.0
Magnetite-Ilmenite	0.1	0.0
<u>Polycrystalline Grains</u>		
Quartz with 2-3 subunits	6.7	6.1
Quartz with >3 subunits	5.0	5.2
Plutonic Rock	17.4	18.0
Metamorphic Rock	0.0	0.0
Volcanic Rock	0.0	0.1
Siliciclastic Rock	0.0	0.0
Intraclastic Grains	0.2	0.1
Allochemical Constituents	0.7	3.6
Microcrystalline Quartz	1.6	2.6

Potential Sand and Gravel Resources

Potential Borrow Area SD-IX

One large potential borrow area (SD-IX) was identified offshore of Mission Beach (Table 26, Figs. 57 and 58). This area is approximately equivalent to Area III identified by Ocean Surveys, Inc. (1981). The northern and southern boundaries of SD-IX are defined by the presence of submarine exposures of Cretaceous and Tertiary bedrock; the eastern boundary is defined by the 9 m isobath; and the western boundary occurs approximately 2.4 km offshore, whereas that of Area III (Ocean Surveys, Inc., 1981) extends about 3.2 km offshore.

The target material (Figs. 59 and 60) includes Holocene nonmarine deposits and possible marine terrace, stream terrace, and basal gravel deposits assigned to the Pleistocene Bay Point Formation. The northeastern corner of SD-IX consists principally of Pleistocene strata, whereas the remainder of the area consists predominantly of Holocene nonmarine strata. Potential borrow area SD-IX is estimated to contain a maximum of 146.8×10^6 m^3 of suitable sand.

Table 26. Summary of potential borrow area SD-IX.

Type of Deposit:

Pleistocene marine terrace, stream terrace and basal gravel deposits of the Bay Point Formation and Holocene nonmarine deposits

Water Depth:

Minimum: 7 meters

Maximum: 28 meters

Range in Mean Grain Size: n = 6

Minimum:	3.06	phi	0.12	mm
Maximum:	0.56	phi	0.68	mm
Mean:	1.48	phi	0.36	mm

Range in Thickness:

Minimum: 0 meters

Maximum: 35 meters

Estimated Volume (x 10^6 m^3)		(x 10^6 yd^3)
Minimum:		
Maximum:	146.8	192.0
Other:		Explanation of value:

Vibracores Penetrating Deposit:

945.5; 1049

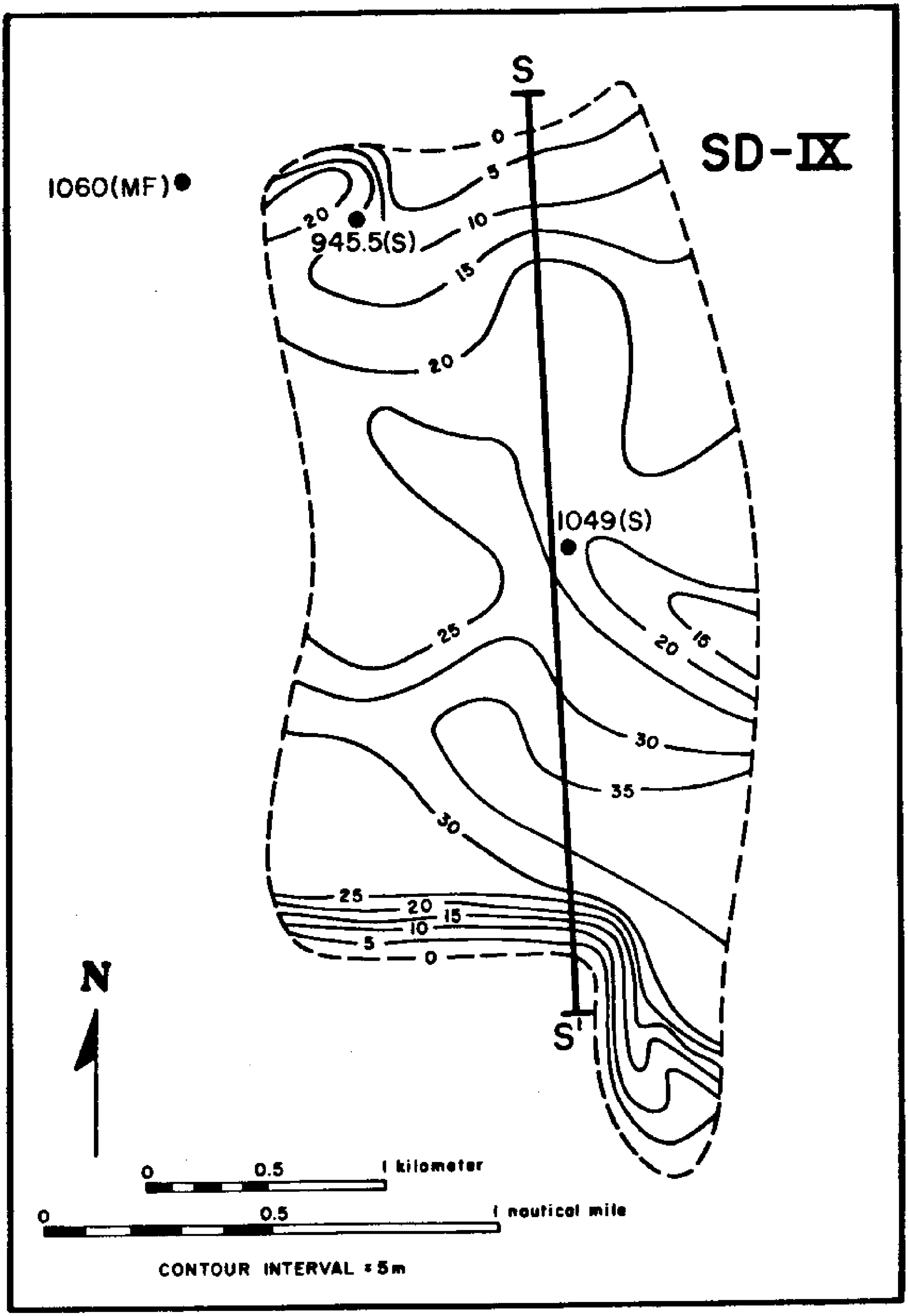


Figure 58. Isopach map of borrow area SD-IX with associated vibracore numbers, sand suitability symbols, and line of geologic cross section S-S'.

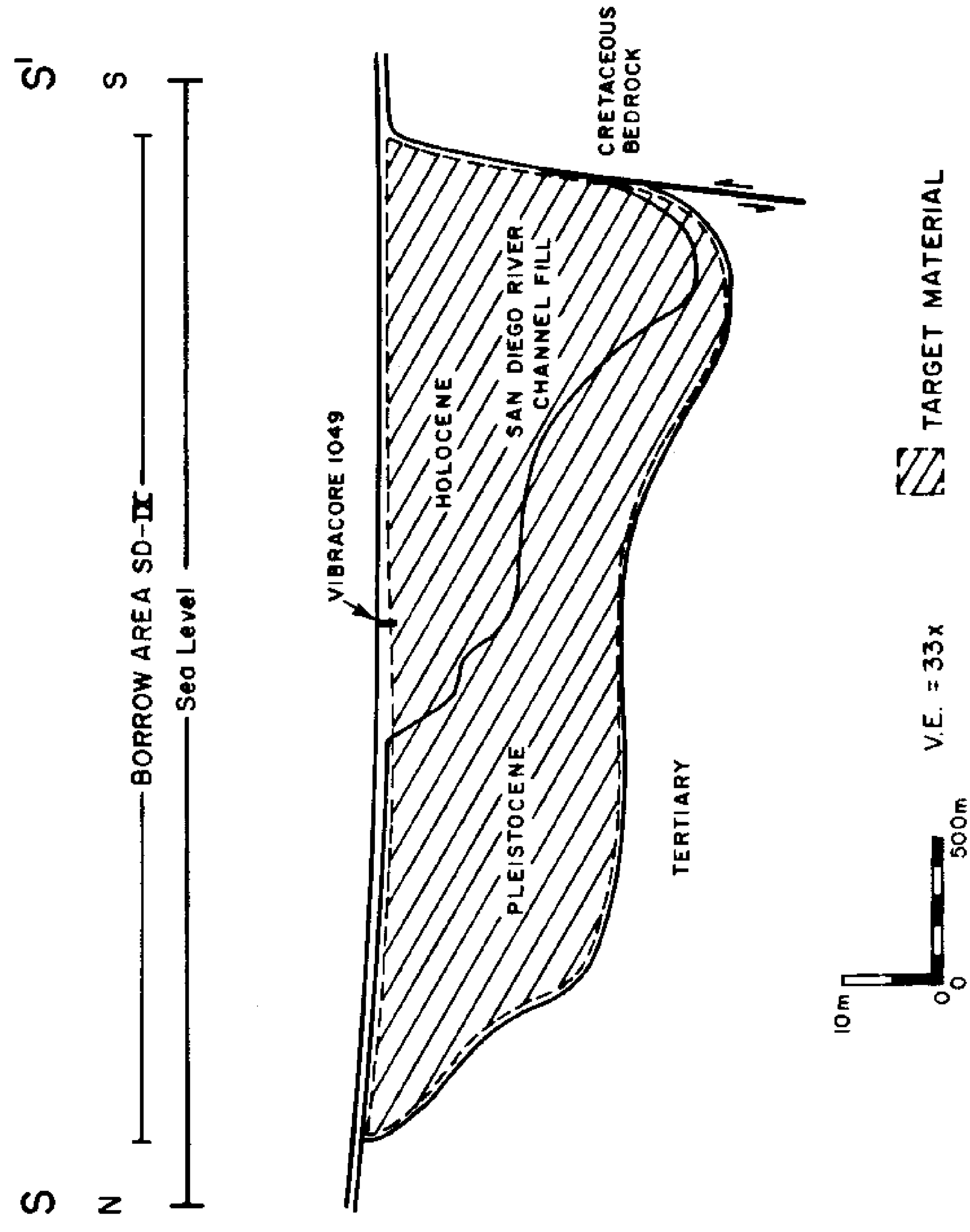


Figure 59. Geologic cross section S-S'.

VIBRACORE LOG

Core number: 1049

Date: 2/81

Total core length (cm): 216

Sheet 1 of 1

Number of core sections: 1

Water depth (ft): 56

Vertical scale: 1 cm = 25 cm

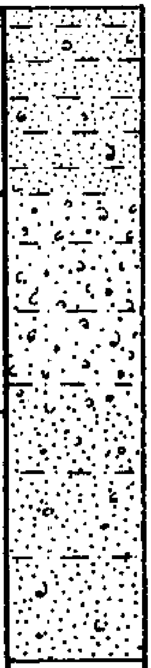
Distance in cm from top of core	Description	Log
0-61	Sand: very fine grained, ranges from silt to coarse sand with occasional sand and gravel size shell fragments; moderately sorted; olive gray (5 Y 4/1); very faint mica laminae, mottling, and possible bioturbation; very slightly micaceous; gradational lower contact.	
61-133	Sand: medium to coarse grained, ranges from silt to gravel with abundant gravel size shell fragments; poorly sorted; olive gray (5 Y 4/1) grading to dusky yellow (5 Y 6/4); apparently massive; abundant whole pelecypod and gastropod shells; gradational lower contact.	
133-216	Sand: dominantly medium to fine sand, ranges from silt to gravel with occasional gravel size shell fragments and rock fragments; mottling and color changes: dusky yellow (5 Y 6/4) from 133-148 cm., dark yellowish brown (10 YR 5/4) from 167-181 cm., and medium dark gray (N4) from 181-216 cm; possible bioturbation.	

Figure 60. Log of vibracore 1049 which is illustrative of the sedimentologic character of borrow area SD-IX.

VIII. SAN DIEGO BAY, SAN DIEGO COUNTY

Introduction

As in the Oceanside and La Jolla areas, the geologic history of the offshore San Diego region (Fig. 61) is dominated by its structure. The San Diego Bay area is cut by many discontinuous, en echelon faults that predominantly trend north, which are bounded by north-northwest trending faults. Moore and Kennedy (1970), Kennedy and others (1980a), and Kennedy and Welday (1980) propose that these faults represent an offshore and southerly extension of the Rose Canyon fault zone, which trends through San Diego Bay, continues along the east side of the San Diego airport (Lindberg Field) and Mission Bay, curves around Mount Soledad, and trends offshore again in La Jolla Bay. To the south, the Rose Canyon fault zone tentatively has been correlated to the Vallecitos-San Miguel fault zone, which trends southeasterly through northern Baja California; however, correlations with the Aqua Blanca and Tres Hermanos fault zones also are possible (Legg, 1979; Legg and Kennedy, 1979).

Moore and Kennedy (1970) and Kennedy and others (1975) suggest that the faults of San Diego Bay and of the offshore bight form the west side of a graben, the eastern boundary of which is the La Nacion fault which occurs approximately 6 km east of the eastern edge of San Diego Bay. This would result in a graben ranging from 6 to 18 km wide, depending on which of the faults was considered the western boundary. A detailed study of the faults in the San Diego offshore bight led Kennedy and Welday (1980) to recognize and name three major faults: The Spanish Bight fault, the Coronado fault, and the Silver Strand fault. Darigo (in preparation) discusses the character of these faults and associated structures.

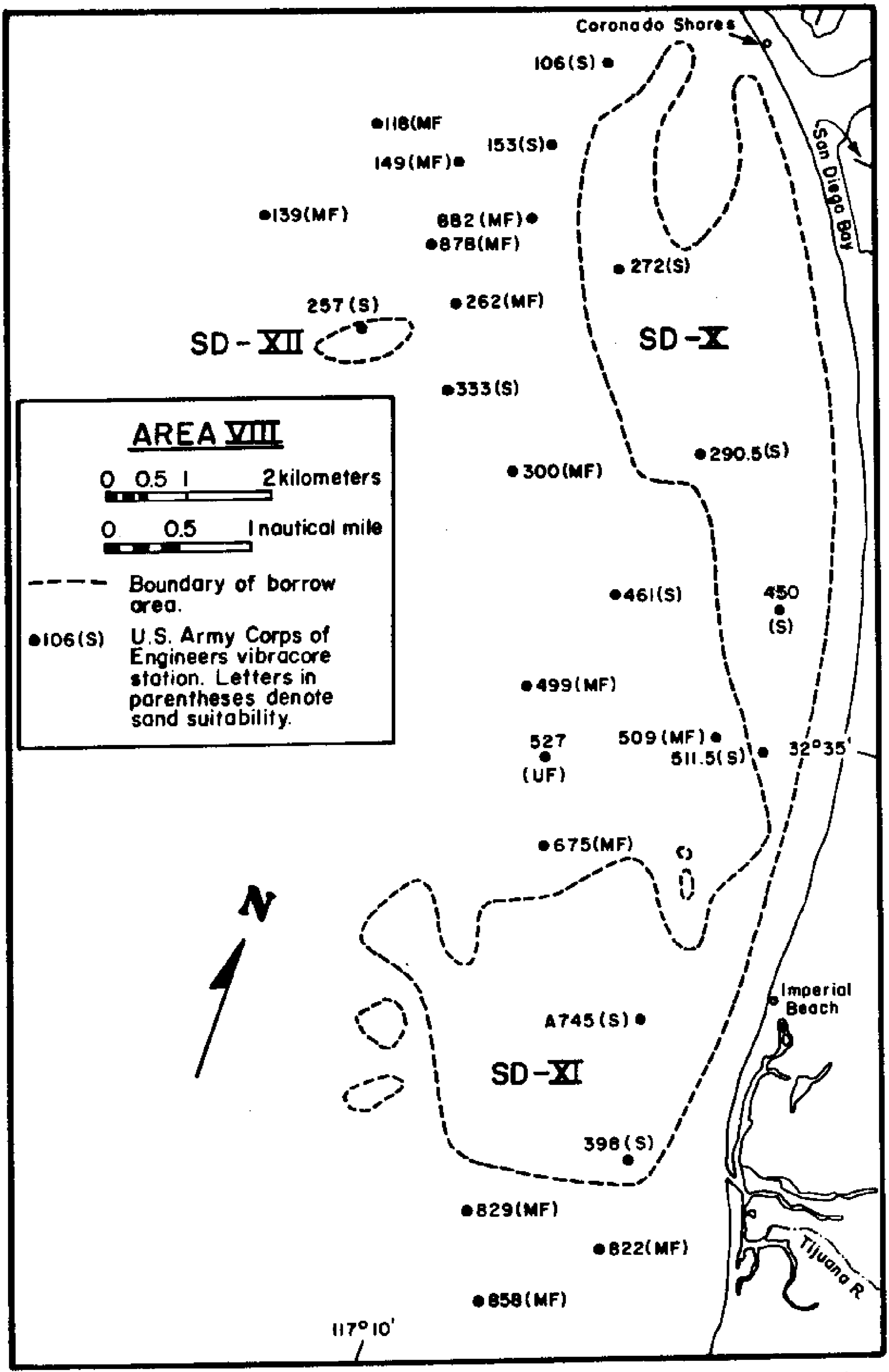


Figure 61. Map of area VIII showing locations of borrow areas SD-X through SD-XII with associated vibracore numbers and sand suitability symbols.

Other major faults in the area include a set immediately south of Point Loma and another set between the Silver Strand and Coronado faults. The set south of Point Loma may be correlated to the north with several short, north-trending faults in the channel between Point Loma and North Island identified by Kennedy and Welday (1980), and possibly to faults mapped by Kennedy (1975) on the east side of Point Loma. The set between the Coronado and Silver Strand faults consists of several parallel, en echelon segments in a strip from 100 to 800 m wide, which may represent an east-stepping part of the Coronado fault.

Pre-Quaternary strata in the bight offshore of San Diego Bay are assigned to the Cretaceous Rosario Group, possibly some Eocene and Miocene units, and the Pliocene San Diego Formation. Quaternary strata include a thick section of Pleistocene basin fill, the Bay Point Formation, and unnamed stream terrace and basal gravel deposits; as well as Holocene nonmarine channel fill deposits and marine cover.

Quaternary Stratigraphy

Upper Pleistocene Strata

Stratigraphy: Just east of San Diego Bay, the Lindavista Formation overlies the San Diego Formation and is cut by the La Nacion fault zone (Artim and Pinckney, 1973; and Kennedy and Tan, 1977). At present, the Lindavista Formation occurs approximately 30 to 60 m above sea level in exposures west of the La Nacion fault zone, and as much as 150 m above sea level within and east of the fault zone. If San Diego Bay is indeed a graben, bounded by the La Nacion fault zone on the east and the San Diego Bay and offshore bight faults on the west, it is possible that Lindavista deposits may have accumulated within the graben and were later lowered below sea level. Dip-slip faults on the east side of the graben offset the Lindavista terrace by as much as 70 m

(Artim and Pinckney, 1973). Along the proposed western boundary, i.e. among the faults in the offshore study area, possible Lindavista deposits cannot be distinguished from the Miocene-Pliocene strata in this area.

Fault-ponded sediment constitutes most of the offshore Pleistocene section. Almost every relatively thick Pleistocene unit is the result of marine and nonmarine strata filling the gaps created by the complex wrench and associated normal faulting in the area. These fault-controlled basins are very small in lateral extent, which makes it difficult to correlate them. The differentiation of Pleistocene from Miocene-Pliocene strata on the seismic profiles is based on cross-cutting relationships, superposition, and differences in seismic signature. Pleistocene strata usually are more transparent, and contain lower amplitude, moderately continuous, more horizontal reflectors; whereas Miocene-Pliocene strata contain higher amplitude, higher frequency, more continuous and more closely-parallel reflectors.

The thickest Pleistocene section occurs in the northwestern corner of the study area. Here, Pleistocene basin fill progrades over Miocene-Pliocene strata, and attains a maximum thickness of 45 to 50 m. Thick Pleistocene sections also have been reported beneath San Diego Bay. Pleistocene fossils have been recovered at about 50 m below the bay floor from a well beneath Coronado Bridge, and lithologically similar deposits extend as deep as 80 m (Kennedy and Welday, 1980). Kennedy and others (1975) report Bay Point-like sand and shells at the bottom of a 60 m well just north of Imperial Beach, and Gray and others (1971) report Pleistocene strata at 88 m b.p.s.l. about 2 km east of the Tijuana River mouth. In comparison, the thickest Pleistocene section identified offshore occurs at a maximum of 63 m b.p.s.l., and zero Pleistocene thickness is thought to occur offshore of Imperial

Beach. A thicker section is to be expected beneath San Diego Bay, because it is closer to the center of the graben and has experienced more subsidence. The disparity between Pleistocene thicknesses east and west of Silver Strand Beach can be explained by pre-Pleistocene vertical displacement along the Silver Strand fault and others which might lie inshore of the seismic coverage. During the Pleistocene, an estuary or strait may have existed between the offshore bight area and the mainland east of the present San Diego Bay, thus forming an island which extended from the north end of Point Loma to the topographic high offshore of Imperial Beach.

Offshore of San Diego Bay, the thickness of the fault-ponded deposits is highly variable, ranging from 5 to 50 m, which suggests that Pleistocene sediment accumulation was controlled mostly by the availability of space.

The shelf offshore of San Diego Bay was influenced by the proximal major river valleys which existed during the late Pleistocene. These are, from north to south; the Chollas, the Sweetwater and Otay which join before entering the offshore area, and the Tijuana. Water wells in the Tijuana River valley (Ellis and Lee, 1919) indicate that it is the widest of the San Diego County valleys, maintaining a 1.5 km width for more than 6 km inland. The wells show that the valley fill overlying a relatively flat valley floor cut into the San Diego Formation consists of a basal, continuous gravel and cobble conglomerate from 3 to 11 m thick, which is overlain by a thick section of sand and silt. Within the main section of valley fill, the basal conglomerate is thought to be Pleistocene and the sand and silt unit is thought to be Holocene. At a time of lower sea level in the late Pleistocene, the basal gravel would have extended offshore, and should be present beneath the drowned river valleys with similar thicknesses. Unfortunately, multiples on the seismic records obscure the base of the Tijuana River valley offshore, but scant evidence suggests that the valley floor may lie from 45 to 50 m b.p.s.l., and that it is overlain by approximately 5 to 6 m of the Pleistocene basal gravel deposit. Older Pleistocene deposits also may lie in the offshore Tijuana River valley, which are adjacent to and cut by the most recent channel. These deposits may represent either older stream terrace deposits or they may be Pleistocene marine deposits, such as those of the Bay Point Formation.

Although no water well data are available for the Sweetwater-Otay and Chollas River valleys to the north, Ellis and Lee (1919) describe the onshore Sweetwater valley as being very narrow with a fill similar to that of the Tijuana River valley, and containing at least 2 m of basal gravel. The Sweetwater and Otay River Valleys merge into one valley from 600 to 1300 m wide. From 1.2 to 3.4 km offshore, a bedrock island approximately 300 m wide occurs in the middle of the Sweetwater-Otay valley. Pleistocene fill ranges from 0 to 11 m in thickness, and thicker sections of possible Pleistocene stream terrace or channel fill deposits may be laterally adjacent to the main Sweetwater-Otay channel.

The Chollas River valley is 400 to 1500 m wide offshore, and the thickness of Pleistocene channel fill deposits range from 3 to 12 m. Again, thicker sections may occur laterally.

Lithology: Pleistocene strata were recovered only in vibracore 153, which is located in the northern part of the study area (Fig. 61). Core 106 stopped penetrating at the top of a Pleistocene unit. The base of core 153 consists of olive gray, sparsely fossiliferous, slightly micaceous, apparently massive, moderately- to poorly-sorted, very fine to fine-grained sand. This portion of core 153 correlates with parallel, continuous reflectors, which occur in the middle of one of the fault basins in this area. Although the seismic reflectors are nearly horizontal in the immediate vicinity of core 153; farther to the southeast, they dip and prograde northwestward onto a strongly reflected, uneven surface. Due to the change is seismic signature, it is clear that the recovered sample cannot be representative of the entire Pleistocene section. The strata filling the faulted basins probably are a combination of alluvial fan deposits, slope wash, channel deposits, and/or estuarine or low-energy marine deposits. In other shelf sectors, where the Pleistocene strata are thinner, these units consist mainly of basal gravel deposits typical of river fill. At times of lower sea level during the Pleistocene, the faulted basins may have formed a strait between Point Loma, which was then an island, and the mainland. Bowersox (1974) and Grotts (1981) have proposed the existence of the "Loma Strait" on the basis of biotal assemblages, which, in turn, suggests the presence of a shallow, sheltered muddy shore environment with isolated sandflats.

Holocene Strata

Stratigraphy: Offshore Holocene strata include nonmarine fill of the major offshore river valleys; coarser-grained, marine sand deposits; and the nearly ubiquitous, very fine-grained, marine cover.

Although true thicknesses often are obscured by multiples, fill in the offshore river valleys constitutes the most voluminous Holocene component. The Chollas and Sweetwater-Otay channels exist as separate valleys for approximately 4 to 5 km offshore, where they coalesce into one longshore-trending channel (Darigo, in preparation). Another channel extends from the Chollas River valley toward Point Loma, and here will be referred to as the "Point Loma River". Southwest of the Sweetwater-Otay channel, what appears to be the main western outlet for the channels extends for at least 4 km west of the middle shelf, longshore channel, and turns southward along bedrock exposures. At the southwest corner of the study area, this channel may merge with the Tijuana River valley. The shape and location of these channels are partly controlled by structure. Where a channel makes a sharp bend, it is usually either following a fault-associated depression or has been laterally offset by faults subsequent to deposition. The Point Loma channel in particular is bounded by north-trending faults in its northern extent, and makes an abrupt turn to the east, perhaps in response to downwarping associated with a major syncline, which trends parallel to exposed Cretaceous rocks. The middle shelf, north-trending channel also may be partly oriented due to faulting. Local uplift associated with the Spanish Bight fault may have prevented the Chollas River valley from achieving a more direct westerly route towards exposed Cretaceous bedrock; rather, it trends southward and joins the Sweetwater-Otay River valley.

The Point Loma channel is the most narrow of the four main channels, and ranges in width from less than 300 to about 900 m. Holocene fill in this channel ranges from 20 to 35 m thick, and fill along the sides of this channel range from 10 to 20 m thick. The base of the channel seems to shallow to the north, which suggests this ancient river flowed to the south.

The Chollas River valley is from 400 to 700 m wide nearshore, and extends as far as 3.6 km offshore, where it widens to 1500 m and joins the other valleys. Holocene stratal thicknesses in the Chollas River valley range from 25 to 36 m in the nearshore segment (3.6 km), and range from 12 to 35 m farther offshore.

The Sweetwater-Otay River valley ranges from 600 to 1300 m wide. The nonmarine Holocene fill in the nearshore part of the channel is from 8 to 26 m thick; in the middle shelf segment, it is from 21 to 23 m thick; and in the channel extending offshore, it is 21 to 34 m thick.

Lithology: A total of 25 vibracores were recovered from the San Diego Bay area (Fig. 61), which range from 1.56 to 5.72 m and average 2.84 m long. Holocene sediment in the San Diego Bay area can be assigned to three distinct categories: (1) very fine- to fine-grained, marine sand; (2) coarser-grained, nonmarine sand in offshore channels; and (3) medium-grained, marine sand not associated with the offshore channels.

The olive gray to olive black, slightly fossiliferous, micaceous, apparently massive, moderately-to well-sorted, very fine- to fine-grained Holocene marine sand appears in all of the vibracores from the San Diego bight, with the exception of A-745 in which only Miocene-Pliocene sediment was recovered. The seismic signature of this material consists of parallel, continuous, low amplitude reflectors. Unlike the shelves off Oceanside, La Jolla, and Mission Beach, the San Diego shelf is characterized by relatively thin stratigraphic sections of this unit, which rarely exceed 5 m. Where the total Holocene thickness in non-channeled areas is greater than 5 m, the section is a combination of the fine-grained Holocene cover and the coarser-grained marine sand unit.

Holocene nonmarine deposits were recovered in 9 cores, and one other core (499) stopped penetration at the top of a nonmarine deposit. Generally those cores located along the channel margins display intercalated very fine-grained, marine and coarser-grained, nonmarine deposits, e.g. vibracores 509, 822 and 829; whereas those in the middle of the channels display uninterrupted nonmarine strata capped by a thin, very fine-grained marine cover, e.g. vibracores 290.5, 300, 333, 398, and 511.5. The nonmarine deposits consist of light to olive gray to yellowish brown, apparently massive to cross stratified, micaceous, moderately- to poorly-sorted, medium-to coarse-grained sand, but range from silt to very coarse-grained sand and gravel. Samples along the channel margins show more marine attributes, such as finer grain size, more shell fragments, bioturbation, etc.

A distinction usually can be made between the nonmarine and very fine-grained marine units on the seismic profiles. The nonmarine sections usually correlate with seismic units that are laterally continuous with the channel and internally poorly reflected. In contrast to the parallel, very continuous reflectors of the marine layers, the nonmarine deposits show chaotic, discontinuous, and occasionally concave, channel-like reflectors. The different seismic signatures imply relative rates of sediment accumulation: the flay-lying, continuous marine reflectors suggest slow deposition, whereas the thickly-bedded, internally chaotic nonmarine more rapid deposition. Where the vibracores penetrated interbedded marine and nonmarine strata, the seismic section shows alternating reflector types, which generally can be detected for individual beds more than 1 m thick.

The medium-grained marine sand unit was recovered in vibracores 153, 257 and 272. The sediment consists of olive-gray, sparsely fossiliferous, micaceous, apparently massive, poorly to moderately well- to well-sorted, medium-grained sand with occasional gravel. The seismic signature of these deposits is similar to those of the nonmarine units, i.e. internally poorly reflected and chaotic. These medium-grained, marine deposits range from less than 1 to 3 or 4 m thick, and they may represent lag deposits associated with the erosion of nearby Cretaceous, Tertiary and/or Pleistocene strata.

Compositional data for 15 Holocene nonmarine, 25 Holocene very fine-grained marine, and 6 Holocene medium-grained marine samples are listed in Table 27. The vast majority of these samples may be classified as feldspathic litharenite, but 3 are lithic arkose and 5 are lithic subarkose (McBride, 1963).

Table 27. Summary of lithologic composition of sand from samples recovered from the San Diego Bay area.

LITHOLOGIC COMPOSITION	HOLOCENE NONMARINE n = 15 Mean %	HOLOCENE VERY-FINE MARINE n = 25 Mean %	HOLOCENE MEDIUM MARINE n = 6 Mean %
Monocrystalline Grains			
Nonundulose Quartz	28.0	19.7	22.5
Undulose Quartz	12.6	8.9	10.4
Plagioclase Feldspar	14.8	10.9	15.7
Potassium Feldspar	5.5	4.0	4.9
Pyroxene	0.1	0.2	0.1
Amphibole	0.5	0.5	0.6
Biotite	4.9	21.2	5.6
Epidote	0.0	0.0	0.1
Sphene	0.0	0.0	0.0
Garnet	0.0	0.0	0.0
Magnetite-Ilmenite	0.1	0.2	0.1
Polycrystalline Grains			
Quartz with 2-3 subunits	7.2	4.6	6.1
Quartz with >3 subunits	4.4	3.4	4.6
Plutonic Rock	16.8	12.4	17.6
Metamorphic Rock	0.1	0.1	0.0
Volcanic Rock	0.2	0.1	0.1
Siliciclastic Rock	0.2	0.2	0.1
Intraclastic Grains	0.1	0.7	0.5
Allochemical Constituents	1.4	9.9	7.4
Microcrystalline Quartz	2.9	2.8	2.8

Potential Sand and Gravel Resources

Potential Borrow Area SD-X

Potential borrow area SD-X occurs between the <5 and 18 m isobaths in the nearshore part of the shelf from Coronado Shores south to Imperial Beach (Table 28, Figs. 61 and 62). The target material at this site includes Miocene-Pliocene, Pleistocene, Holocene nonmarine and Holocene medium-grained marine deposits (Figs. 63 and 64). Holocene nonmarine deposits occur only in the Chollas and Sweetwater-Otay River channels, and Holocene medium-grained marine deposits form a thin layer on top of Pleistocene and Tertiary deposits. Pleistocene deposits include a basal gravel in the Chollas and Sweetwater-Otay channels, and slope-wash deposits filling the small basins in the northern part of SD-X. Miocene-Pliocene deposits underlie all of SD-X, and become a possible target where the Quaternary strata thin. Potential borrow area SD-X is estimated to have a maximum of 265.7 x 10^6 m^3 of suitable sand.

Potential Borrow Area SD-XI

Potential borrow area SD-XI is actually continuous with SD-X, but a convenient division is placed immediately north of Imperial Beach (Fig. 61). SD-XI is located between the 4 and 27 m isobaths, and extends from the nearshore zone off Imperial Beach southward to the northern edge of the Tijuana River valley (Table 29, Figs. 61 and 65). The target material in SD-XI consists of Miocene-Pliocene strata with smaller quantities of Pleistocene and medium-grained, marine Holocene sand deposits on its west side, and a small pocket of Holocene nonmarine strata in its southeast corner (Figs. 66 and 67). The western extent of the Pleistocene and marine, medium-grained, Holocene deposits was determined largely by a change in surface texture from rough to smooth as observed on side-scan sonar records.

Table 28. Summary of potential borrow area SD-X.

Type of Deposit:

Tertiary (?), Pleistocene basal gravel and slope wash deposits, and Holocene nonmarine and marine, medium-grained sand deposits.

Water Depth:

Minimum:	<5 meters
Maximum:	18 meters

Range in Mean Grain Size: n = 12

Minimum:	2.64	phi	0.16	mm
Maximum:	0.31	phi	0.81	mm
Mean:	1.29	phi	0.41	mm

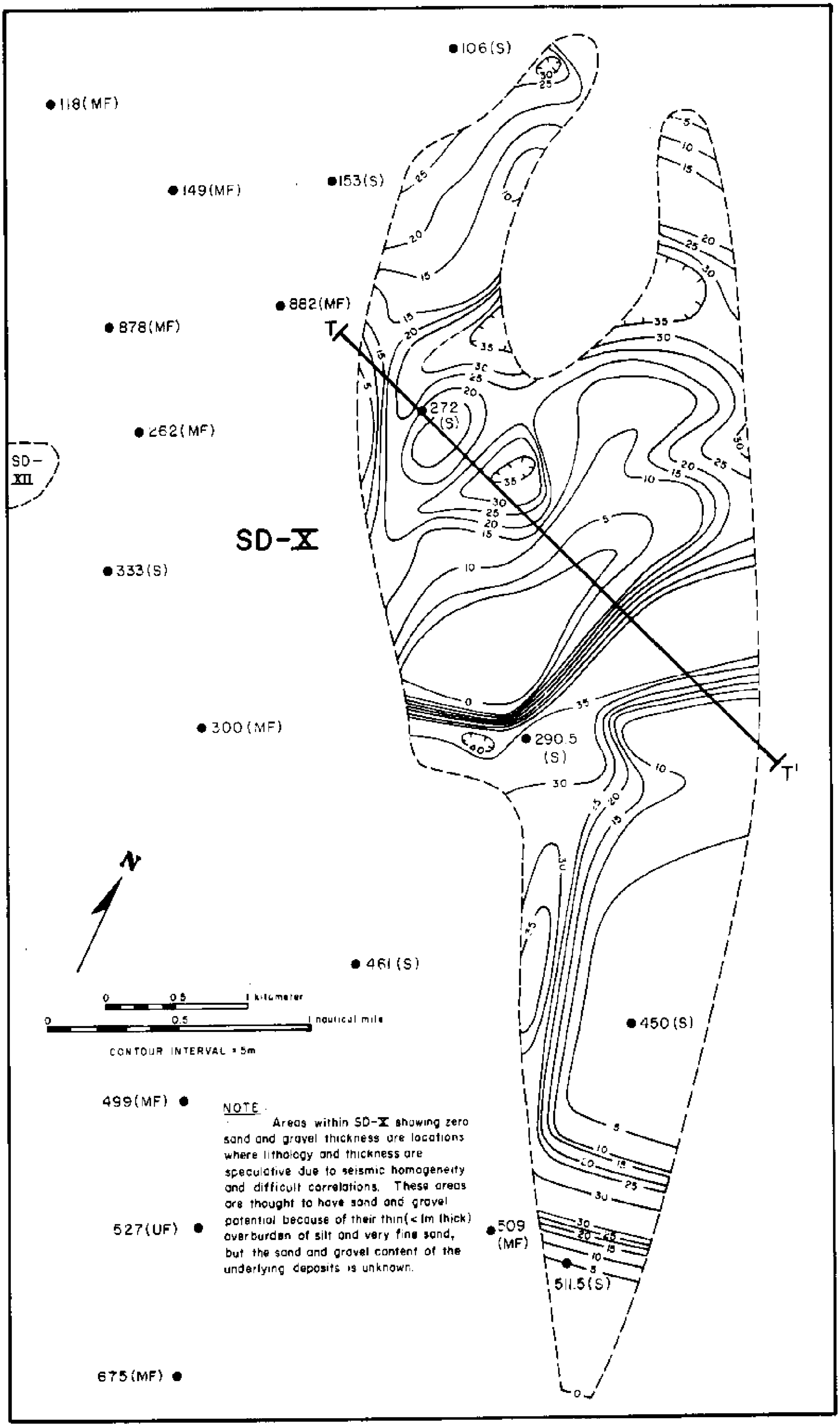
Range in Thickness:

Minimum:	<5 meters
Maximum:	40 meters

Estimated Volume	(x 10^6 m^3)	(x 10^6 yd^3)
Minimum:		
Maximum:	265.7	347.5
Other:		Explanation of value:

Vibracores Penetrating Deposit:

272; 290.5; 511.5



NOTE.
Areas within SD-X showing zero sand and gravel thickness are locations where lithology and thickness are speculative due to seismic homogeneity and difficult correlations. These areas are thought to have sand and gravel potential because of their thin(< lm thick) overburden of silt and very fine sand, but the sand and gravel content of the underlying deposits is unknown.

Figure 62. Isopach map of borrow area SD-X with associated vibracore numbers, sand suitability symbols, and line of geologic cross section T-T'.

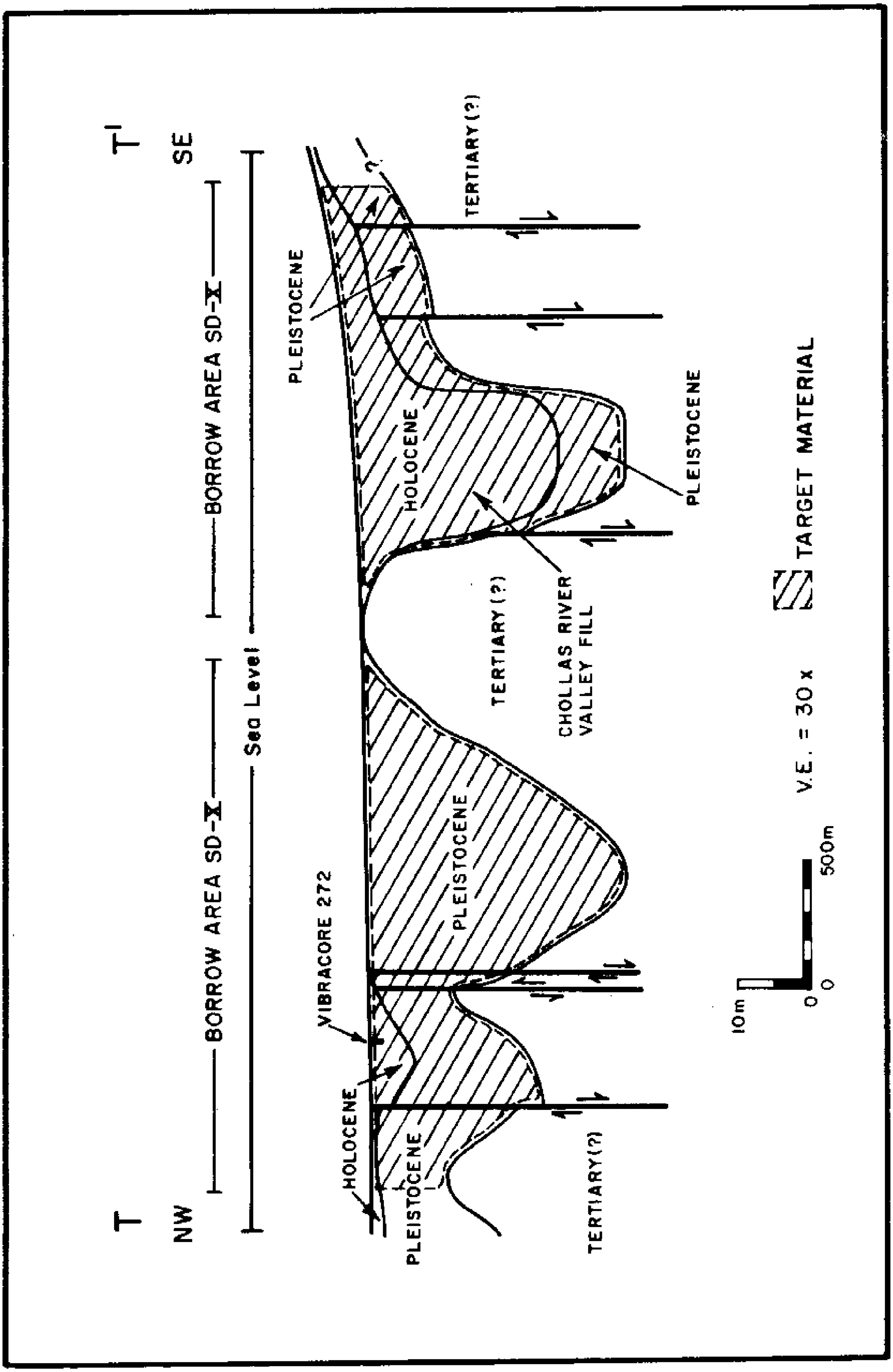


Figure 63. Geologic cross section T-T'.

VIBRACORE LOG

Core number: 290.5
Date: 2/81
Total core length (cm): 347
Sheet 1 of 2
Number of core sections: 1
Water depth (ft): 58
Vertical scale: 1 cm = 25 cm

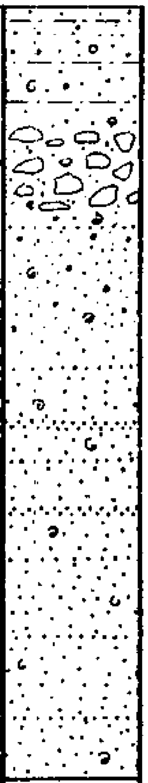
Distance in cm from top of core	Description	Log
0-51	Sand: medium to coarse grained, ranges from silt to very coarse sand; moderately sorted; moderate yellowish brown (10 YR 4/2); apparently massive; large gravel clasts (1-8 cm dia.) concentrated from 39-51 cm; slightly micaceous; minor shell fragments; gradational lower contact.	
51-109	Sand: medium to very coarse grained, ranges from very fine sand to gravel; moderately sorted; dark yellowish orange (10 YR 6/6); apparently massive with large gravel clasts (1-8 cm dia.) from 51-66 cm; minor amount of shell fragments; gradational lower contact.	
109-180	Sand: medium grained, ranges from very fine to very coarse sand; moderately to moderately well sorted; moderate yellowish brown (10 YR 4/2); predominantly massive with occasional coarse sand interbeds and faint mica laminae that are slightly deformed concave downward; occasional small shell fragments; no lower contact.	
180-256	Sand: medium grained, ranges from very fine to very coarse sand; moderately well sorted; moderate yellowish orange (10 YR 6/6); predominantly massive with faint mica laminae that are deformed concave downward; occasional shell fragments; sharp lower contact.	

Figure 64.1 Log of vibracore 290.5 which is illustrative of the sedimentologic character of borrow area SD-X.

VIBRACORE LOG

Core number: 290.5

Date: 2/81

Total core length (cm): 347

Sheet 2 of 2

Number of core sections: 1

Water depth (ft): 58

Vertical scale: 1 cm = 25 cm

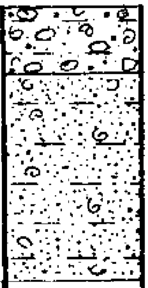
Distance in cm from top of core	Description	Log
256-278	Sand: fine to medium grained, ranges from silt to gravel, the gravel size fraction consists predominantly of large clasts 1-3 cm dia. and shell fragments; moderately to poorly sorted; moderate yellowish brown (10 YR 5/4) chaotic mixture of clasts, shell fragments and sand; large shell fragments and whole pelecypod shells concentrated throughout; sharp lower contact.	
278-347	Sand: very fine to fine grained, ranges from silt to coarse sand, the coarse sand fraction being predominantly shell fragments; moderately well sorted; olive black (5 Y 2/1) apparently massive; slightly micaceous; occasional shell fragments.	

Figure 64.2 Log of vibracore 290.5 which is illustrative of the sedimentologic character of borrow area SD-X.

Table 29. Summary of potential borrow area SD-XI.

Type of Deposit:

Tertiary (?), Pleistocene, and Holocene nonmarine and marine, medium-grained sand deposits.

Water Depth:

Minimum: 4 meters

Maximum: 27 meters

Range in Mean Grain Size: n = 7

Minimum:	2.65	phi	0.16	mm
Maximum:	-0.15	phi	1.11	mm
Mean:	1.34	phi	0.40	mm

Range in Thickness:

Minimum: 0 meters

Maximum: 15 meters

Estimated Volume (x 10^6 m^3)		(x 10^6 yd^3)
Minimum:		
Maximum:	24.1	31.5
Other:		Explanation of value:

Vibracores Penetrating Deposit:

A-745; 398

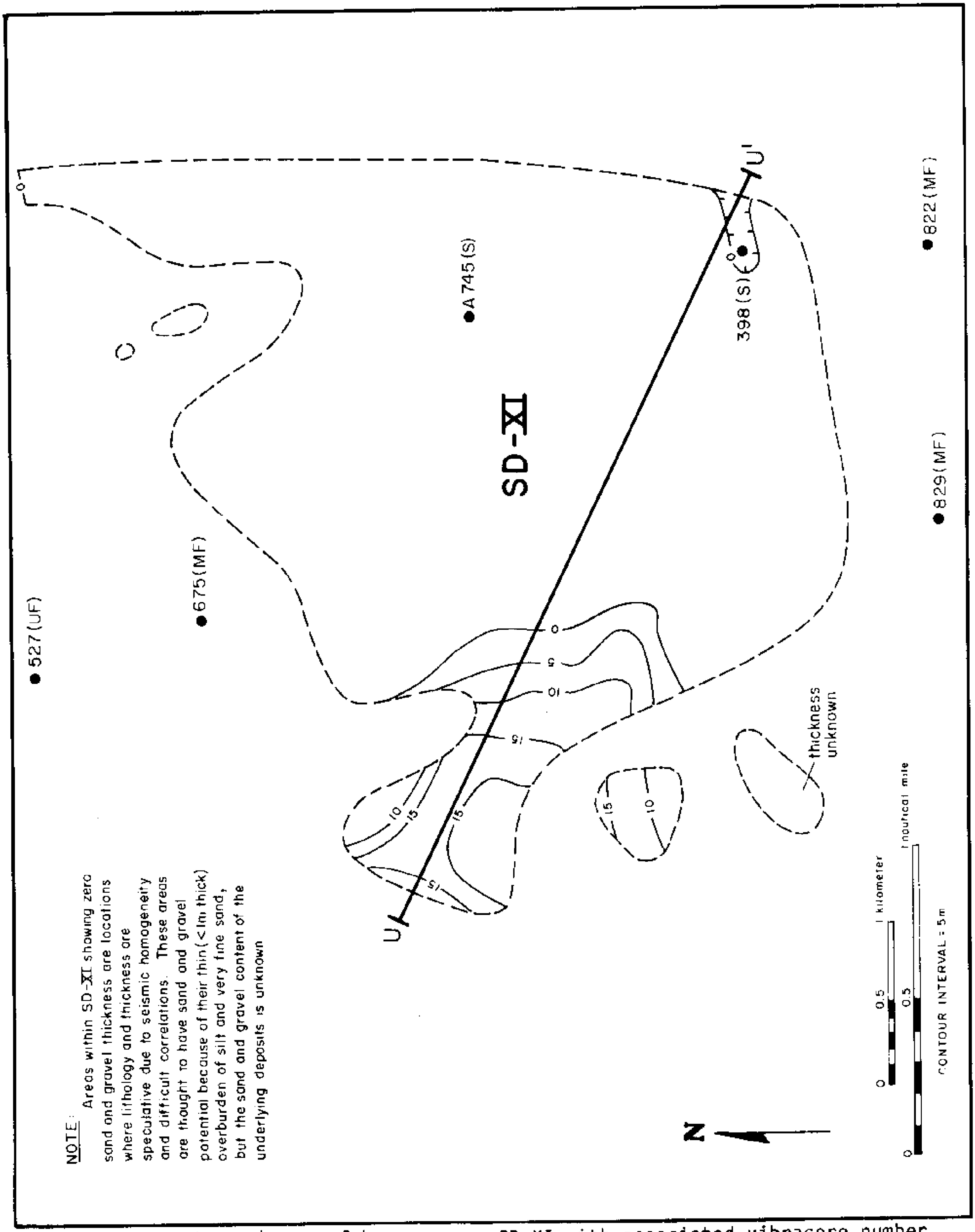


Figure 65. Isopach map of borrow area SD-XI with associated vibracore number, sand suitability symbols, and line of geologic cross section U-U'.

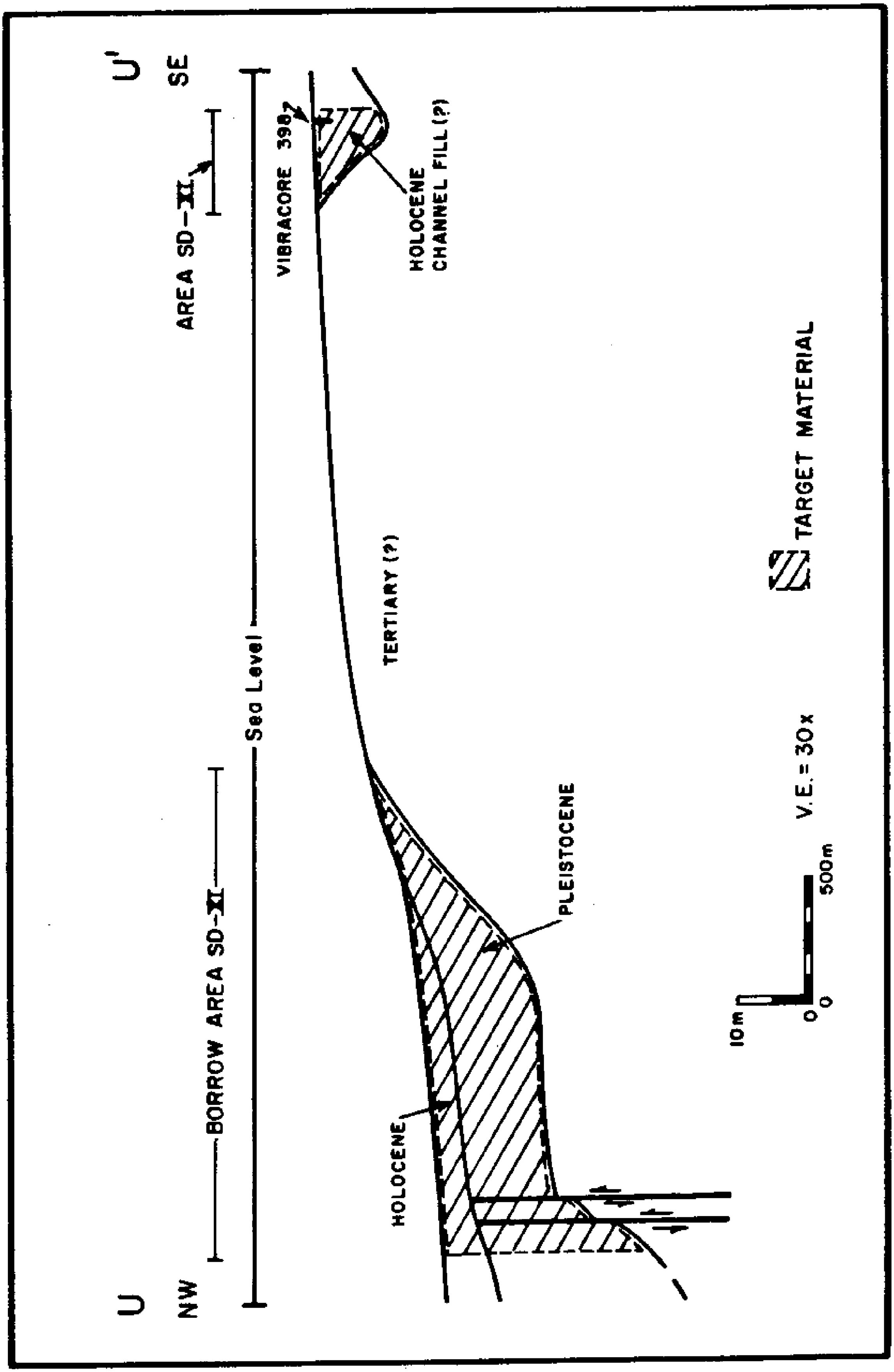


Figure 66. Geologic cross section U-U'.

VIBRACORE LOG

Core number: 398

Date: 2/81

Total core length (cm): 240

Sheet 1 of 1

Number of core sections: 1

Water depth (ft): 37

Vertical scale: 1 cm = 25 cm

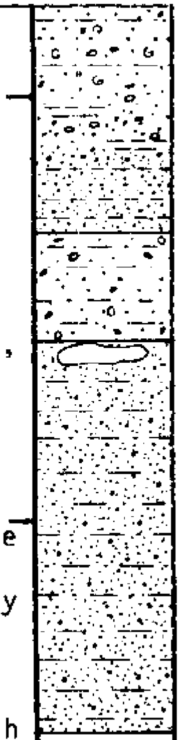
Distance in cm from top of core	Description	Log
0-29	Sand: broad range from silt to gravels with the mode being medium sand, the gravel fraction contains a small amount of rock and shell fragments; poorly sorted; light olive gray (5 Y 5/2); apparently massive; occasional shell fragments throughout; gradational lower contact.	
29-74	Sand: broad range of grain sizes: pockets of clayey silt intermixed with pockets of medium to very coarse sand with occasional gravel, from 29-49 cm, grading to muddy, homogeneous, fine to coarse sand, from 49-74 cm; poorly sorted; olive black (5 Y 2/1); very deformed layers of sediment from 29-49 cm, but apparently massive from 49-74 cm; slightly micaceous; sharp lower contact.	
74-110	Sand: coarse grained, ranges from silt to gravel, the gravel fraction consists of rock fragments; moderately sorted; olive gray (5 Y 2/1); apparently massive; sharp lower contact.	
110-170	Sand: very fine to fine sand, ranges from silt to very coarse sand; moderately sorted; dark yellowish brown (10 YR 4/2); apparently massive; possible bioturbation; large clast 11 cm dia. from 110-120 cm; no lower contact.	
170-240	Sand: same as interval 110-170 cm. but contains no clasts.	

Figure 67. Log of vibracore 398 which is illustrative of the sedimentologic character of borrow area SD-XI.

Potential Borrow Area SD-XII

Potential borrow area SD-XII is fairly small, and is located from 2 to 3 km west of SD-X (Fig. 61). This potential borrow area occurs between the 17 and 22 m isobaths, and is estimated to contain no more than 0.4 x 10^6 m^3 of suitable sand (Table 30, Figs. 61 and 68). The target material is the medium-grained, marine Holocene unit, which is no more than 1 m thick throughout SD-XII (Figs. 68 and 69).

Table 30. Summary of potential borrow area SD-XII.

Type of Deposit:

Holocene, marine, medium-grained sand deposit

Water Depth:

Minimum: 17 meters

Maximum: 22 meters

Range in Mean Grain Size: n = 4

Minimum:	3.06	phi	0.12	mm
Maximum:	1.19	phi	0.44	mm
Mean:	1.92	phi	0.26	mm

Range in Thickness:

Minimum: 1 meters

Maximum: 1 meters

Estimated Volume	(x 10^6 m^3)	(x 10^6 yd^3)
Minimum:		
Maximum:	0.4	0.5
Other:		Explanation of value:

Vibracores Penetrating Deposit:

257

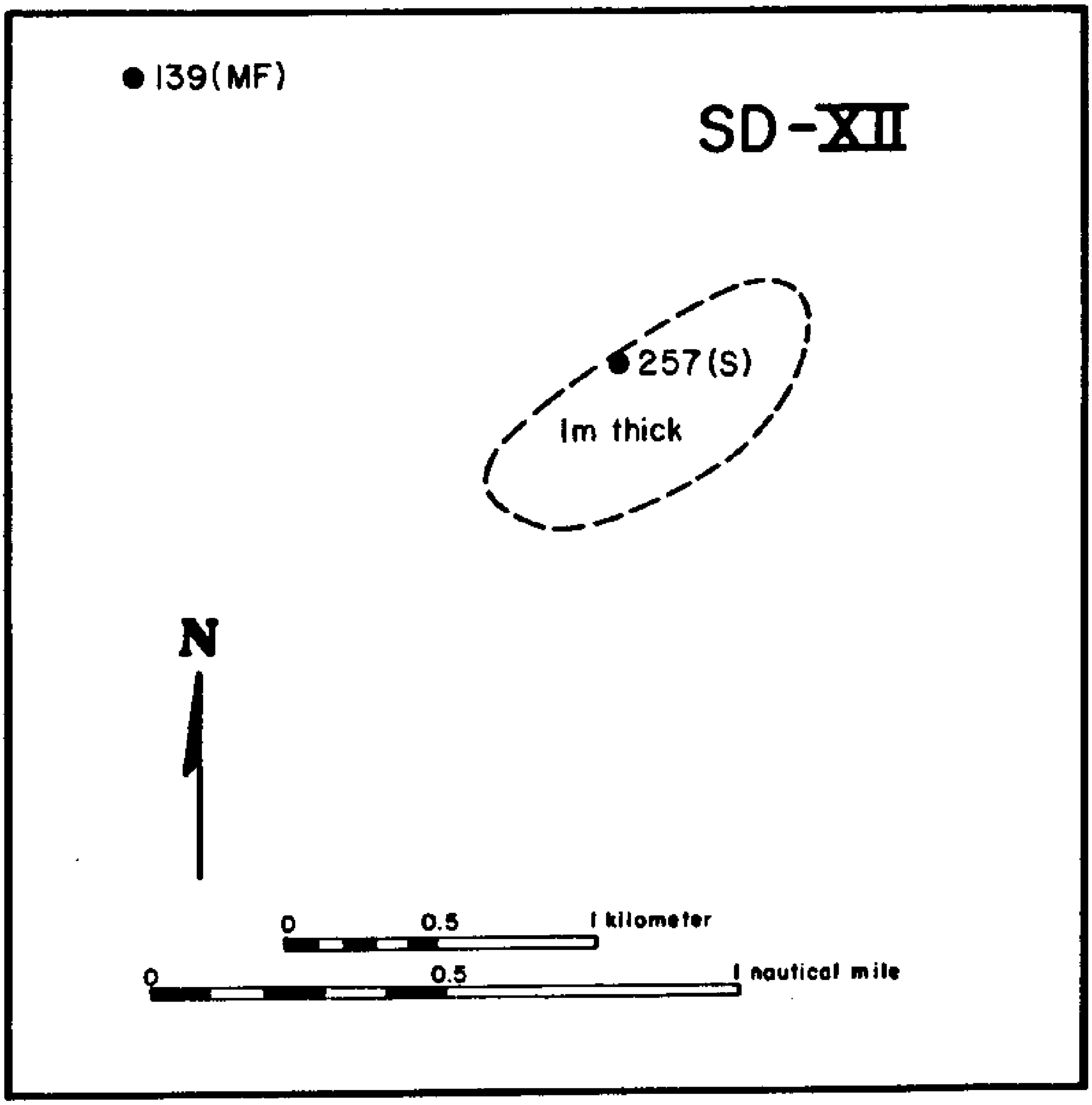


Figure 68. Isopach map of borrow area SD-XII with associated vibracore numbers and sand suitability symbols.

VIBRACORE LOG

Core number: 257

Date: 2/81

Total core length (cm): 235

Sheet 1 of 1

Number of core sections: 1

Water depth (ft): 55

Vertical scale: 1 cm = 25 cm

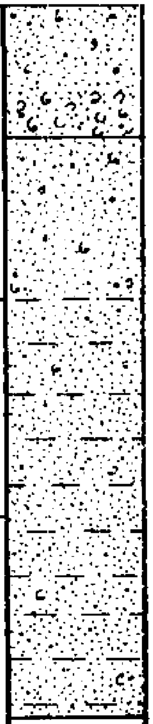
Distance in cm from top of core	Description	Log
0-45	Sand: medium to fine grained, ranges from very fine to very coarse sand with very coarse sand to gravel size shell fragments; moderately to poorly sorted; moderate yellowish brown (10 YR 5/4) intermixed with olive black (5 Y 2/1) grading downwards to dark yellowish orange (10 YR 6/6); predominantly massive with sparse pelecypod and other shell fragments grading downward to very concentrated from 29-45 cm; slightly micaceous; sharp lower contact.	
45-96	Sand: fine to coarse grained, ranges from very fine sand to gravel; moderately to poorly sorted; moderate yellowish brown (10 YR 5/4); intermixed with olive black (5 Y 2/1); apparently massive; slightly micaceous; occasional shell fragments; gradational lower contact.	
96-168	Sand: very fine grained, ranges from silt to medium sand; moderately well to well sorted; olive black (5 Y 2/1); apparently massive; slightly micaceous; sparse shell fragments; no lower contact.	
168-235	Sand: same as interval 96-168 cm but predominantly fine grained.	

Figure 69. Log of vibracore 257 which is illustrative of the sedimentologic character of borrow area SD-XII.

SUMMARY

Approximately 1,366 x 10^6 m^3 of suitable sand and gravel occur in 22 potential borrow areas on the inner continental shelf of southern California from Santa Monica Bay to the United States-Mexico border (Tables 31). Although considerable geologic information is available concerning potential borrow areas in Santa Monica and San Pedro Bays, much more seismic and vibracore data is needed to further delineate the borrow areas along the San Diego County shelf.

In lieu of the volume of suitable material in these potential borrow areas, the necessity of continued beach nourishment and restoration programs, and the bordering levels of commercial profitability, further consideration of offshore sand and gravel mining is warranted for the southern California shelf.

Table 31. Summary of potential offshore sand and gravel resources in southern California from Santa Monica Bay to the United States-Mexico border.

Potential Borrow Area	Minimum Volume of Suitable Material x 10^6 m^3	Maximum Volume of Suitable Material x 10^6 m^3
I. SANTA MONICA BAY, LOS ANGELES COUNTY		
1. B-V	13.8	50.5
2. B-IV	248.5	
3. B-III	26.8	60.4
4. B-II	32.9	77.2
5. B-I	16.0	26.0
Total	338.0	462.6
II. SAN PEDRO BAY, LOS ANGELES AND ORANGE COUNTIES		
6. A-III	34.0	78.8
7. A-II	148.3	168.2
8. A-IV	11.3	
9. A-V	6.5	21.8
10. A-I	61.6	102.4
Total	261.7	382.5
III. DANA POINT AREA, ORANGE COUNTY		
NONE		
IV. OCEANSIDE AREA, SAN DIEGO COUNTY		
11. SD-I		24.9
12. SD-II		20.7
Total		45.6
V. OCEANSIDE TO LA JOLLA AREA, SAN DIEGO COUNTY		
13. SD-III		12.6
14. SD-IV		9.5
15. SD-V		7.9
16. SD-VI		2.2
Total		32.2

Table 31. Con't

VI.	LA JOLLA AREA, SAN DIEGO COUNTY		
	17. SD-VII		2.4
	18. SD-VIII		3.8
		Total	6.2
VII.	MISSION BEACH AREA, SAN DIEGO COUNTY		
	19. SD-IX		
		Total	146.8
VIII.	SAN DIEGO BAY, SAN DIEGO COUNTY		
	20. SD-X		265.7
	21. SD-XI		24.1
	22. SD-XII		0.4
		Total	290.2

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APPENDIX A

VIBRACORE LOGS AND SEDIMENT DESCRIPTIONS

This appendix contains vibracore sediment descriptions based on megascopic and microscopic examination. Core locations are indicated in the appropriate section of the main body of this report. An explanation of the symbols used for the vibracore logs is provided on page ix of this appendix. Sediment color is based on wet samples.

Sediment names are based on the Wentworth grain-size classification, which is summarized as follows.

Sediment	Size (mm)	Phi
Gravel	>2	<-1
Very coarse sand	1.0 to 2.0	0 to -1
Coarse sand	0.5 to 1.0	1 to 0
Medium sand	0.25 to 0.5	2 to 1
Fine sand	0.125 to 0.25	3 to 2
Very fine sand	0.0625 to 0.125	4 to 3
Silt and clay	<0.0625	>4

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I. Santa Monica Bay, Los Angeles County

A. North of Borrow Area B-IV 1

Core B-68 2

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Core B-64 4

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Core B-52 12

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Core V-52 16

Core V-53 18

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Core B 57 23

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Core B-46 26

Core V-31 27

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Core B-43 31

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Core V-49 43

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Core D-07 157

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Core 509 209
Core 511.5 211
Core 527 212
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APPENDIX B

RESULTS OF SEDIMENT GRAIN-SIZE ANALYSIS

A. Summary tables of grain-size data.

In this section of Appendix B, the sample number, mean phi, mean mm, standard deviation, skewness, kurtosis, mode, weight percent gravel, weight percent sand, and weight percent fines (silt and clay combined) are listed for each sediment sample. The first part of each sample number refers to the vibracore from which the sample was collected, and the second part refers to the sample depth in cm from the top of that core. Vibracores obtained by personnel from the University of Southern California are prefixed by the letters V, H or D. Vibracores obtained by personnel from the U. S. Army Corps of Engineers Coastal Engineering Research Center are designated by a number with the prefix A or B generally referring to the core half examined. It should be noted that all grain-size values presented in this report are based on the weight percentage of sediment retained on a given sieve, rather than the percentage passing through.

B. Results of grain-size analysis for each sediment sample.

In this section, more specific grain-size information as well as a histogram is provided for each sample. The following data are listed: sample number, sediment weight by phi class, total sample weight, weight percent by phi class, cumulative weight percent by phi class, inverse cumulative weight percent by phi class, mean phi, mean mm, standard deviation, skewness, kurtosis, weight percent gravel, weight percent sand, weight percent fines (silt and clay combined), and a histogram based on phi class intervals.

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B. Results of grain-size analysis for each sediment sample

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      Core B-68, 000 cm 1

      Core B-68, 154 cm 2

      Core B-68, 300 cm 3

      Core B-68, 420 cm 4

      Core B-68, 590 cm 5

      Core B-65, 000 cm 6

      Core B-65, 120 cm 7

      Core B-65, 280 cm 8

      Core B-65, 360 cm 9

      Core B-65, 450 cm 10

      Core B-65, 563 cm 11

      Core B-64, 061 cm 12

      Core B-64, 091 cm 13

      Core B-64, 244 cm 14

Core B-64, 302 cm 15

Core B-64, 330 cm 16

Core B-64, 361 cm 17

Core B-64, 483 cm 18

Core B-64, 544 cm 19

Core B-64, 584 cm 20

B. Borrow Area B-IV

Core B-61, 030 cm 21

Core B-61, 122 cm 22

Core B-61, 244 cm 23

Core B-61, 307 cm 24

Core B-61, 399 cm 25

Core B-61, 427 cm 26

Core B-61, 460 cm 27

Core B-61, 488 cm 28

Core B-61, 546 cm 29

Core B-62, 000 cm 30

Core B-62, 150 cm 31

Core B-62, 180 cm 32

Core B-62, 315 cm 33

Core B-63, 000 cm 34

Core B-63, 030 cm 35

Core B-63, 091 cm 36

Core B-63, 163 cm 37

Core B-63, 198 cm 38

Core B-63, 200 cm 39

Core B-63, 229 cm 40

Core B-63, 290 cm 41

Core B-63, 338 cm 42

Core B-63, 391 cm 43

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Core V-53, 115 cm 80

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Core V-53, 370 cm 82

Core V-53, 410 cm 83

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Core V-53, 540 cm 86

Core B-58, 000 cm 87

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Core V-43, 305 cm 95

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Core B-57, 357 cm 100

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Core V-13, 008 cm 403

Core V-13, 055 cm 404

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Core A-19, 173 cm 414

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Core A-19, 229 cm 417

Core A-19, 302 cm 418

Core A-19, 391 cm 419

Core A-19, 399 cm 420

Core A-19, 450 cm 421

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Core V-11, 038 cm 425

Core V-11, 070 cm 426

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Core D-04, 000 cm 771

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APPENDIX C

CUMULATIVE FREQUENCY CURVES FOR SEDIMENT SAMPLES

This appendix contains a cumulative frequency curve plotted on normal probability paper for each sediment sample. It should be noted that these plots are based on the weight percentage of sediment retained on a given sieve rather than the percentage passing through a given sieve.

C-I. Area I. Santa Monica Bay, Los Angeles, County

C-II. Area II. San Pedro Bay, Los Angeles and Orange Counties

C-III. Area III. through VIII. Dana Point Area, Orange County through San Diego Bay, San Diego County

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Core V-22, 090 cm 607

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Core V-28, 040 cm 614

Core V-28, 075 cm 615

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Core 945.5 000 cm 889

Core 945.5 048 cm 890

Core 945.5 100 cm 891

Core 1049, 000 cm 892

Core 1049, 081 cm 893

Core 1049, 133 cm 894

Core 1060, 000 cm 895

Core 1060, 052 cm 896

VIII. San Diego Bay, San Diego County 897

Core 106, 000 cm 898

Core 106, 115 cm 899

Core 118, 000 cm 900

Core 118, 095 cm 901

Core 139, 000 cm 902

Core 139, 108 cm 903

Core 139, 210 cm 904

Core 139, 312 cm 905

Core 149, 000 cm 906

Core 149, 025 cm 907

Core 149, 090 cm 908

Core 149, 152 cm 909

Core 153, 000 cm 910

Core 153, 045 cm 911

Core 153, 066 cm 912

Core 153, 130 cm 913

Core 153, 240 cm 914

Core 153, 339 cm 915

Core 257, 000 cm 916

Core 257, 045 cm 917

Core 257, 096 cm 918

Core 257, 168 cm 919

Core 262, 000 cm 920

Core 262, 078 cm 921

Core 262, 165 cm 922

Core 272, 000 cm 923
Core 272, 069 cm 924
Core 272, 122 cm 925
Core 272, 155 cm 926
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Core 290.5 051 cm 928
Core 290.5 109 cm 929
Core 290.5 180 cm 930
Core 290.5 256 cm 931
Core 290.5 278 cm 932
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Core 822, 051 cm 979
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Core 829, 000 cm 985

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Core 829, 265 cm 989

Core 829, 283 cm 990

Core 829, 340 cm 991

Core 829, 372 cm 992

Core 829, 398 cm 993

Core 858, 000 cm 994

Core 858, 102 cm 995

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Core 878, 000 cm 997

Core 878, 120 cm 998

Core 882, 000 cm 999

Core 882, 120 cm 1000

APPENDIX D

RESULTS OF PETROGRAPHIC MODAL ANALYSIS

Methodology

Grain thin sections generally were prepared for the medium sand fraction (0.25 to 0.50 mm; 2 to 1 phi) of the obtained vibracore samples. Additional grain thin sections sometimes were prepared for both the coarse sand fraction (0.50 to 1.00 mm; 1 to 0 phi) and the fine sand fraction (0.125 to 0.25 mm; 3 to 2 phi) to evaluate mineralogic variation as a function of grain size. Where more than one identical sample number occurs in the computer listings, the petrographic analyses are ordered from coarse- to fine-grained fractions of that particular sample. Half of each thin section was stained with sodium cobaltinitrate to aid in distinguishing potassium feldspar from quartz and plagioclase. A minimum of 300 grains were counted on each thin section using the line method described by Galehouse (1971, p. 392-394). The correct identification of at least 300 grains per thin section provides that the true compositional value for each major mineral is within ±6% of the obtained number frequency value at a 95% confidence level (Van der Plas and Tobi, 1965; summarized in Galehouse, 1971, p. 395-397). The quartz classifications of Basu and others (1975) and Young (1976) were employed. Compositional abbreviations listed on the computer output are identified on page iii.

Appendix D is divided into two parts. Part A includes the listings and simple data descriptions for the general areas I through VIII, and thus includes all of the obtained petrographic data. Part B includes the listings and simple data descriptions for potential borrow areas where sand samples were recovered.

References

Basu, A., Young, S. W., Suttner, L. J., Jones, W. C., and Mack, G. H., 1975, Re-evaluation of the use of undulatory extinction and polycrystallinity in detrital quartz for provenance interpretation: Jour. Sed. Petrology, v. 45, p. 873-882.

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Van der Plas, L., and Tobi, A. C., A chart for judging the reliability of point counting results: Am. Jour. Sci., v. 263, p. 87-90.

Young, S. W., 1976, Petrographic textures of detrital polycrystalline quartz as an aid to interpreting crystalline source rocks: Jour. Sed. Petrology, v. 46, p. 595-603.

Compositional Abbreviations Listed on Computer Output

1.	ID	vibracore number
2.	IDD	sample depth in cm from top of vibracore
3.	NONUNQTZ	nonundulatory monocrystalline quartz
4.	UNQTZ	undulatory monocrystalline quartz
5.	PLAG	plagioclase feldspar
6.	KSPAR	potassium feldspar
7.	PYROX	pyroxene
8.	AMPHIB	amphibole
9.	BIOTITE	biotite
10.	EPIDOTE	epidote
11.	SPHENE	sphene
12.	GARNET	garnet
13.	FEMIN	magnetite and other opaque iron oxides
14.	QTZ 2-3	polycrystalline quartz with 2-3 subunits
15.	QTZ >3	polycrystalline quartz with >3 subunits
16.	META	metamorphic rock fragments
17.	PLUTON	plutonic rock fragments
18.	VOLC	volcanic rock fragments
19.	CLASTIC	siliciclastic sedimentary rock fragments
20.	ALLOCH	allochemical carbonate grains
21.	CHERT	chert
22.	INTRA	intraclastic carbonate grains
23.	NOID	unidentified grains

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