DEPARTMENT OF THE INTERIOR

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Pollution Studies of Drakes Estero, and Abbotts Lagoon Point Reyes National Seashore, California, USA

by

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Illustrations

Tables

Appendices

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Pollution Studies of

Drakes Estero and Abbotts Lagoon

Point Reyes National Seashore,

California

Abstract

Pollution Studies of Drakes Estero and Abbotts Lagoon were initiated as a research project on the sediments of Drakes Estero. The National Park Service (NPS) wanted to further the baseline study to include a compilation of information on possible pollution and sedimentation inputs into Drakes Estero and Abbotts Lagoon. The study called for a compilation of literature of research conducted on lagoons and estuaries of the Pacific Coast of the United States. The study investigated sedimentation patterns and sediment accumulation rates for the two areas, the amounts of herbicides and pesticides in the sediment of the systems, and the concentrations of plant nutrients in creeks entering the the study sites during storm events.

The study compiled an annotated bibliography, with over 490 entries, of literature on research conducted in lagoons and estuaries of the West coast of the United States (Anima, 1990). Based on interpretations of geophysical records, Pb^{210} and $Carbon^{14}$ dating, the study determined that sediment input into Drakes Estero and Abbotts Lagoon over the last 8,000 years was about 35 cm/100 yrs, and fluctuated from 12 cm/100yrs to 30 cm/100yrs over the last 120-150 years.

Sedimentation rates calculated for the two study areas are similar to sedimentation rates calculated by other researchers working in similar environments. Laboratory analysis of sediment samples collected on the upper reaches of Drakes Estero and the bottom of Abbotts Lagoon indicate that the amounts of herbicides and pesticides is below the limits for ingestion by organisms as set by the National Academy of Sciences and the Environmental Protection Agency.

The nutrient study indicates that conductivity values were higher during storm events of water year 1988, probably due to washout of soil salts built over the summer. Hagar (1990) has a complete report on the nutrient study.

Section I Introduction

There are few areas along the California coast where man has not had a significant impact on the estuarine or lagoonal environment. Drakes Estero and Abbotts Lagoon, to a degree, are exceptions to this in that they are in a nearly natural setting. However, even here the effects of human intrusion may exist. This study investigated the environmental and chemical inputs into Drakes Estero and Abbotts Lagoon to determine if the area has potential pollution problems that need to be addressed. The results of the study have potential application to other lagoons and estuaries along the Pacific Coast of the United States.

Drakes Estero and Abbotts Lagoon are part of Point Reyes National Seashore, located approximately 45 km northwest of the mouth of San Francisco Bay and 30 km south of Bodega Bay Harbor (fig. 1). The land around Drakes Estero, originally part of the Berry Spanish land grant, consists of farm lands used for grazing dairy and beef cattle. The area came under the control of the National Park Service in 1962 when 259 km^2 (64,000 acres) of land were acquired. Today the area includes 284 km^2 (70,187 acres) of land (Don Neubacher,

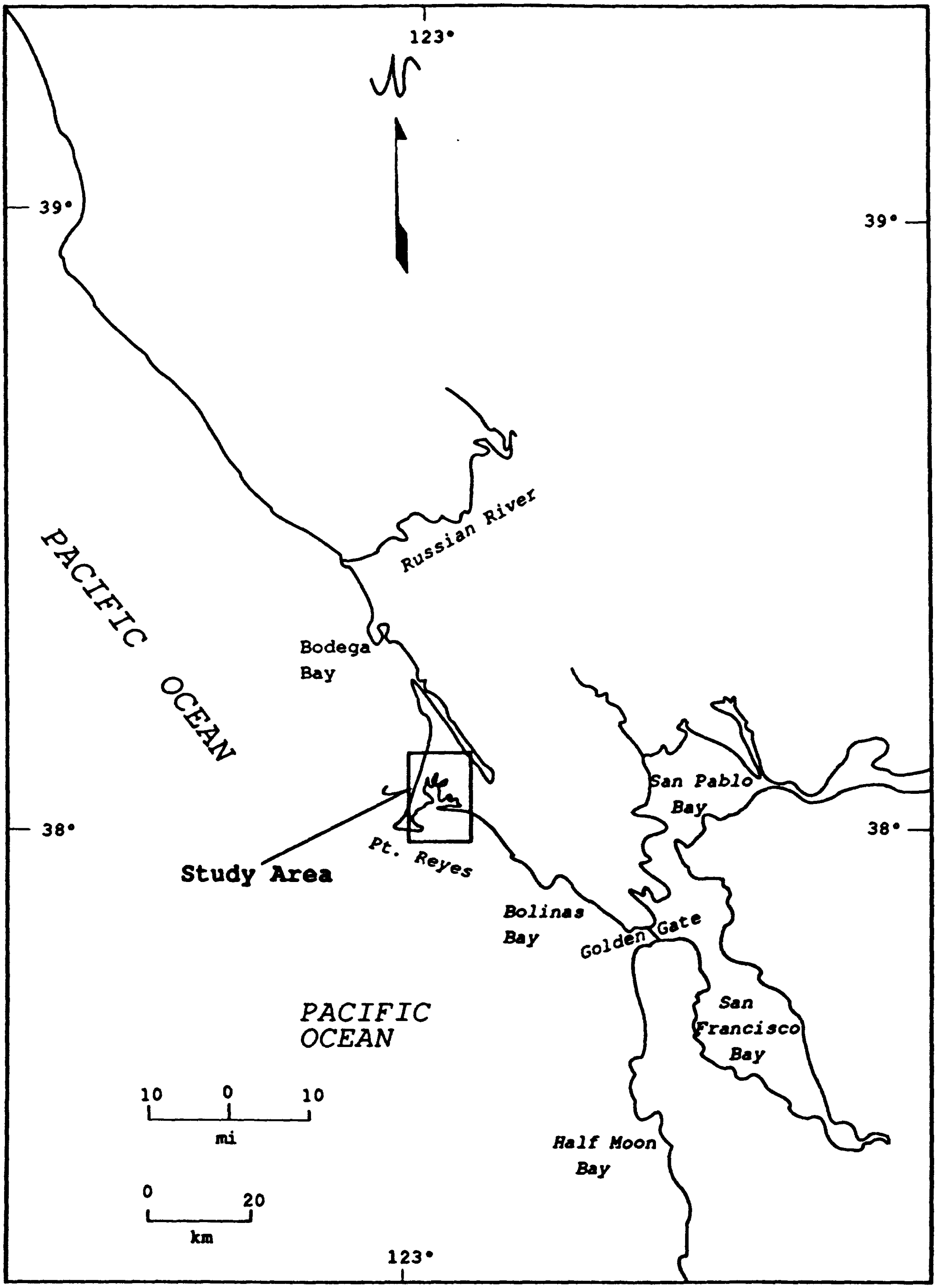


Figure 1. Map show location of the study area.

Point Reyes National Seashore staff, 1990, personal communication). The National Park Service attempts to protect the natural beauty of the area and preserve it for the good of the visiting public. This research was conducted to develop a baseline of environmental characteristics and monitor the area to identify potential future problems and what can be done to maintain the area in its nearly natural state.

1. Background;

Drakes Estero and Abbotts lagoon are aesthetically very pleasing localities, for which the National Park Service bears the responsibility for formulating a comprehensive management plan to benefit the thousands of visitors that visit the park yearly and to preserve the seashore environment.

This report results from a two year study requested by the National Park Service, Point Reyes National Seashore, to investigate pollution inputs into Drakes Estero and Abbotts Lagoon. The work was conducted by the U.S. Geological Survey with funding provided by the National Park Service under a two-phase program.

This study utilized coring, bathymetric profiling, geophysical profiling, and chemical and physical sediment analyses to establish an overall sedimentologic and pollution input baseline. This information can be used to support or initiate ongoing monitoring and management programs. The study gathered over 18 km of geophysical and bathymetric tracklines, 48 vibracores, 26 box cores, sediment size analysis was conducted on 39 sample sites. Of the 48 vibracores, 14 cores were selected for herbicide and pesticide analysis as well as for PB^{210} analysis. Numerous SCUBA dives were made both to obtain box and vibracores and to make visual observations.

The first year was directed at conducting a pollution study focused on herbicide inputs, later expanded to include pesticide inputs, and the compilation of an annotated bibliography. The second year examined nutrient inputs from surrounding grazing land and sedimentation rates in the lagoons.

The research benefited from two previous years of work on sediment textural variations and inlet morphological changes of Drakes Estero (Anima, 1989). Abbotts Lagoon was added to the research area when the pollution studies project was started.

2. Field Procedures

The initial work on the sediments and morphology of the study area was conducted during the summer months of 1984-86. During this time vibracores, box cores, lagoon inlet surveys, observational SCUBA dives, and geophysical profiling was conducted. Most of the coring and all of the diving and seismic profiling were done from the R/V Fast Eddy, a 6.4 m (21 ft) boat, with support for the vibracoring from a 4.0 m

(13 ft) boat. The oyster farm located on Schooner Bay (fig. 2) served well as an accessible launch site for the boats when the tides were sufficiently high.

a. Navigation - Navigation and surveying stations on-land were initially surveyed to existing bench marks. Stations were selected according to accessibility, the ability to tie the point to an existing survey marker, and maximum visibility from the areas being worked. The stations allowed for precise coring site locations with the use of a surveying instrument, and geophysical trackline locations with the use of navigation trisponders. Geophysical tracklines were restricted by channel depths and the location of dense beds of *Zostera marina*, which fouled the electronic equipment rigged over the side of the survey vessel. The tracklines were run in a manner that would give the optimum coverage over the tidal channels, but were restricted to the deeper tidal channels in which the research vessel could transit.

Three U.S. Coast and Geodetic Service bench marks provided reference points of navigation (fig. 2) These bench marks were utilized to locate four temporary survey stakes with a Hewlett Packard 3802a Total Station. This instrument uses infrared light reflected off of either a single prism or prism array to give horizontal distances, vertical elevation differences, and azimuth readings from a pre-set zero mark, such as a known north point or another survey stake. When the total station was not available, a nautical sextant was used from the boat to triangulate between flags set up at the survey stakes. The survey stakes aided in locating coring sites, geophysical profile lines, and dive sites, and in barrier spit surveying.

When conducting geophysical surveys from a boat a Del Norte 504 navigational system was used. This system uses microwave trisponders (transmitters) located at known reference points that interact with a boat-mounted receiving antenna to measure distances between trisponders for exact location. The trisponders were set up at the U.S. Coast and Geodetic Survey bench mark at the west end of the entrance and at each of the three temporary survey stakes. The boat-mounted trisponder was connected to a microprocessor with paper recorder. The system tracked the exact location of the boat that was simultaneously collecting geophysical and bathymetric records. Accuracy of the system in this configuration is within 1 m.

b. Geophysical Profiling High-resolution single-channel seismic reflection profiles totaling 18.8 line km were run in Drakes Estero to provide a graphic representation of the shallow subbottom (fig. 3) These profiles were obtained with an EG&G double plate Uniboom system with a power output of 600 J. A one-quarter second sweep rate was used for all profiles. The incoming signal was filtered and

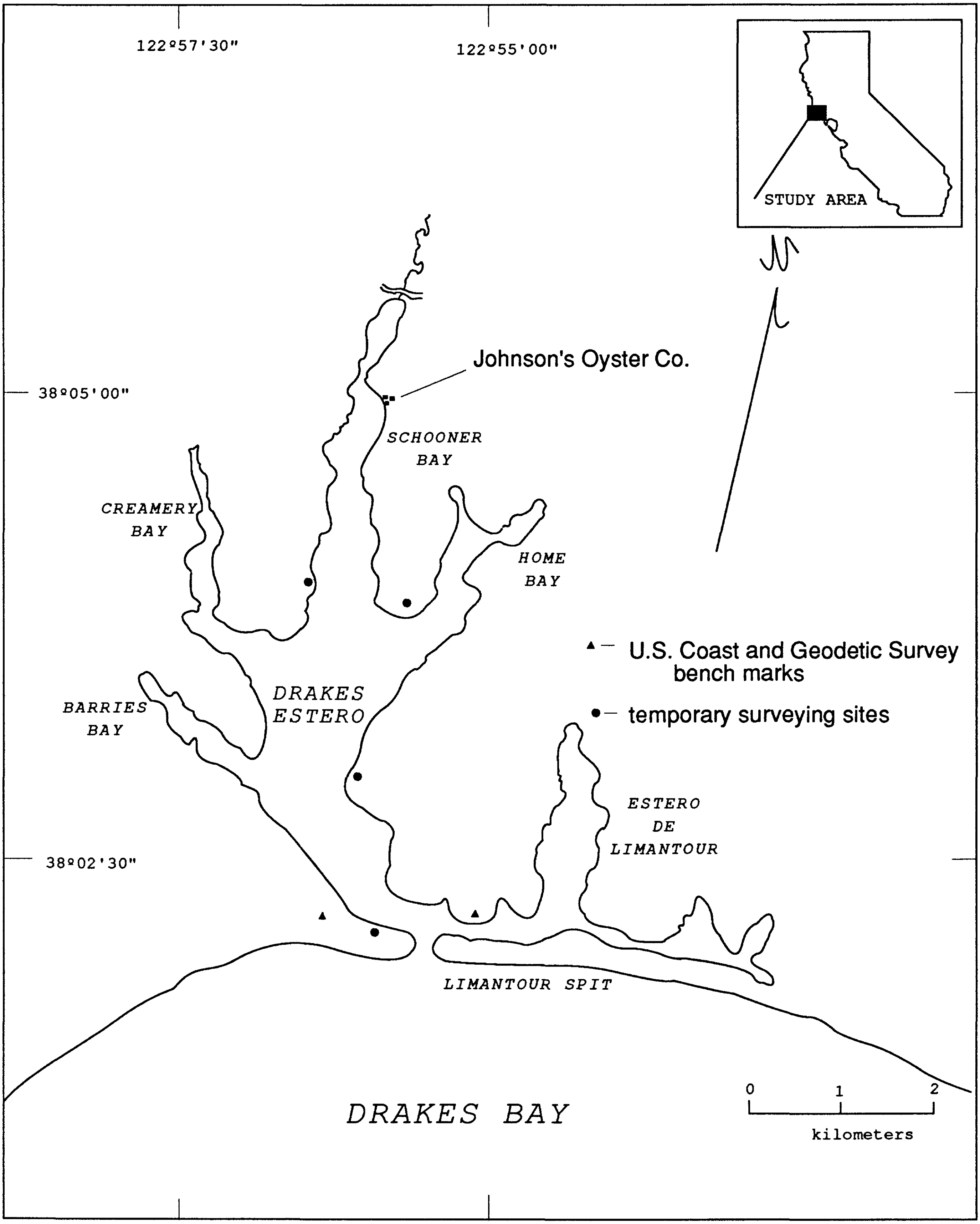


Figure 2. Location of bench marks and temporary survey stations used in both surveying of the spits and in running geophysicial surveys in Drakes Estero.

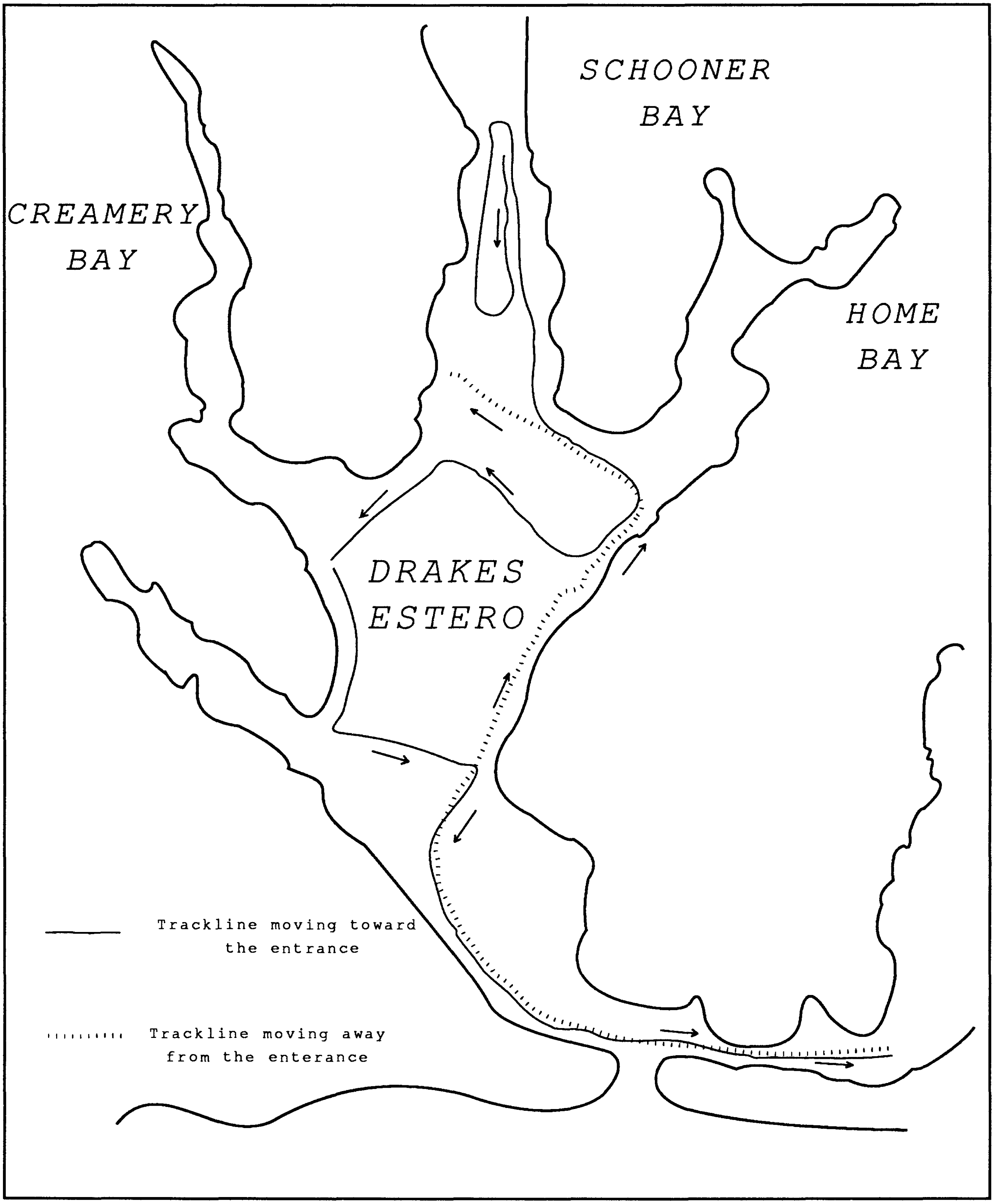


Figure 3. Map showing geophysical and bathymetric tracklines in Drakes Estero.

pre-amplified between 550-1200 Hz. The system was also equipped with a 3-element hydrophone, 502 amp amplifier, and an EPC-4100 graphic recorder. The seismic profiles were run with accompanying bathymetry to aid in geophysical record interpretation by comparing water depths. Event marks were coordinated using radio communication to keep reference points for integration of navigation, geophysics, and bathymetry records.

c. Bathymetry Twenty line kilometers of bathymetric records were acquired in Drakes Estero (fig. 3), and 6.2 line kilometers in Abbotts Lagoon (fig. 4). Bathymetric tracklines were run using a Lowrance X-15B computer sonar with variable scale. Examples of bathymetry records (Appendix A1) used to produce the preliminary bathymetric map of Drakes Estero (fig. 5) show in detail those areas where subaqueous bedform features are found in the main channels of the estero. The preliminary bathymetric map of Abbotts Lagoon (fig. 6) was produced from bathymetric records shown in Appendix A2, (refer to trackline maps and bathymetric profiles). The bathymetric profiles were used to produce the sediment textural maps (Appendix B) with information gathered by sediment sampling and diving. All tracklines were tied into surveying stations using event marks coordinated through radio communication.

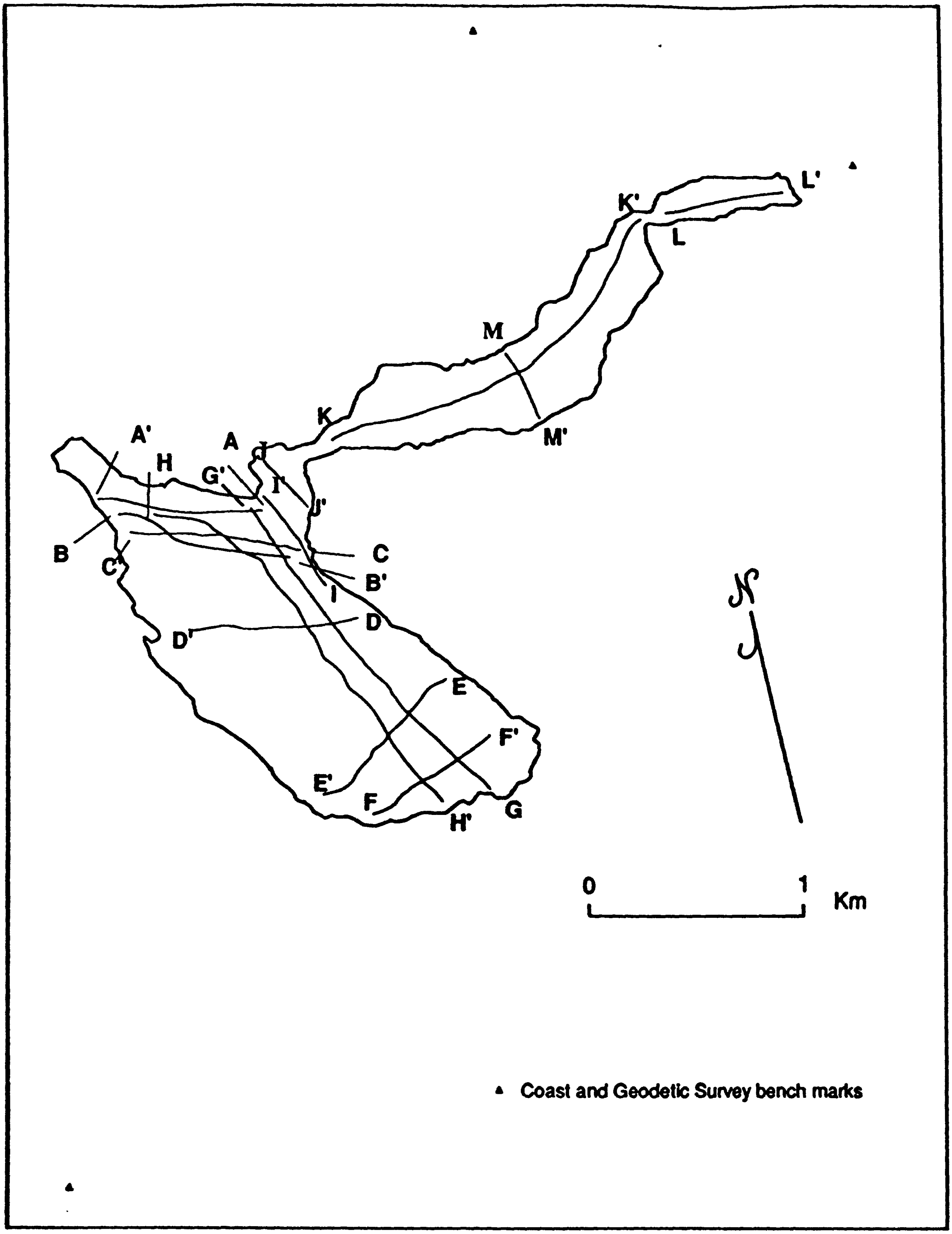


Figure 4. Map showing bathymetric tracklines in Abbotts Lagoon.

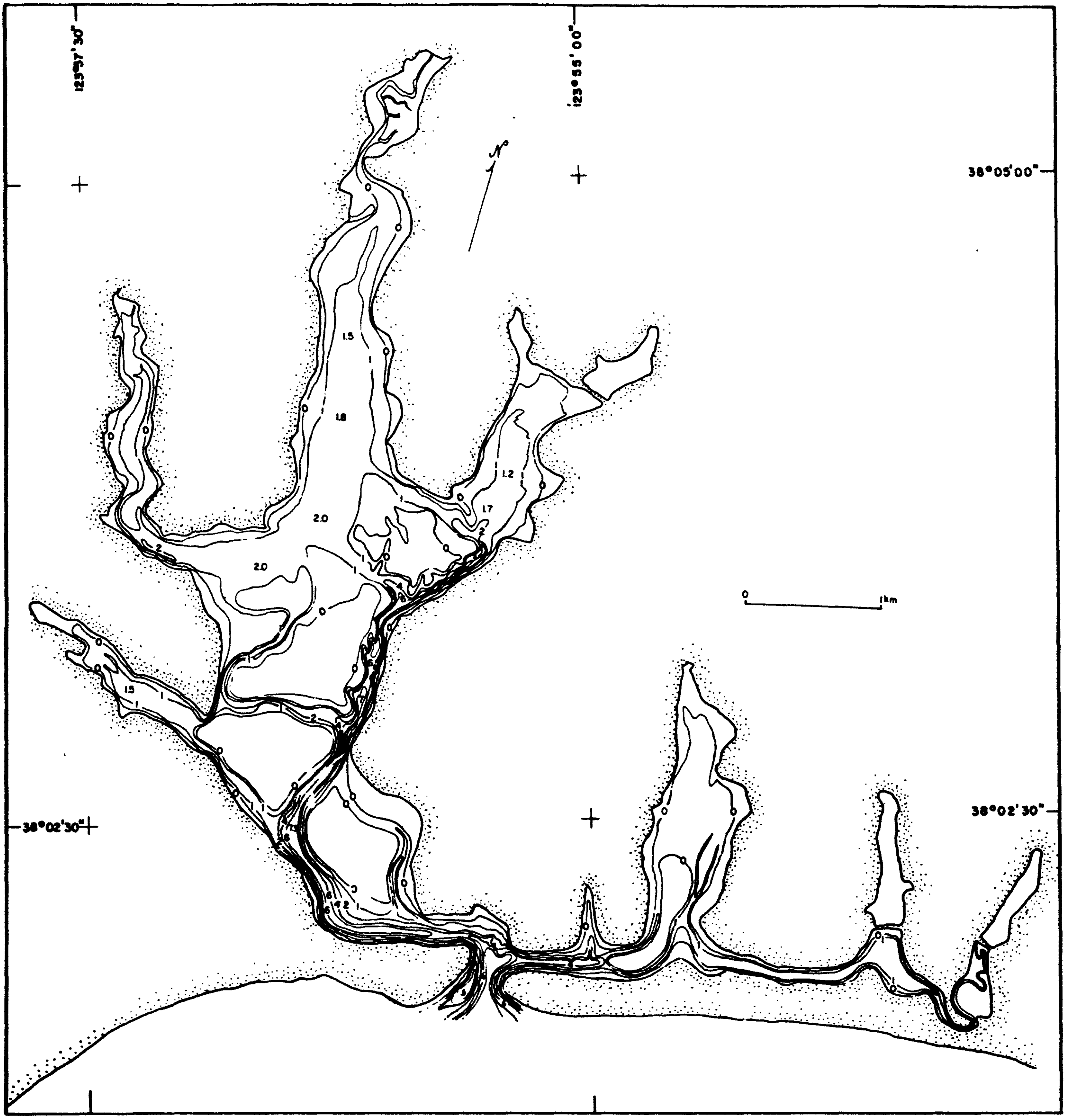


Figure 5. Preliminary bathymetric map of Drakes Estero.

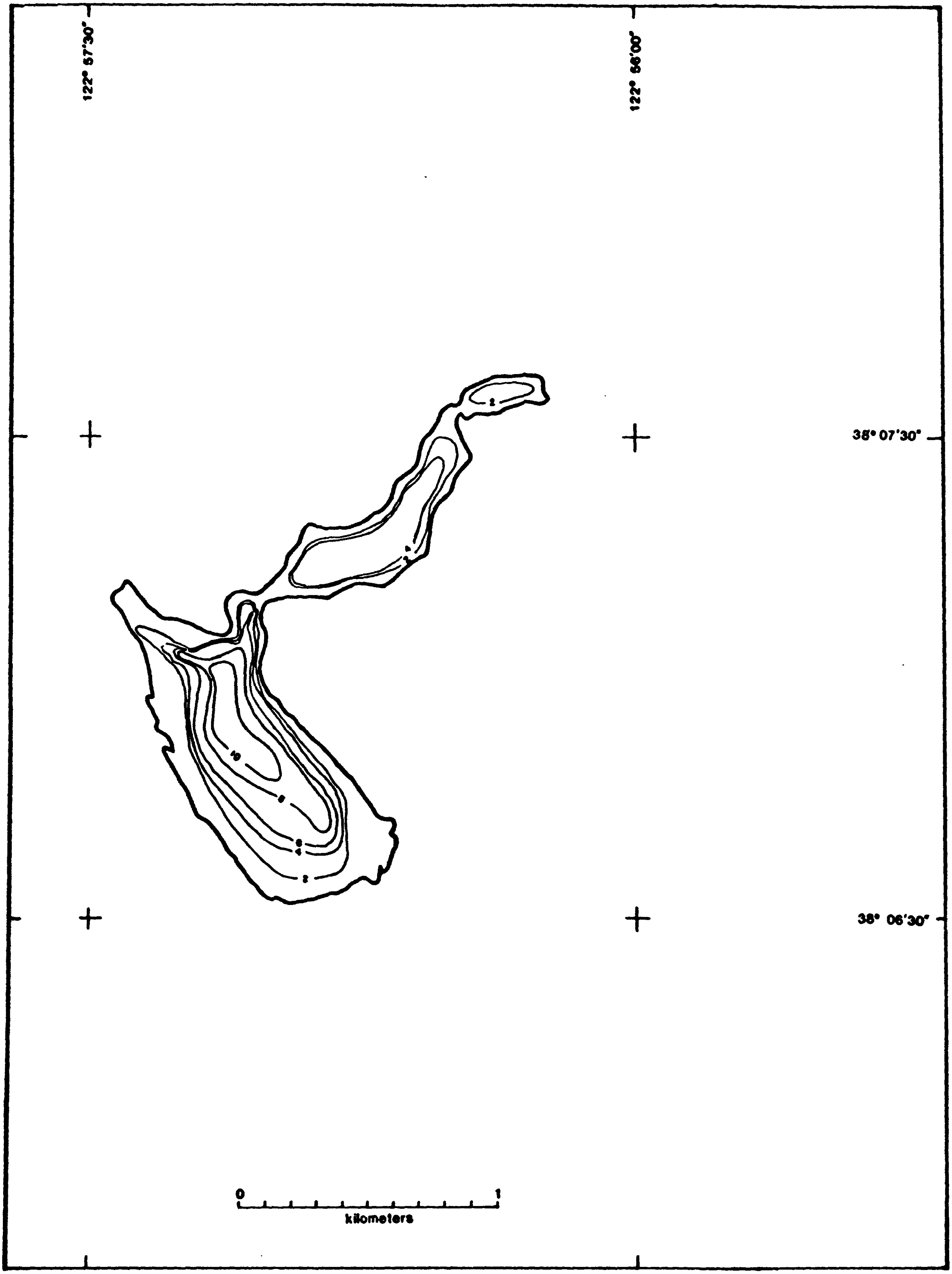


Figure 6. Preliminary bathymetric map of Abbotts Lagoon.

d. Coring - Three types of coring devices were utilized to collect sediment samples. Senckenberg box cores (8 cm X 16 cm X 21 cm), were used to acquire sediment samples of the uppermost part of the sediment column (Bouma, 1964, 1969; Clifton, 1971). A sliding-hammer type of coring device was used to collect 8.5 cm diameter tube cores, and a hydraulically powered vibracorer having a 24 kg jackhammer was used to collect 7.45 cm diameter aluminum tube cores. The best penetration achieved by either tube coring system was 2.20 m. The cores were collected over a three summer period. Sediment samples were taken from the cores to run the various laboratory analyses required. Selection of coring sites (Appendix C) was based on environmental characteristics and the potential of the core to give the most representative sedimentologic and stratigraphic example of the depositional setting. The selection of sub-samples used for sediment textural analysis, age dating, and herbicide and pesticide analyses was dictated by the requirement of the analysis procedure being utilized. The age dating and herbicide and pesticide analyses required the finest grain sizes for optimal results.

3. Estuary Uses

a. Surrounding Farmland - Six ranches surrounding Drakes Estero support an approximate total of 1,185 head of cattle. (Table 1). The Murphy (340 head of cattle), Gallagher (200 head of cattle), and Horic (370 head of cattle) ranches are the largest ranches adjacent to the estero. The Nunes (100 head of cattle), and Lunny (175 head of cattle) ranches utilize very little range land on the estero (Point Reyes National Seashore personnel communication, 1988).

Abbotts Lagoon is surrounded by three ranches: McClures (590 head of cattle), Evans, (200 head of cattle), and Lunny (175 head of cattle), totalling 965 head of cattle. The Lobaugh ranch is located within the Abbotts Lagoon drainage basin and has 450 head of cattle.

b. Oyster Industry - The Johnson Oyster Company has grown oysters on Drakes Estero since 1940, and, prior to that time, the Drakes Bay Oyster Company conducted oyster farming in the early 1930's (Barrett, 1963). The lagoon offers an environment suitable for a mariculture industry. Presently the lagoon supports approximately 26 racks, 20 beds of staked oysters, and an unknown number of bagged oysters on its subtidal channels and intertidal flats. The main headquarters for the company is located on the upper northeast shore of Schooner Bay. The company supports approximately 25-30 employees involved in various aspects of the industry.

c. Recreation - The estero is infrequently used as a launching point for canoes, and kayaks. Clams are dug on the intertidal flats during the lower tides of the year. The

Table 1. Numbers of livestock on Ranches surrounding Drakes Estero and Abbotts Lagoon

Drakes Estero	Head of Cattle(*)	Acres(#)	Hectares (Ha)	Animals Per/Ha
Murphy	340	3,012.82	1,219.77	.28
Gallagher	200	1,656.27	670.55	.30
Horic	370	1,211.41	490.45	.75
Nunes	100	1,472.40	596.11	.17
Abbotts Lagoon				
McClures	590	1,691.97	685.00	.86
Evans, Grossi, Rodgers	200 + ~13 goats	2,745.00	1,111.34	.18
Lunny	175	<1,473.92	596.73	.29

*- Based on data provided by the National Park Service

#- Based on 1960 land ownership (Mason,1970)

Park Service has maintained a trail system around the estero that allows hikers to enjoy the beauty of the estero itself.

Section II. Hydrology and Morphology of the Study Area

1. General Description

a. Drakes Estero - Local geomorphology and recent offshore surveys (McCulloch , 1984) indicate that Drakes Estero is the exposed part of a drowned stream valley that was inundated during the post-Wisconsinan sea-level rise. In its present configuration, it represents a stage of sedimentary filling intermediate between a broad unfilled trough with poorly developed intertidal flats and marsh, like Tomales Bay, and of a basin that has been extensively filled with broad intertidal marsh and flats, like Elkhorn Slough.

The estero is protected from the open coast by Limantour Spit (fig. 7), a barrier 4.1 km long by approximately 200 m wide covered by beach dune ridges. The inlet to the estero has migrated in an east to west direction and then reversed during historic times. Figures 7 and 8 show a comparison of historic maps, photographs, and recent surveys of the entrance of the estero. During the course of this study, surveys of the barrier spits were conducted and the barriers were found to have migrated approximately 80 meters in 1 year. Historic map comparisons show up to 800 meters of spit building to the east over a twenty year period. The variation of the

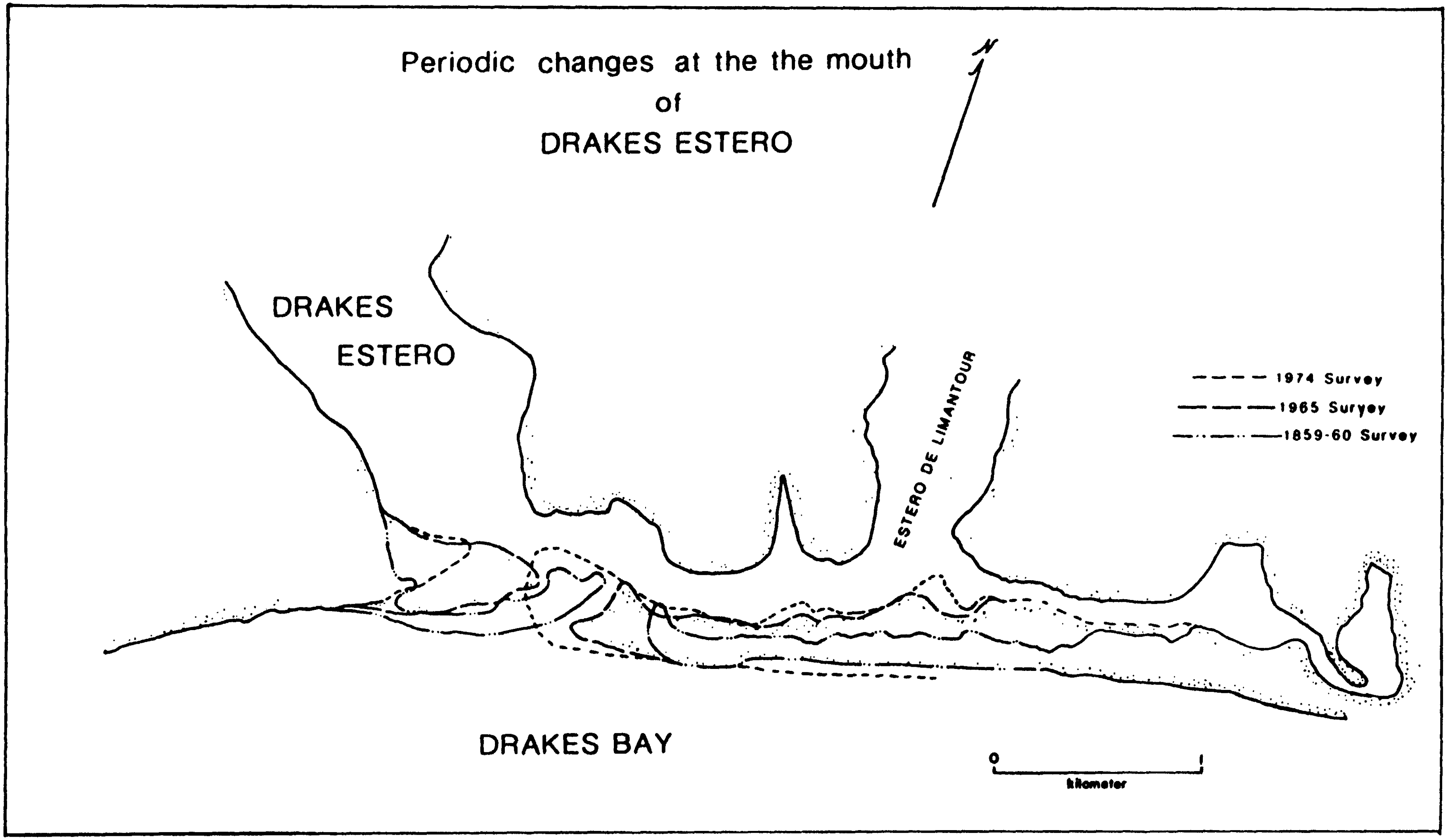


Figure 7. Map showing changes in the inlet to Drakes Estero compiled from both aerial photographs and historic maps.

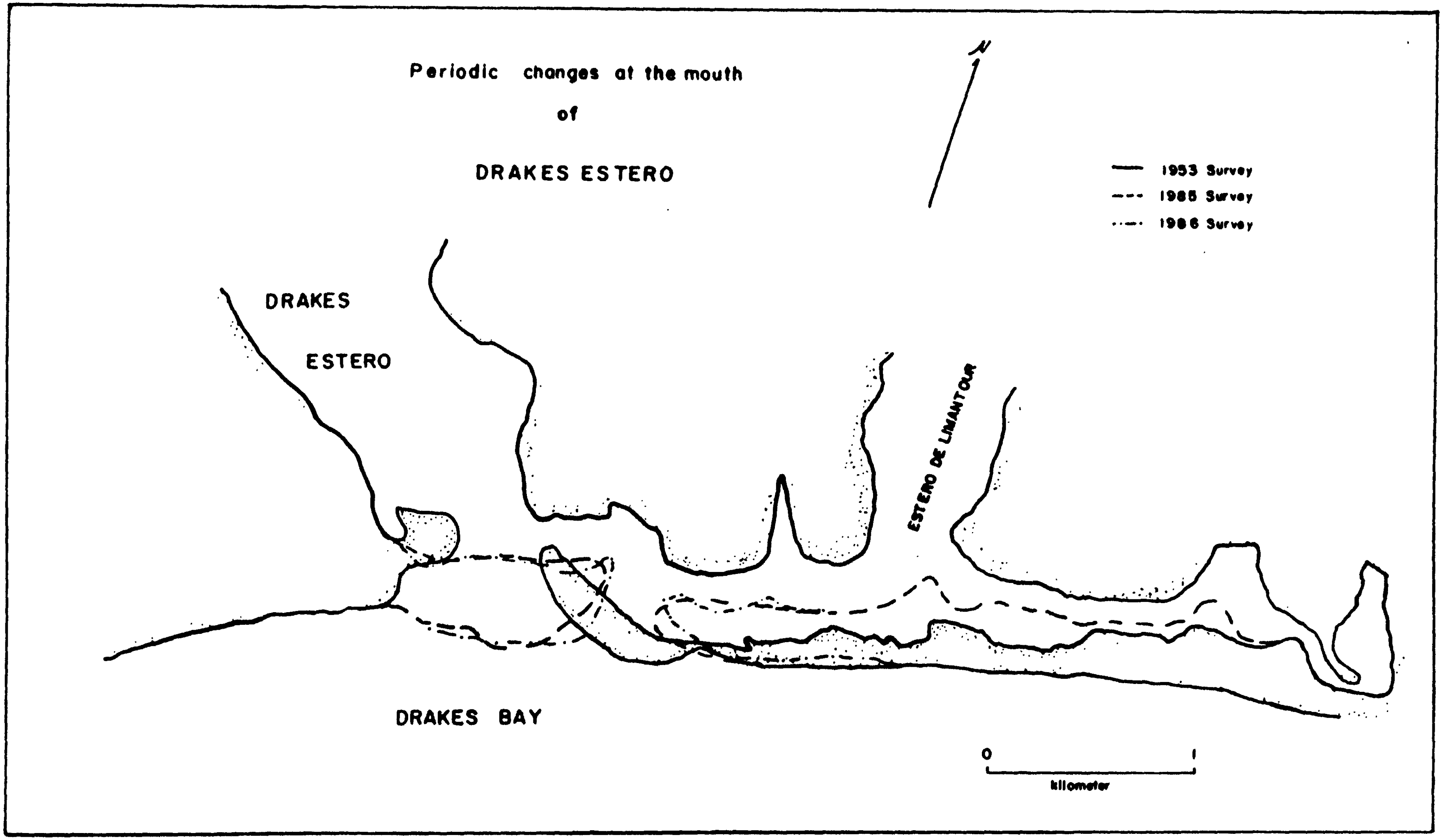


Figure 8. Map showing changes at the entrance to Drakes Estero as compiled from historic maps and surveys conducted in 1985 and 1986.

position and depth of the entrance of the estero has a significant role in the sediment distribution within the lagoon.

The estero is defined as a coastal lagoon because of the minimal influx and dilution of sea water by fresh water. The estero consists of five branching bays that have intertidal mud flats and sand flats around their margins. The branching bays converge into a central area that also has sandy to muddy intertidal flats along its margins and three large sand to silty sand intertidal flats in the central area. From west to east within the estero the branches are; Barries Bay (.35 km^2), Creamery Bay (.54 km^2), Schooner Bay (1.58 km^2), Home Bay (.77 km^2), and Estero de Limantour (.91 km^2) (Table 2). The total area of the lagoon at higher high tide is 9.4 km^2. Of this area, approximately 4.8 km^2 consist of intertidal flats that are exposed during low tide. Maximum water depths in Drakes Estero were found at the entrance and near the first major bend in the main channel west of the inlet, where the water depth is between 7.0 and 7.9 m (fig. 5)

b. <u>Abbotts Lagoon</u> - The Abbotts Lagoon system is composed of two arms that range in depth from 11.0 m to 2 m, and have a combined area of approximately .91 km^2 (fig. 6). The largest (approximately .64 km^2) and deepest (11 m near its center) arm lies closest to the ocean. Normally it is not open to the sea and is not tidally influenced, but occasionally Abbotts Lagoon has opened to the sea either by natural erosion or by digging through the barrier by the local inhabitants. The last known breach of the barrier is reported to have occurred in 1982 when a combination of high rainfall and large waves eroded the barrier bar causing most of the water in the oceanside arm to drain (Evans, D, 1988, personnel communication). The upper arm extends to the northeast from the main arm. This arm has an area of approximately 0.64 km^2 and a maximum depth of 5.9 m (fig. 6). At its upper end a small unnamed stream flows into it from the northeast.

c. Tides and Currents -

The tides in the study area are semidiurnal with a tidal range of between -2.0 to 2.2 meters in Drakes Estero. The highest currents measured were near the mouth of the lagoon and ranged between 32 cm/sec. and 46 cm/sec (Table 3). The tidal currents have formed an ebb tidal delta at the entrance of the lagoon that extends 400 meters into Drakes Bay. Inside the entrance there is no typical flood tidal delta, but as will be detailed later, the intertidal flats located inside the mouth might be the remnants of a former flood tidal delta.

Abbotts Lagoon is not tidally influenced and is not normally open to sea, although sedimentary features in the lagoon adjacent to the location of the most recent (1982) break in the barrier are remnant berm overwash features that developed as the barrier closed (Appendix A2, lines B-B', & C-C').

Table 2. Current Measurements

Current measurements were taken just inside the mouth of the lagoon and along the straight portion of the main channel. Measurements were taken during an ebbing tide.on August 16,1986.

Current measurements at a point just inside the mouth:

Time	Distance (m)	time (t[1])	Velocity(t[2]) (cm/sec.)
0930	30	1 min 33 sec.	32.3
0955	30	1 min 21 sec.	37.0
1003	30	1 min 21 sec.	37.0
1011	30	1 min 13 sec.	41.1
1016	30	1 min 08 sec.	44.1
Measurements along the main channel at trisponder station 2 (Refer to Figure 2)			
1110	30	1 min 14 sec.	40.5
1113	30	1 min 04 sec.	46.9
1125	30	1 min 05 sec.	46.2
		average Velocity	40.6

Table 3. Drainage Basin Area for Drakes Estero and Abbotts Lagoon Water shed area

Location	Drainage area (km^2)
Glenn brook creek	5.68
Barries Bay	3.43
Creamery Bay	5.71
Schooner Bay	12.83
Home Bay	11.68
Estero de Limantour	7.59
Total drainage area	46.92
Abbotts Lagoon	10.51

b. Streams - Six perennial streams flow into the Drakes Estero system: Summit Creek, Bayview Creek, Glennbrook Creek, a small unnamed creek that flows into Estero de Limantour, Home Ranch Creek, and the stream that roughly parallels Sir Francis Drake Highway and flows into Schooner Bay. Four ephemeral streams flow into the system, including two small creeks west of Home Ranch Creek that flow into Home Bay and small creeks that flow into Creamery and Barries Bays. The creeks drain into Drakes Estero from the high-relief topography that surrounds the estero (fig. 9) and flow into the estero at the heads of each of its five bays.

Abbotts Lagoon has two small unnamed streams that drain the surrounding rolling topography. One empties into the southern end of the ocean-side arm, the other flows into the uppermost onshore arm (fig. 10).

The total drainage basin area of Drakes Estero is approximately 46.9 km^2 (Table 2), and the total drainage basin area of Abbotts Lagoon is 10.5 km^2. The average stream gradient is 90 m/1000 m with an average stream discharge of $<10\ m^3\ s^{-1}$, (Johnson, 1976).

e. Salinity - Water sampling in Drakes Estero was conducted during October 1987 and again on September 1988. (refer to fig. 26, & 27 for sampling sites). The salinity differs little in water samples collected in the upper intertidal zone and on the open coast (Table 4).

Abbotts Lagoon is a brackish or nearly fresh water lagoon with some increase in the salinity in its bottom waters from 1984 to 1987. The northeastern arm is less saline than the main arm and the salinity in the lagoon overall was less in 1989 than in 1987 (refer to tables 5, & 6, and fig. 12).

Section III. Results

General Description

Site selection was important for sediment samples destined for laboratory analysis in that fine-grained materials give optimal results for Pb^{210}, herbicide, and pesticide analysis. For this reason the cores selected for those analysis were obtained form the upper intertidal areas of Drakes Estero, and from the cores from Abbotts Lagoon that contained the finest grain sizes. The herbicide and pesticide analysis was conducted by the U. S. Geological Survey Water Resources Division Central Laboratories in Denver Colorado under Schedule 1305 for the herbicides, and Schedule 1325 for pesticides.

Samples collected for nutrient and grain size analysis were collected either from the creeks selected for monitoring or from cores collected from the study area.

1. Sediment

Textural analysis was conducted on thirty box cores, tube cores or grab samples collected in Drakes Estero (fig. 13) and nine samples from Abbotts Lagoon (fig. 14). Samples

Figure 9. Topographic map of the area surrounding Drakes Estero showing the streams that flow into the estero and the relief of the area.

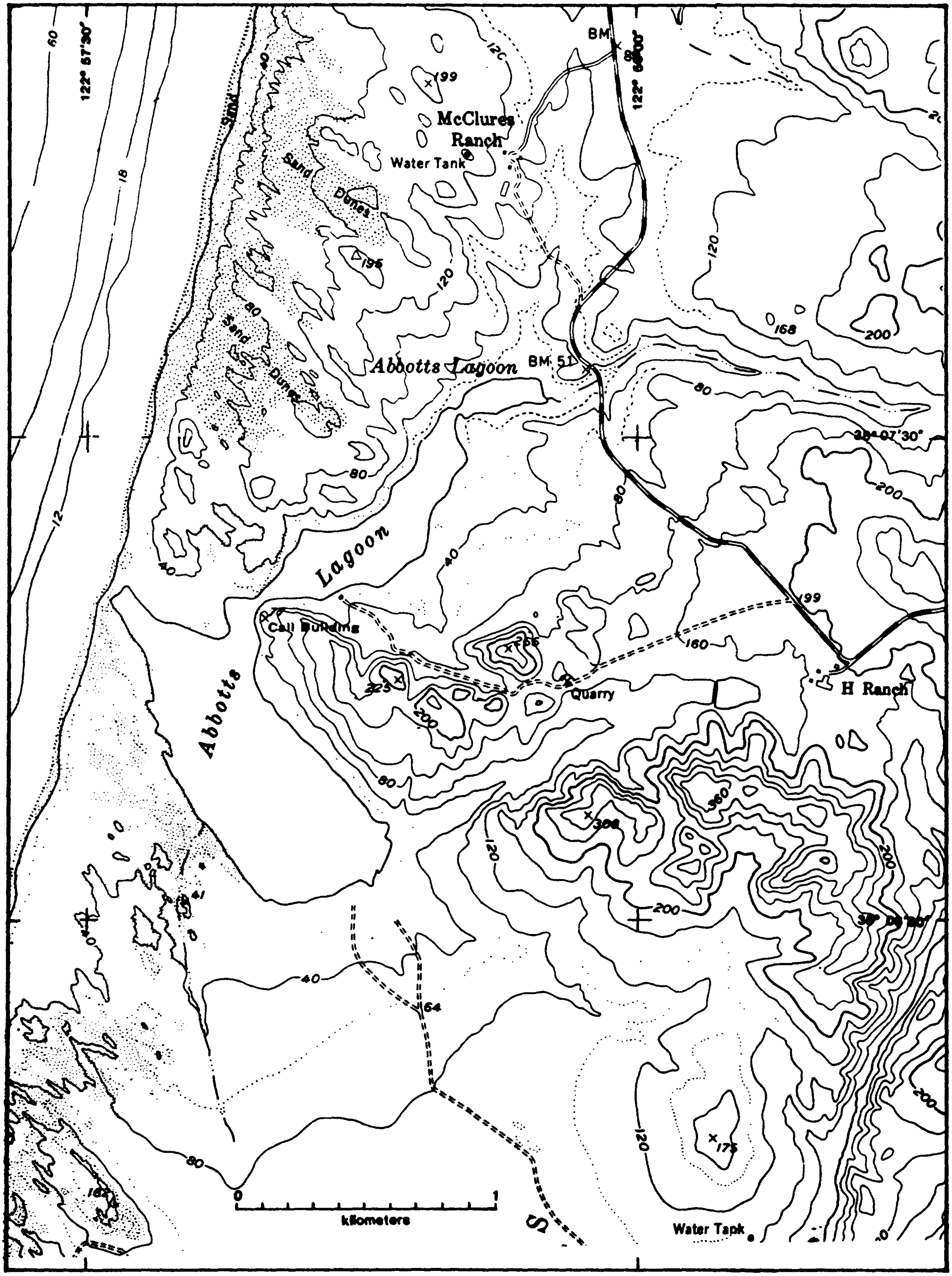


Figure 10. Topographic map of the area surrounding Abbotts Lagoon showing the two streams that flow into the lagoon and the topography of the area.

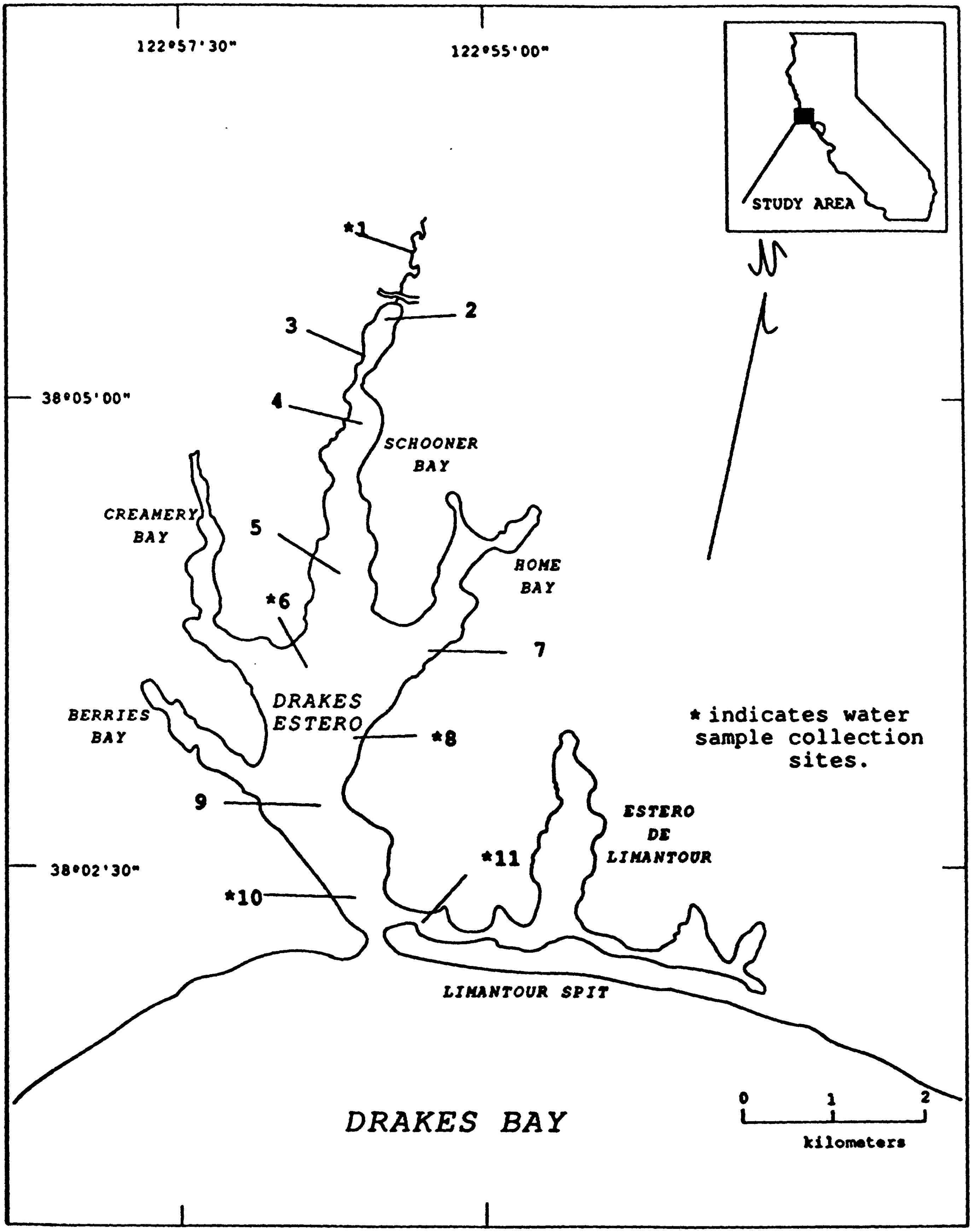


Figure 11. Map of sample locations used for salinity measurements in Drakes Estero.

Table 4. Salinity and Conductivity, measurements taken in Drakes Estero

Salinity, conductivity, and temperature measurements carried out on June 18,1987. Measurements were made during low tide and continued into the beginning of flood tide. Refer to map for sample and measurement stations. Five calibration water samples were also collected and measured in the laboratory using a Guildling Autosal model 8400A. The field measurements were made using a Beckman Electrodeless induction salinometer that measures salinity in $^{o}/_{oo}$, temperature in ^{o} C, and conductivity in milli-mhos / cm. Stations with (*) correspond to calibration water samples.

Corrected salinities were calibrated by performing linear regression analysis, forced through the origin, on the five calibration samples, which yielded; Field Salinity = 1.078 Lab Salinity. Therefore Corrected Salinity = Field Salinity/1.0784.

Laboratory calibration measurements:

Station	H_2O depth (m)	Salinity	Conductivity	Temp(°C)
1	0.0	33.670	.96626	
2	0.0	34.308	.98256	
3	0.0	34.356	.98379	
4	0.0	34.101	.97729	
5	0.0	33.969	.97394	

Field measurements:

Station	H_2O depth (m)	Salinity	Corrected Salinity	Conductivity	Temp(°C)
1*-1	0.0	36.1	33.5	46.8	18.0
2	0.0	38.9	36.1	48.7	16.6
2bott.	0.5	38.9	36.1	48.7	16.6
3	0.0	39.3	36.4	48.5	16.1
3bott	0.5	39.5	36.6	48.5	15.9
4	0.0	38.1	35.3	47.9	16.5
4bott	1.1	38.0	35.2	47.8	17.0
5	0.0	37.1	34.4	47.3	16.8
5bott	1.5	36.0	33.4	46.0	16.8
2*-6	0.0	36.7	34.0	46.2	16.3
6bott	1.0	36.8	34.1	46.0	16.2
7	0.0	36.8	34.1	45.2	15.3
7bott	1.5	34.8	32.3	42.8	15.2
3*-8	0.0	37.0	34.3	47.5	17.3
8bott	1.5	37.4	34.7	47.5	17.5
9	0.0	37.3	34.6	46.3	16.1
9bott	7 0	33.0	30.6	41.7	15.9
4*-10	0.0	37.0	34.3	45.4	15.3
10bott	6 0	37.1	34.4	45.0	14.8
5*-11	0.0	37.0	34.3	44.8	15.0
11bott	6 0	37.0	34.3	43.6	13.6

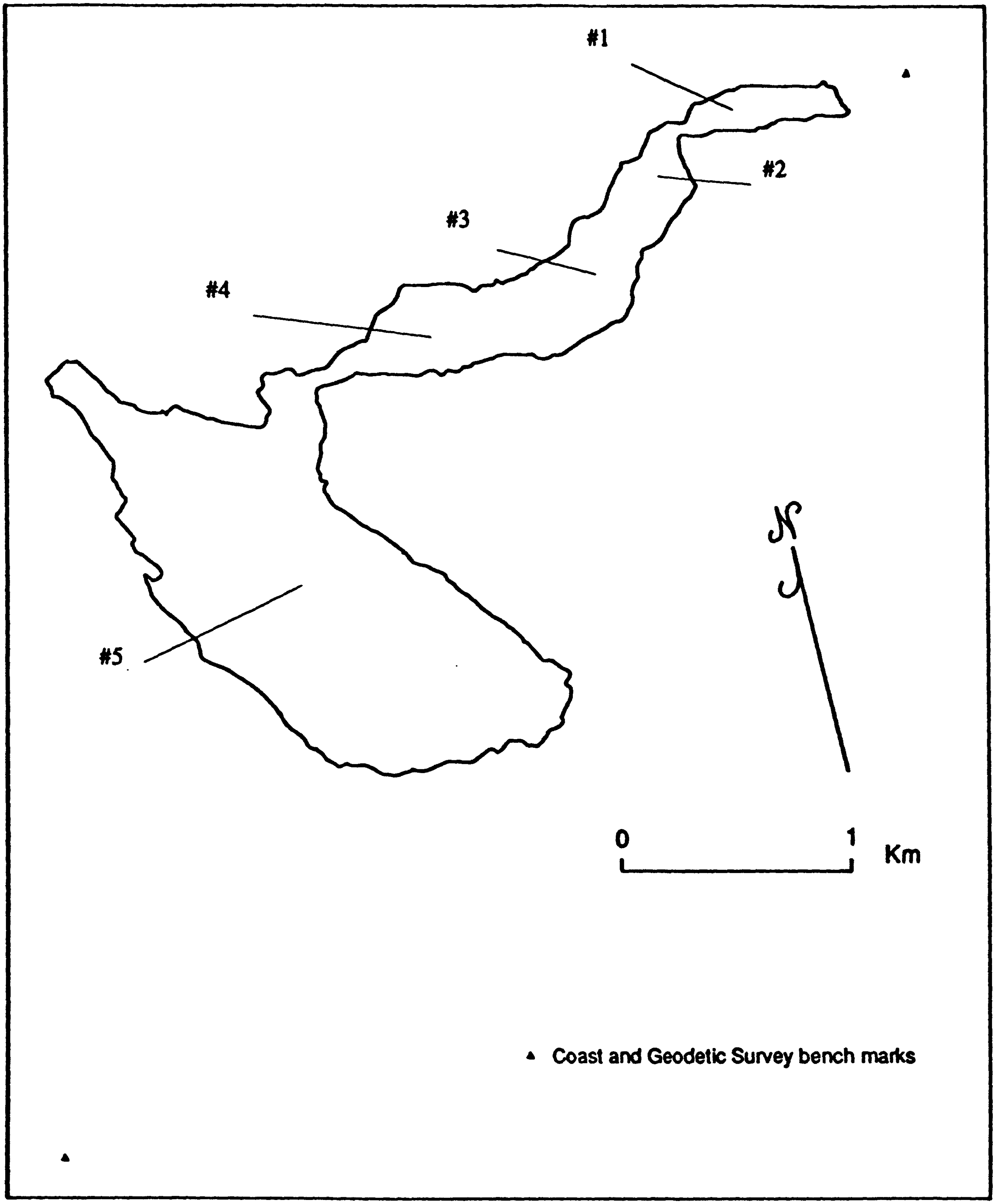


Figure 12. Map of sample locations used for salinity measurements in Abbotts Lagoon

Table 5. Salinity and Conductivity Measurements Taken in Abbotts Lagoon

Salinity, Conductivity, and temperature measurements carried out on June 24, 1987. All measurements were made in the field using a Beckman Electrodeless induction salinometer that measures salinity in $^{o}/_{ooo}$, temperature in ^{o}C, and conductivity in mill-ohms/cm. Locations of sampling stations on fig.

Station		Salinity	Conductivity
AL62487-1		6.317	.20973
	2	6.315	.20969
	3	6.316	.20971
	4	6.311	.20956
	5	6.309	.20949

Table 6. Salinity and Conductivity Measurements Abbotts Lagoon April

Sample site	Water temp (°C)	salinity	conductivity	H_2O Dep
Site 1	16.1	.40	.20	surfac
	15.8	.25	.26	2m
Site 2	16.4	.25	.48	surfac readin same a
Site 3	16.3	.27	.46	surfac
	16.0	.44	.58	<4m
Site 4	16.2	.36	.50	surfac
	15.3	.38	.75	5 m
Site 5	15.2	3.46	4.83	surfac
	15.8	3.41	4.80	10 m

were analyzed by rapid sediment analyzer, and hydrophotometer using standard laboratory techniques, (Thiede, 1976), and the results were plotted using statistical measures of Folk and Ward (1957) (Table 7).

The sediment distribution within each of the five bays and central portion of the Drakes Estero and Abbotts Lagoon have been characterized based on grain size analysis and diving observations.

a. Drakes Estero

Sediment in Drakes Estero ranges between medium grained sand to medium-fine silt, and varies slightly within each branching bay and the central estero area (fig. 13, Table 8). Medium- to fine-grained sand is found in the main tidal channels of Drakes Estero where the winnowing effects of the tidal currents transport out the fine-grained material leaving the coarser material. The entrance of the estero contains medium- to fine-grained well sorted sand. The sediment becomes siltier on the intertidal flats and in the upper ends of each bay. In the mid to upper parts of the branching bays, where silt becomes predominant, the tidal channels become less distinct to a point where mud makes up the tidal flats and the channels take on a meandering dendritic pattern and become very narrow and shallow. This is most obvious in Creamery Bay, Home Bay, and Estero de Limantour. In Schooner Bay the channel is somewhat artificial in that it has been

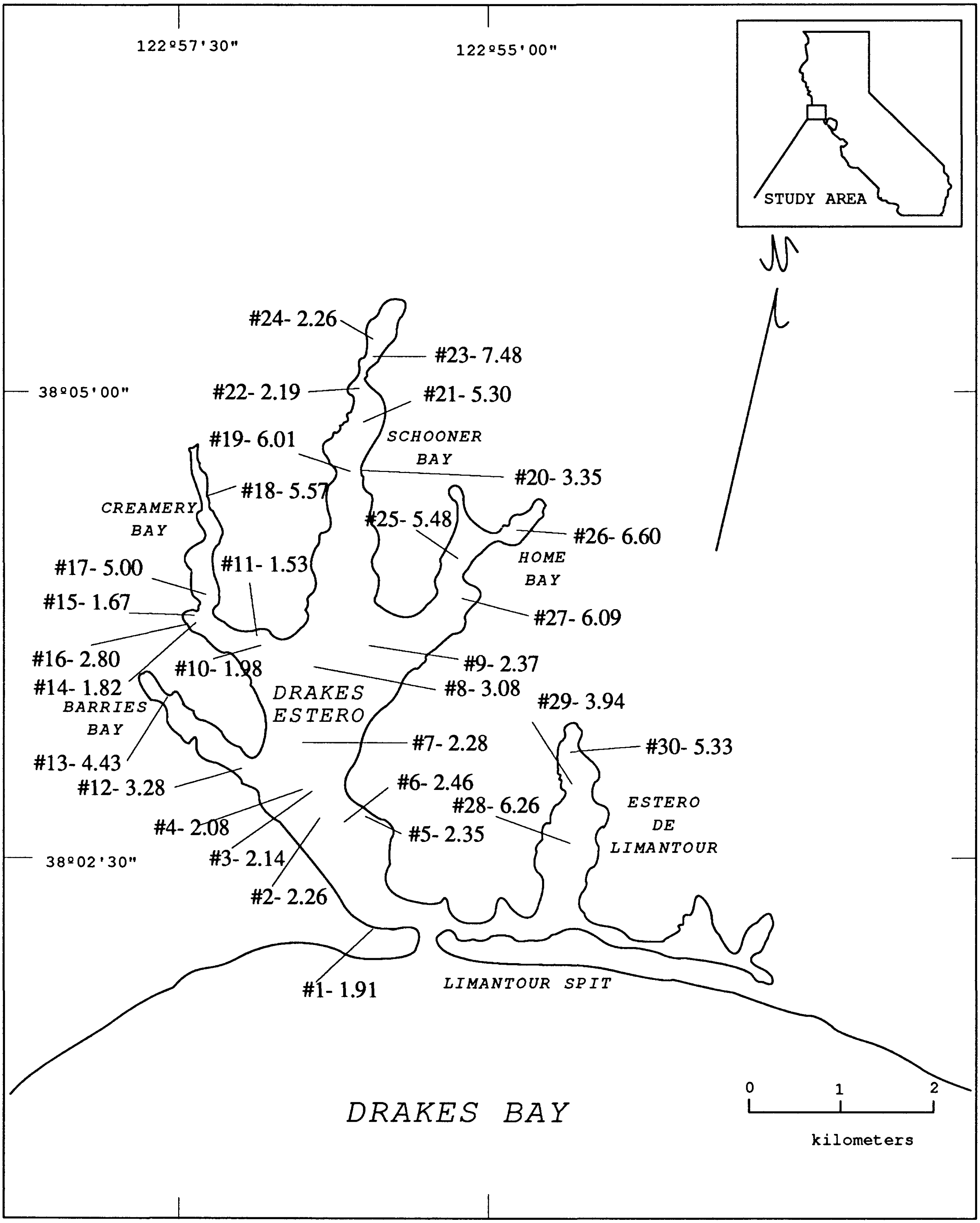


Figure 13. Map showing location of sample sites used for grain size analysis in Drakes Estero. Numbers match mapped number on Table 8, number following represents the mean grain size, in phi (ø).

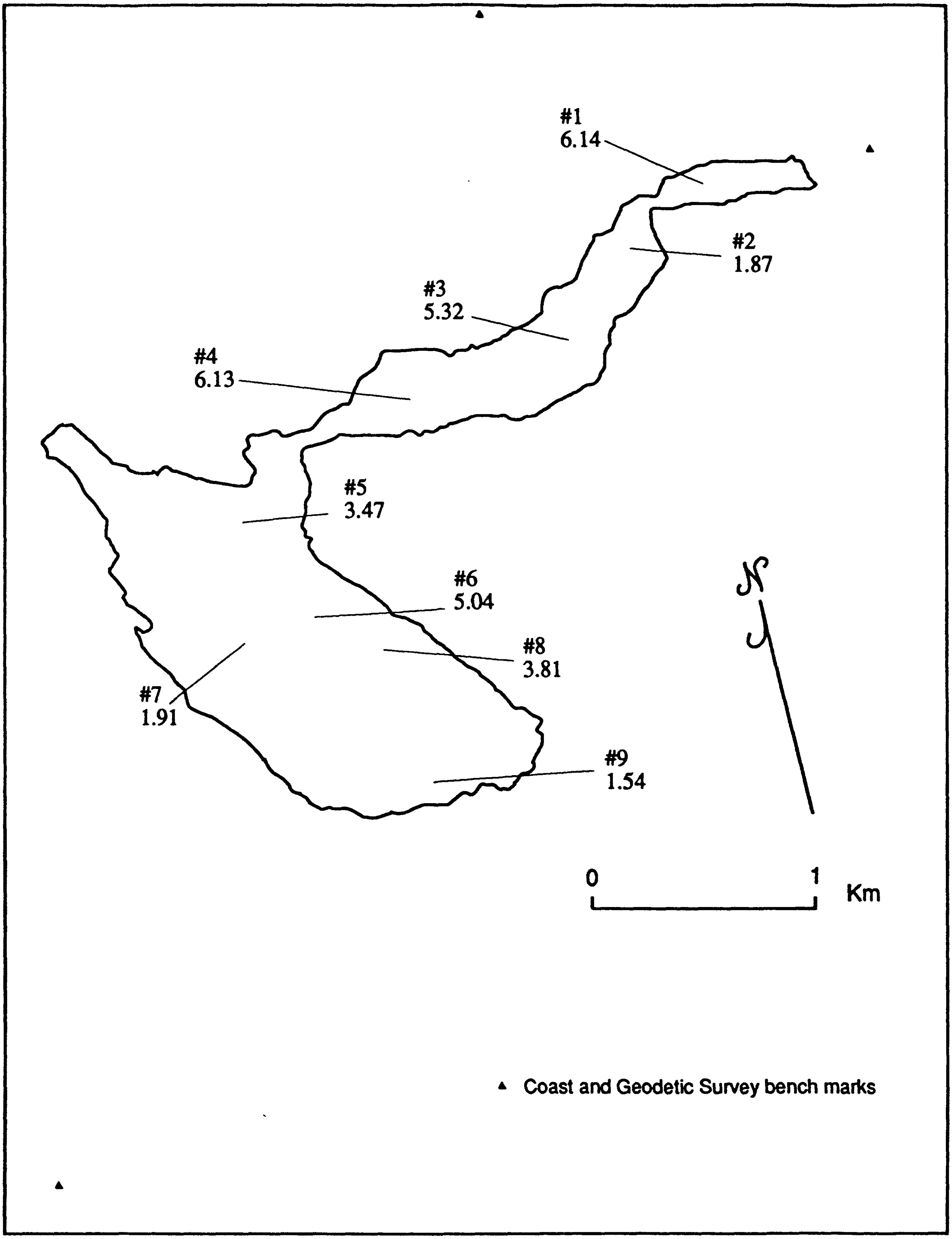


Figure 14. Map of grain size distribution in Abbotts Lagoon. First number corresponds to numbers on Table 9, second number is grain sizes in phi (ø).

Table 7.
Terminology and Phi size equivalents in milimeters

Milimeters	Phi (ø) units	Size class
4096	-12.00	
1024	-10.00	Boulder
256	-8.00	
64	-6.00	Cobble
16	-4.00	Pebble
4	-2.00	
3.36	-1.75	
2.83	-1.50	Granule
2.38	-1.25	
2.00	-1.00	
1.68	-0.75	
1.41	-0.50	Very coarse sand
1.19	-0.25	
1.00	0.0	
0.84	0.25	
0.71	0.50	Coarse sand
0.59	0.75	
0.50	1.0	
0.42	1.25	
0.35	1.50	Medium sand
0.30	1.75	
0.25	2.0	
0.210	2.25	
0.177	2.50	Fine sand
0.149	2.75	
0.125	3.0	
0.105	3.25	
0.088	3.50	Very fine sand
0.074	3.75	
0.0625	4.0	
0.053	4.25	
0.044	4.50	Coarse silt
0.037	4.75	
0.031	5.0	
0.0156	6.0	Medium silt
0.0078	7.0	Fine silt
0.0039	8.0	Very fine silt
0.0020	9.0	
0.00098	10.0	
0.00049	11.0	Clay
0.00024	12.0	
0.00012	13.0	
0.00006	14.0	

Table 8. Grain size analysis for samples collected in Drakes Estero

Sample								Ratios		Dist. fm	Mapped
Number	Median	Mean	Sorting	Skew.	Kurt.	sand/silt	silt/clay	sand/clay	sand/mud	Enterance	Number
DE070485-6	1.9	1.91	0.36	0.14	0.91	389.83	0.31	119.82	91.65	0.05	1
DE070485-4	2.4	2.26	0.41	0.43	0.98	249.24	2.33	580.74	174.39	1.7	2
DE070485-3	2.16	2.14	0.41	0.06	0.95	257.5	1.02	261.85	129.82	1.95	3
DE070485-1	2.11	2.08	0.55	0.05	1.1	51.58	2.16	114.00	35.98	1.96	4
DE070185-7	2.3	2.35	0.49	0.17	1.74	28.38	3.77	107.08	22.43	1.4	5
DE070185-6	2.49	2.46	0.37	0.03	1.4	193.86	1.05	204.5	99.5	1.5	6
DE082085-1	2.24	2.28	0.69	-0.35	12.42	670.8	0.67	447.18	268.31	2.4	7
DE063086-2	3.00	3.08	0.67	0.26	1.59	9.76	12.77	124.67	9.05	3.1	8
DE063086-3	2.71	2.37	1.04	-0.52	2.79	49.86	0.67	33.24	1.6	3.15	9
DE081885-4	1.94	1.98	1.07	0.36	2.59	19.51	1.88	36.71	12.74	3.55	10
DE081885-1b	1.54	1.53	0.58	0.18	1.65	40.63	2.83	115.15	30.03	3.55	11
DE081287-3	3.04	3.28	0.94	0.41	0.99	2.89	26.69	77.21	2.79	2.6	12
DE080887-1	4.31	4.43	1.51	0.16	1.33	0.92	10.7	9.86	0.84	3.75	13
DE081887-7	1.84	1.82	0.89	0.16	1.51	22.35	4.41	98.52	18.22	4.15	14
DE081885-5	1.67	1.67	0.49	0.05	0.99	151.07	1.46	220.86	89.71	4.16	15
DE071786-1	2.39	2.8	1.5	0.45	1.07	3.74	10.93	40.9	3.43	4.16	16
DE081187-1	4.64	5	1.74	0.34	1.04	0.79	6.54	5.16	0.68	4.3	17
DE071786-2	5.15	5.57	1.46	0.43	1	0.13	8.51	1.08	0.11	5.2	18

Table 8.(con't) Grain size analysis for samples collected in Drakes Estero

Sample Number	Median	Mean	Sorting	Skew.	Kurt.	Ratios sand/silt	silt/clay	sand/clay	sand/mud	Dist. fm Enterance	Mapped Number
DE72386-2	5.66	6.01	1.7	0.29	1.28	0.14	5.06	0.72	0.12	5.0	19
DE070385-5	3.34	3.35	0.5	0.01	2.21	24.39	2.75	67.084	17.89	5	20
DE072386-1	4.96	5.3	1.66	0.37	0.78	0.87	5.19	4.52	0.73	5.5	21
DE073185-9	2.1	2.19	1.07	0.41	2.52	16.27	2.31	38.32	11.59	5.85	22
DE073185-1	6.9	7.48	2.42	0.36	1.26	0.1	2.13	0.16	0.05	6.25	23
DE073185-5	2.11	2.26	1.88	0.37	1.76	11.28	1.35	15.26	6.48	6.4	24
DE080787-5	5.23	5.48	1.66	0.32	1.02	0.25	5.25	1.31	0.21	4.5	25
DE080787-4	6.22	6.6	2.14	0.19	1.67	0.17	3.17	0.55	0.13	4.45	26
DE081287-1	5.79	6.09	1.53	0.29	1.19	0.08	6.5	0.54	0.07	3.6	27
DE081287-2	5.95	6.26	1.75	0.26	1.42	0.13	4.88	0.65	0.11	1.9	28
DE080787-3	3.7	3.94	1.14	0.47	1.76	1.8	9.7	17.4	1.63	2.3	29
DE080687-1	5.29	5.33	2.09	0.13	0.86	0.78	3.4	2.63	0.6	2.55	30

scoured out by the constant boat traffic from the oyster operation.

Silt on intertidal flats along the margins of the estero is derived from the local bedrock, the Purisima Formation, which weathers into large blocks that further disintegrate under the influences of wind-driven waves and tidal currents. The finer suspended sediment is deposited on the intertidal areas where tidal current velocities are minimal . Finer sediment is also found adjacent to areas of dense vegetation where the vegetation baffles the effects of currents and allows for the deposition of the suspended sediment.

Sediment sorting decreases from well sorted in the tidal channels to poorly sorted toward the surrounding cliffs. Sediment is very well sorted along the channels and channel margins and becomes increasingly poorly sorted at the base of the cliffs where silt, sand, and pebbles to boulder size material is mixed. Sediment becomes more poorly sorted and grain size increases toward the small streams that flow into the estero, where coarser grained sediment is deposited on the proximal portion of the deltas that form at the mouths of the streams. At the mouth of Schooner Bay, Home Bay and Estero de Limantour, the source of the deposited material is a combination of underlying Monterey Formation and the granitic rocks found along Inverness Ridge. In the upper reaches of Barries Bay and Creamery Bay the sediment does not show the same pattern because the source material is a combination of fine grained aeolian sand, and the more friable silt portions of the Purisima Formation.

b. Abbotts Lagoon

Abbotts Lagoon has medium- to fine-grained sand along the west side of the lagoon adjacent to the open ocean. Along the north side of the lagoon, active sand dunes are migrating into the lagoon and depositing fine-grained sand (Table 9, fig.14). While diving we observed that this aeolian sand interfingers with fine silt and organic matter at the bottom of the lagoon. Along the seaward side of the lagoon, medium-grained sand was deposited as megaripples during the time the lagoon was open to sea. The megaripple structures are visible in the bathymetric profiles (Appendix A2), and were probably formed on sills (Clifton, et al., 1973) that formed inside the lagoon as it began to close after the 1982 break in the barrier. Bathymetry profiles show the steep face at the base of the barrier, then a more gentle rise with ridges toward the west . The steep topography of the west side of the lagoon diminishes toward the south where berm overwash processes are not the major depositional process but aeolian deposition is more pronounced (Appendix A2). The south end of the main arm of the lagoon is also composed of medium to fine sand deposited by aeolian and older berm overwash deposition. The stream that flows into the southern end of the Abbotts Lagoon carries silt and organic material into a small marsh along the southeast side of the lagoon. Both arms of Abbotts

Table 9. Grain size analysis for samples collected in Abbotts Lagoon

Sample Number	Median	Mean	Sorting	Skew.	Kurt.	Ratios sand / silt	silt / clay	sand / clay	sand / mud	Mapped Number
AL041789-1	5.8755	6.1387	2.0114	0.3001	0.8612	0.089	3.953	0.354	0.071	1
AL041789-2	1.8155	1.8722	0.7015	0.2629	1.3034	69.165	0.667	46.110	27.666	2
AL041789-3	4.4735	5.3205	1.4939	0.8265	0.9069	0.032	8.424	0.269	0.029	3
AL041789-4	5.7315	6.1273	1.9447	0.3935	0.9059	0.046	4.092	0.190	0.037	4
AL072487-1	2.1409	3.4750	2.2364	0.8496	1.1112	3.960	2.416	9.568	2.801	5
AL041789-5	5.4806	5.0388	2.7012	-0.1357	0.7894	0.731	3.560	2.603	0.571	6
AL041789-6	1.7028	1.9107	1.3788	0.5560	4.8682	9.659	3.021	29.178	7.257	7
AL073087-3	3.6040	3.8108	1.0947	0.4811	2.9796	3.588	4.967	17.819	2.987	8
AL081387-1	1.5046	1.5359	0.4267	0.0661	1.8261	607.591	0.667	405.086	243.046	9

Lagoon are located in well consolidated, resistant Monterey Formation, which, unlike the Purisima Formation does not contribute large amounts of fine grained sediment. Along the east shore of the main arm of the lagoon the shore line is composed of large blocks of Monterey Formation with very little silt and clay as a matrix. While diving, we noted that the east shore is composed of cobbles and some boulders in a pebble matrix. A green colored algae covers the surface of the sediment-water interface and changes with depth to a brown colored algae. Diving and coring was not conducted in the upper arm. Sediment sampling, water sampling, and bathymetric profiling were conducted.

Abbotts Lagoon contains fine-grained silt and clay material in the upper arm and at the bottom of the main arm. This fine grained material is deposited from the small streams that flow into the upper two lagoons and from organic material along the shore of these lagoons. The streams, aeolian processes and overwash probably provide the bulk of the sediment in Abbotts Lagoon.

Bar graphs and point plots illustrate the composition of sediment at various points within both Abbotts Lagoon and Drakes Estero. The plots illustrate how the sediment tends to decrease in size away from the entrance in the case of Drakes Estero (Appendix D). In Abbotts Lagoon the sediment changes from medium-grained silt in the upper arm to medium sand in the narrow connection between the two arms. The sudden increase in grain size within the lagoon can probably be attributed to erosion of bedrock exposed at the connections between the arms during periods of high stream flow when precipitation is highest. The main arm of the lagoon shows an increase in grain size adjacent to the west and south shores of the lagoon.

2. Herbicide Analysis

The method used in the determination of chlorophenoxy acid herbicides, and their esters and salts, in bottom material are detailed in Wershaw, R.L., et al. 1987. Chlorophenoxy acid herbicides and their esters are extracted with either diethyl or methyl t-butyl ether from an acidified slurry of bottom material. The extracted herbicides are hydrolyzed to the free acids, which are converted to their methyl esters with boron trifluoride-methanol and purified using adsorption chromatography. The methyl esters are determined by gas chromatography using electron-capture detectors.

The minimum detectable concentration of chlorophenoxy acid herbicide in these bottom materials was 0.10 μg/kg. Values of <1.0 μg/kg are reported (Table 10) and reflect the quality of the samples submitted having background material that inhibited the lower detection levels. The reported levels is still considered as being negligible in the samples analyzed, (Ralph White, U.S.Geological Survey Water Resources, personnel communication, 1990).

Results of the herbicide analysis indicate that the amounts of herbicides found in the cores collected in both

Drakes Estero and Abbotts Lagoon range between <0.1 to <1.0 μg/kg and are reported only at or slightly above the level of detection for 2,4-DP, 2,4,D, 2,4,-T, and Silvex. Table 10 show the results of the analysis and the location of the coring sites. Herbicide (2,4,D) residues have been found to persist for months in bottom muds of cold lakes or environments with a low oxygen content (U.S. Environmental Protection Agency, 1974); such environments, however, are dissimilar to that in Drakes Estero. A study conducted on eleven streams in the western United States were monitored for 2,4-D, 2,4,5-T, and Silvex, the study resulted in no herbicide residues found (Brown and Nishioka, 1967). The analyses indicate that the amount of herbicide introduced is not appreciable and that any herbicide introduced into Drakes Estero is not preserved because the estero is shallow and is constantly being flushed by tides and because the estero does not attain the low O^2 levels nor the low temperatures that would be conducive to the preservation of herbicides. The low levels found in the estero could also be due to relatively small amounts of herbicides introduced into the system. In Abbotts Lagoon, the bottom water conditions could serve to preserve herbicides because there is no tidal flushing like that in Drakes Estero. However, the amounts found in the analyses suggest that there is very little input by streams or runoff.

3. <u>Pesticide Analysis</u>

The method used for determination of organochloride and organophosphorous insecticides, PCB's, and PCN's are extracted from bottom material with acetone and hexane (Wershaw, R.L., et al. 1987). The organophosphorous insecticides are determined by gas chromatography using flamephotometric detectors. The extracts are then purified using adsorption chromatography on an alumina column. If PCB's, PCN's, and toxaphenes are present, the extracts are further purified using a silica gel column. The organochlorine compounds are determined by gas chromatography using electron-capture detectors.

The reporting of concentrations of organochlorine compounds and organophosphorous insecticides in bottom material with the exception of, chlordane, perthane, toxaphene, PCB's, PCN's and organophosphorous insecticides are limited to a detection limit of 0.1 µg/kg, and are reported as, less than 0.1 µg/kg. Values of 0.1 to 1.0 µg/kg, are reported to one significant figure (table 11).

Concentrations of chlordane, perthane, PCB's, and PCN's in bottom materials are limited to a detection limit of 1.0 µg/kg, and are reported as less than 1.0 µg/kg. Values of 1.0 µg/kg and above, are reported to two significant figures.

Concentrations of toxaphene in bottom materials are limited in detection to 10 µg/kg, and are reported as less than 10 µg/kg (Wershaw, R.L., et al., 1972) (table 11).

Results of the pesticide analysis indicate that all tested pesticide compounds were low or below the analytical cutoff points for the compounds tested, except for DDE which in Schooner, Estero de Limantour, Abbotts Lagoon, Barries Bay, and Creamery Bay, did show concentrations between 0.1 to 2.1 μg/kg (Table 11). Although the amounts of traceable DDE fluctuated somewhat in those sample localities, the amount reported are low. The results can be compared to the National Academy of Sciences National Academy of Engineering (1973) recommended safe level of 1,000 μg/kg ΣDDT (the sum of DDD, DDE, and DDT) wet weight for the protection of fish-eating wildlife. Also the U.S. Environmental Protection Agency (1980) based ambient water-quality criteria for protection of aquatic life at an

Table 10. Results of Herbicide Analysis µg/kg

Station ID	2, 4-DP µg/kg	2,4,D µg/kg	2,4,-T µg/kg	Silvex µg/kg
AL071787-2	<1.0	<1.0	<1.0	<1.0
AL072487-1	<1.0	<1.0	<1.0	<1.0
AL073087-2	<0.1	<0.1	<0.1	<0.1
DE080687-1	<0.1	<0.1	<0.1	<0.1
DE080787-4	<1.0	<1.0	<1.0	<1.0
DE081087-1	<1.0	<1.0	<1.0	<1.0
DE081087-3	<1.0	<1.0	<1.0	<1.0

Table 11a. Pesticide Analysis

Location: Barries Bay

Station ID: DE080887-1	**Results** µg/kg
Gross PCN #	<1.
ALDRIN, BTM. MAT.	<0.1
LINDANE,	<0.1
CHLORDANE,	<1.
DDD	<1.0
DDE	0.1
DDT	<0.1
DIELDRIN	<0.1
ENDOSULFAN	<0.1
ENDRIN	<0.1
TOXAPHENE	<10.
HEPTACHLOR	<0.1
HEPT EPOX	<0.1
METHOXYCHLOR	<0.1
Gross PCB @	<1.
MIREX	<0.1
PERTHANE	<1.

Location: Creameary Bay

Station ID: DE081187-1	**Results** µg/kg
Gross PCN #	<1.
ALDRIN, BTM. MAT.	<0.1
LINDANE,	<0.1
CHLORDANE,	<1.
DDD	<0.1
DDE	0.2
DDT	<0.1
DIELDRIN	<0.1
ENDOSULFAN	<0.1
ENDRIN	<0.1
TOXAPHENE	<10.
HEPTACHLOR	<0.1
HEPT EPOX	<0.1
METHOXYCHLOR	<0.1
GROSS PCB @	<1.
MIREX	<0.1
PERTHANE	<1.

@ - Polychlorinated biphenyls
# - Polychlorinated naphthalenes

Table 11b. Pesticide Analysis

Location: Schooner Bay, north

Station ID: DE081087-3	**Results** µg/kg
Gross PCN #	<1.
ALDRIN, BTM. MAT.	<0.1
LINDANE,	<0.1
CHLORDANE,	<1.
DDD	<0.1
DDE	0.2
DDT	<0.1
DIELDRIN	<0.1
ENDOSULFAN	<0.1
ENDRIN	<0.1
TOXAPHENE	<10.
HEPTACHLOR	<0.1
HEPT EPOX	<0.1
METHOXYCHLOR	<0.1
Gross PCB @	<1.
MIREX	<0.1
PERTHANE	<1.

Location: Home Bay

Station ID: DE080787-4	**Results** µg/kg
Gross PCN #	<1.
ALDRIN, BTM. MAT.	<0.1
LINDANE,	<0.1
CHLORDANE,	<1.
DDD	<0.1
DDE	<0.1
DDT	<0.1
DIELDRIN	<0.1
ENDOSULFAN	<0.1
ENDRIN	<0.1
TOXAPHENE	<10.
HEPTACHLOR	<0.1
HEPT EPOX	<0.1
METHOXYCHLOR	<0.1
Gross PCB @	<1.
MIREX	<0.1
PERTHANE	<1.

@ - Polychlorinated biphenyls
# - Polychlorinated naphthalenes

Table 11c. Pesticide Analysis

Location: Estero de Limantour

Station ID: DE080687-1	**Results** µg/kg
Gross PCN #	<1.
ALDRIN, BTM. MAT.	<0.1
LINDANE,	<0.1
CHLORDANE,	<1.
DDD	<0.1
DDE	0.2
DDT	<0.1
DIELDRIN	<0.1
ENDOSULFAN	<0.1
ENDRIN	<0.1
TOXAPHENE	<10.
HEPTACHLOR	<0.1
HEPT EPOX	<0.1
METHOXYCHLOR	<0.1
Gross PCB @	<1.
MIREX	<0.1
PERTHANE	<1.

Location: Abbotts Lagoon, Mid lagoon

Station ID: AL073087-2	**Results** µg/kg
Gross PCN #	<1.
ALDRIN, BTM. MAT.	<0.1
LINDANE,	<0.1
CHLORDANE,	<1.
DDD	<0.1
DDE	0.9
DDT	<0.1
DIELDRIN	<0.1
ENDOSULFAN	<0.1
ENDRIN	<0.1
TOXAPHENE	<10.
HEPTACHLOR	<0.1
HEPT EPOX	<0.1
METHOXYCHLOR	<0.1
Gross PCB @	<1.
MIREX	<0.1
PERTHANE	<1.

@ - Polychlorinated biphenyls
# - Polychlorinated naphthalenes

Table 11d. Pesticide Analysis

Location: Abbotts Lagoon, North

Station ID: AL072487-1	**Results** μg/kg
Gross PCN #	<1.
ALDRIN, BTM. MAT.	<0.1
LINDANE,	<0.1
CHLORDANE,	<1.
DDD	<0.1
DDE	2.1
DDT	<0.1
DIELDRIN	<0.1
ENDOSULFAN	<0.1
ENDRIN	<0.1
TOXAPHENE	<10.
HEPTACHLOR	<0.1
HEPT EPOX	<0.1
METHOXYCHLOR	<0.1
Gross PCB @	<1.
MIREX	<0.1
PERTHANE	<1.

@ - Polychlorinated biphenyls
# - Polychlorinated naphthalenes

estimated safe tissue concentration of 150 μg/kg ΣDDT wet weight in fish. The results of the pesticide analysis show that the levels of traceable DDE in the sediment analyzed are below the limits set by the National Academy of Sciences and the U.S. Environmental Protection Agency for organisms. Another study conducted by Gilliom and Clifton (1989) using 66 samples from various sites along the San Joaquin River report concentrations for the majority of their samples at many orders of magnitude above what is reported in this study. In their study they used sediment as the analytical medium, and submitted their samples to the same analytical laboratory that ran the analysis for this report.

4. Sedimentation Rates

Sedimentation rates can be determined using various dating techniques. By using information about the depth of the sample below the sediment surface coupled with an age using one of the accepted dating techniques, or comparing differences in water depth over repeated bathymetric surveys, workers have calculated sedimentation rates for various coastal settings. Rowntree, (1973) discusses the variations and errors between the techniques that must be considered in using sedimentation rates, and points out problems in the numbers presented by various workers.

Table 12 shows some consistency in the majority of rates given for long term deposition that range from 3 to 70 cm/100 yrs. The dating method used for the long term deposition rates are the same with the exception of the work of Gorsline and Stewart, 1962, and Schwartz, 1983, but the sedimentation rates arrived at by these workers are similar to the other studies. The inconsistencies in the dates could be attributed to the location of the sample in the study area or to the difference in sediment input into each of the study areas. Table 13 gives short-term sedimentation rates calculated using various methods in other estuaries and lagoons along the west coast of North America and in other parts of the world. As the table indicates, the different methods used adds variation to the overall trend of the combined sedimentation rates. There are extremely high sedimentation rates reported by Warme (1971), Shepard (1953), and Schwartz (1983), but as pointed out by Rowntree (1973), the sampling methods used, the variables used in the calculations, and the depositional environments sampled varied for the three studies.

A recent study conducted by Mudie (1984) used palynology from two samples collected 0.50 meters below the sediment surface in a salt marsh area adjacent to Estero de Limantour. Based on radiocarbon dating from the base of the core, an average sedimentation rate of the whole section was suggested at 10.0 cm/100 years. The study then looked at the first appearance of two pollen types, *Rumex acetosella* (first introduced into California in the period 1825-1848) at 35 cm, and *Plantago lanceolata* (first introduced into California around the 1850's) at 15 cm, and calculated an average rate of accumulation of 50 cm/100 years from the time of first appearance of the two pollen types to 1974. The paper attributes the interval of rapid sedimentation to the establishment of cattle ranches in the area which reflects the accelerated erosion following overgrazing (Mudie, 1984). During the time since 1860 sedimentation has probably dropped to about 15 cm/100 years (Mudie, 1984)

Sedimentation rates presented here for Drakes Estero and Abbotts Lagoon were calculated by dividing the depth within the core sample from which sediment was dated, by the age the dated sediment. The sedimentation rates determined for Drakes Estero and Abbotts Lagoon are based on nine cores sub-sampled for C^{14} dating, and 18 cores sub-sampled for Pb^{210} analysis. The results suggest average sedimentation rates higher than the rates reported by Mudie (1984), with the number of samples and the more depositional settings sampled by this study accounting for the wider range of sedimentation rates. This study did, however, calculate sedimentation rates similar to Mudie's for C^{14} analysis, and higher for the more recent ages using Pb^{210}.

Another method used in Drakes Estero, that will be discussed later, measured the depth of sediment cover over the pre-transgressive valley floor as determined by the interpretation of the geophysical records. The depth of sediment cover was divided by the estimated inception of the marine transgression, which gave a longer range sedimentation rate than determined by C^{14} and Pb^{210} analyses.

Table 12. Long term deposition rates in estuaries

Worker	Location	Method	Sedimentation Rate cm/100 yrs
Redfield, 1967	Barnstable Marsh, MA.	C^{14}	19.2
Rusnak, 1960	Laguna Madre, TX.		10.1
Gorsline & Stewart, 1962	Bahia de San Quintin, Baja California, Mexico	Geomorphic analysis	33.5
Anima, (this study)	Drakes Estero, CA	C^{14}	1.3 - 43.7
Anima, (this study)	Abbotts Lagoon, CA	C^{14}	3.8
Darienzo, 1987	Netarts Bay, OR	C^{14}	10.8
Mudie, 1980	Drakes Estero, CA	radiocarbon	8.8 - 10.1
	Elkhorn Slough, CA	radiocarbon	5.1 - 8.1
	Del Mar Lagoon, CA	radiocarbon	3.8 - 4.2
	Mission Bay, CA	radiocarbon	12.1 - 12.8
	Tiajuana Lagoon	radiocarbon	9.0 - 10.1
	Los Penasquitos, CA	radiocarbon	9.4 - 9.5
Schwartz, 1983	Elkhorn Slough, CA	Amino acid and C^{14}	11-28
Peterson, 1983	Netarts Bay, OR	C^{14}	21.0 33.5 40-70

Table 13. Short term deposition rates in estuarie

Worker	Location	Method	Sedimentatior Rate cm/100
Schou, 1967, p. 137-138 using data from Nielsen, 1935	Danish Marshes (Skallingen)	accretion above layers of colored sand	19.8
Shepard, 1953	Bays of central Texas Coast	comparison of hydrographic surveys 1875-1935	91.4
Stevenson,& Emery, (1958)	Newport Bay, CA	Depth of estuarine sediments--recent change in depositional environment	45.7
Schwartz, 1983	Elkhorn Slough, CA	Amino acid and C^{14}	11-150
Warme (1971)	Mugu Lagoon, CA	extrapolation from depth of undated shells in sediments	76.2
Thompson, (1971)	Humboldt Bay, CA	2.75 years of monitoring of vertical accretion; interpretation of historical surveys, dredging data	30.5
Mudie, 1980	Drakes Estero, CA	pollen	5.0
	Mission Bay, CA	pollen	11.2
	Los Penasquitos, CA	pollen	8.2
Anima, (this study)	Drakes Estero, CA	PB^{210}	9 - 60
Anima, (this study)	Abbotts Lagoon, CA	PB^{210}	8 - 19

a. Carbon^{14} Dating;

Carbon^{14} provides a determination of the age of organic matter in the sediment. The practical range of radiocarbon dating is from 200 to 35,000 years Before Present (BP). Hogg (1982), and Terasmae (1985), present excellent discussions of the theory and basic principles of the C^{14} method. Carbon^{14} analysis was done on wood fragments collected from five vibracores collected in Drakes Estero, and one core from Abbotts Lagoon. The cores were carefully examined after being split in the laboratory and any wood fragments were noted and the distance from the top of the core measured before removal from the core. The data reflect the possibility that the wood fragments extracted could be detrital wood and therefore older than sediment they were removed from. The lack of large wood fragments suggests that most of the material found, although detrital, would reflect the age of the sediment layer they were extracted from. Small fragments of wood disintegrate faster than larger fragments, thus if all the fragments are small the C^{14} dates probably reflect the sediment age. Larger fragments, in contrast, decay slower and would be older than the sediment. Table 14, list the samples used and the dates calculated.

The C^{14} data presented on Table 14 can be used to estimate average sedimentation rates over the length of single cores collected from various parts of the study area. Normally 50 grams of sample are required to run C^{14} analysis, but because the amount of organic matter found in some of the cores was so low, an accelerator facility was used which can attain dates from smaller samples. Samples from a core collected in upper Barries Bay, DE080887-1, at .35 m, and .70 m below the top of the core do not coincide with the depth age pattern seen in the other cores; the same is true in a core collected in Creamery Bay, DE081187-1, from .65 m and 1.55 m below the the top of the core. This inconsistency could be attributed to the small sample size submitted for analysis giving unreliable dates, or simply that the dated material might have been eroded from an older stratigraphic layer and redeposited higher in the stratigraphic column. The results suggest an average sedimentation rate for Drakes Estero of 12 cm/100 years. If the samples with the inconsistent dates collected in Creamery and Barries Bay are excluded and considered anomalous, the average sedimentation drops to 9.1 cm/100 years. In either case the average sedimentation rates are low compared to the results of the Pb^{210} analysis.

The absence of wood or plant fragments in the cores collected from the central portions of Drakes Estero precluded age dating for this part of the system.

The sedimentation rate for the upper 112 cm in Abbotts Lagoon was calculated to be 3.8 cm/100 yrs, based on a sample size of 1.51 mg for the C^{14} dates.

b. Pb^{210} Analysis

The Pb^{210} method of determining sedimentation rates is based on the occurrence of excess radioactive lead, Pb^{210}, a member of the $Uranium^{238}$ decay series. $Radon^{222}$ which has a half life of 3.8 days (Lederer and others, 1968), diffuses from the soil into the atmosphere and remains chemically inert until it decays through four short-lived nuclides, (Po^{218}, Pb^{214}, Bi^{214},Po^{214}) to Pb^{210}. This isotope is rapidly removed from the atmosphere into the hydrosphere by rain, snow, and dry fallout and provides a measurable flux to the land and waters of approximately 0.5 to 1.0 dpm (disintegrations per minute) $Pb^{210}/cm^2/yr$ depending on the latitude and distance from continental land masses (Benninger, 1976, Carpenter and others, 1982). Pb^{210} is also supplied to the hydrosphere by stream runoff and decay of Ra^{226} in the water column, but these sources are insignificant when compared with the atmospheric source (Benninger, 1976). There seems to be no significant formation of Pb^{210} as a result of nuclear detonations (Beasley, 1969). From the water column, it is rapidly removed to the bottom sediments. Several mechanisms have been proposed for the removal of Pb^{210} from the hydrosphere, including adsorption on particulate clays or organic matter and coprecipitation with Fe and Mn oxides. The chemical behavior of lead makes it immobile in the sediments. Pb^{210}, which has a half life of 22.26 years (Höhndorf, 1969), undergoes beta decay to Bi^{210} in the sediment column. This

Table 14. Carbon ^{14} Analysis of Core material

Sample Number	Location	Smpl. Wt. (mg)	Core Depth (m)	Age Determination	± yrs.	Sedimentation Rate cm/ 100 yrs
AL081387-1	Abbotts Lagoon	1.51	1.12	2,920	±45	3.8
DE072386-1	Schooner Bay	1.26	1.00	1,760	±45	5.7
DE072386-1	Schooner Bay	1.93	1.60	2,490	±45	6.4
DE080787-2	Estero de Limantour	1.45	1.51	1,290	±45	11.7
DE080887-1	Berries Bay	1.89	1.32	1,440	±40	9.2
DE080887-1	Berries Bay	0.52	.35	2,780	±70.	1.3
DE080887-1	Berries Bay	2.33	.70	560	±40	12.5
DE081187-1	Creamery Bay	0.31	.65	1,110	±60	5.9
DE081187-1	Creamery Bay	.56	1.55	355	±50	43.7
DE080588-2	Home Bay Mouth	1.73	5.5 H_2O*	95	±40	--

Average sediment accumulation rate for Drakes Estero is 12.05 cm/100 yrs.
Sediment accumulation rate for Abbotts Lagoon is 3.8 cm/100 yrs.

* This sample was collected at a water depth of 5.5 m in an submarine outcrop that is 3 m thick underlying a silty/sand with eel grass (*Zostra marina*) bed. The exposure is located along the erosional bank of the NE margin of the main tidal channel. This sample is probably younger than the outcrop and should be considered erroneous until more dates can be aquired from the same area.

daughter product undergoes another decay to Po^{210}, which has a half life of 138.4 days (Leder and others, 1968), and alpha decays to stable Pb^{206} ((Martin and Rice, 1981). Three general assumptions must be met when using the dating method: 1.) the Pb^{210} flux to the sediments has been constant during the time interval of the dating range. This is called the inheritance assumption. 2.) There has been negligible migration of Pb^{210} in the sedimentary column after deposition. This is called the closed-system assumption. 3.) The sedimentation rate has been constant during the period of time to be determined (Martin and Rice, 1981).

The method used in this study to measure Pb^{210} activity was alpha counting. The method involves measurement of Po^{210} activity (Robbins and Edgington, 1975; Flynn, 1968; Millard, 1963; Nozaki and Tsunogai, 1973). If Pb^{210} and Po^{210} are in secular equilibrium, which has been shown to exist in some sediments (Benninger, 1976; Nittrouer and others, 1979), the alpha decay of Po^{210} can be used to measure the Pb^{210} activity of both the Pb^{210} produced by the decay of Ra^{226} in the sediment column (supported Pb^{210}) and the Pb^{210} added from external sources (excess Pb^{210}). In recently deposited sediments that contain large amounts of organic matter, the Po^{210}/Pb^{210} activity may be >1.0. This disequilibrium can be verified by analyzing the ingrowth of Pb^{210} 6 months after the original analysis and comparing the second activity with the initial activity. A calibrated Po^{208} spike is used to calculate the activity of the Pb^{210} activities (Martin, and Rice,1981).

The 22.3 yr half-life of Pb^{210} allows the analytical technique to examine sedimentary events back 100-150 yr. Pb^{210} has been used in obtaining sedimentation rates in a number of depositional settings. Nittrouer et al., (1979) used Pb^{210} on the Washington continental shelf to work out the geochronology of the sediments. Koide et al. (1972) similarly obtained geochronologies from shelf sediments off the Santa Barbara coast, and Van der Wijk and Mook (1987) used Pb^{210} to obtain chronologies used in lake acidification studies. Paez-Osuna, and Mandelli (1985) measured seasonal depositional processes from a core taken in Laguna Mitla, a Mexican coastal lagoon. Armentano and Woodwell (1975) utilized the process in the study of sedimentation rates from a Long Island salt marsh. El-Daoushy (1986) dated Scandinavian aquatic and peat deposits using Pb^{210}. Benninger et al. (1975) used Pb^{210} as a tracer in a river-estuarine system. Martin and Rice (1981) give an excellent overview of laboratory analysis procedures.

Sedimentation rates were calculated from Pb^{210} analysis of sediment sub-samples collected from vibracores. The method requires fine grained sediment with little to no sand content to obtain optimum results. This requirement did not allow for dating of sediment in the central portion, the mouth or in the main channels of the estero. Sub-sampling of the vibracores was carried out using a scheme suggested by

Dr. C. Nittrouer of the State University of New York, Stoney Brook, who conducted the analysis. The core was measured and all the material between prescribed intervals was sub-sampled. Sampling intervals were at: 0-1 cm, 3-4 cm, 6-7 cm, 9-10 cm, 13-14 cm, 17-18 cm, 21-22 cm, 26-27 cm, 31-32 cm, 36-37 cm, 41-42 cm, 46-47 cm, then every 10 cm there after to 1 meter. The sampling scheme is based on the theory that Pb^{210} is only traceable within the upper 1 meter of the core, and that the first 50 cm is the most important portion of the sedimentary column (Nittrouer, 1989 personal communication). Unless the area is undergoing very rapid sedimentation, the upper meter should contain the last 150 to 200 yrs, which is the useful limit of Pb^{210} dating. Sub-sample size was between 20-50 gms of sediment. The sub-samples were refrigerated after collection.

The average sedimentation rate based on Pb^{210} for the 18 cores is 30.5 cm/100 years, which is slightly more than half that reported by Mudie (50 cm/100 years)(1984). The results of the Pb^{210} analysis (Table 15) show that there is some uncertainty in the sedimentation rates calculated. The uncertainty comes from the high amount of bioturbation throughout the estero. The sedimentation rates presented on Table 15, although higher than the sedimentation presented by Mudie 1984, are similar to results of other workers using the same dating method (Table 16). Careful study of Pb^{210} data suggest that systematic variations in sedimentation rate occur within the estero. Overall the sedimentation rates in each of the bays where multiple cores were analyzed show a decrease in sedimentation rate down the bay. Based on Pb^{210} dates, sediment is being deposited at a higher rate in the upper part of the bays near the source of sediment supply. Cores from similar environmental settings that have comparable biological activity give good agreement, i.e., DE080687-1, DE080787-2 & 5, DE080887-1 & 3. Although the high bioturbation rate in most of Drakes Estero does add some degree of uncertainty,

Table 15. Results of PB^{210} Analysis
Drakes Estero & Abbotts Lagoon

Sample Number	Sample site	Sediment Accumulation Rate (cm/100 yrs
DE080887-1	Upper Berries Bay	23
DE080887-3 *	Lower-mid Berries Bay	9.0
DE081287-3	Lower Berries Bay	<10
DE081187-1*	Creamery Bay	29
DE081087-1#	Across from Oyster Co.	very rapid sed rate or active mixing
DE081887-2#	First bend from Oyster Co.	rapid deposition or active mixing
DE081087-3	Upper Schooner Bay	46
DE080787-4#	Home Bay NE of bridge	rapid deposition or active mixing
DE080787-5	Upper Home Bay	27 (excellent profile)
DE081287-1	Lower Home Bay	32
DE080687-1	Upper Estero de Limantour	53
DE080787-2	Upper Estero de Limantour East	25
DE080787-3*	Upper Estero de Limantour West	20
DE081287-2	Lower-mid Estero de Limantour	60
AL072487-1*	North Abbotts Lagoon	8.0
AL072887-1		more samples needed
AL073087-2	Mid Abbotts Lagoon	19
AL073087-3		deeper samples needed

Average sediment accumulation rate for Drakes Estero is 30.5 cm/100 yrs.
Average sediment accumulation rate for Abbotts Lagoon is 13.5 cm/100yrs.
- either rapid deposition of the upper 50 cm of the core or active mixing by benthic organisms causing erratic profiles, resulting in unclear interpretations.
* - very high uncertainty resulting from biological mixing

Table 16. Comparison of Pb^{210} studies in North America (modified from Grootes, 1983)

Worker	Location	Sedimentation Rat cm/100 yrs
Koide et al., 1972	Santa Barbara, CA	39.0
Koide et al., 1973	Baja California	27.0
Bruland et al., 1974	Coast Southern California	7.0 - 9.0
Armentano and Woodwell, 1975	Salt marsh, Long Island	47.0 - 63.0
Smith and Walton, 1980	Saguenay Fjord	10.0 - 70.0
Anima, (this study)	Drakes Estero, CA	9.0 - 60
Anima, (this study)	Abbotts Lagoon, CA	8.0 - 19.0

the consistency of the sedimentation rates calculated throughout the estero system should be considered as a good approximation of true ages. The oldest date calculated was 122 yrs. before present (B.P.) from a core collected in upper Home Bay; the sedimentation rate calculated (27 cm/100 yrs.) reflects the proximity of the core to a source of sediment. Analyses conducted on cores collected at the uppermost reaches of the bays show higher sedimentation rates than cores from the middle areas of the bays. Estero de Limantour reflects this most graphically; at the upper reaches of the estero the sedimentation rate reached 53 cm/100 yrs. in an area downstream from the creek that flows into it. The sedimentation rate decreases down the estero (25 cm/100 yrs., 20 cm/100 yrs.) to the point where open ocean processes increase the sedimentation rate (60 cm/100 yrs.) by berm overwash and tidal input of sediment. Table 15 shows that upper bay samples indicate slightly higher sedimentation rates than do the lower to mid bay samples; this is due to proximity of the sample sites to one of the streams that flow into the bay.

Samples analyzed from Abbotts Lagoon show a sedimentation pattern similar to that of Drakes Estero. A core collected from the north part of the main arm of Abbotts Lagoon shows a sedimentation rate of 8.0 cm/100 yrs., similar to the rate attained from a sample collected in mid-Barries Bay, 9.0 cm/100 yrs. neither area is undergoing rapid sedimentation. Samples collected in mid Abbotts Lagoon, however, indicate a higher sedimentation rate, 19 cm/100 yrs., which resemble that of a sample collected in upper Barries Bay, 23 cm/100 yrs. this again is probably a reflection of the proximity of the sample sites to a stream mouth.

5. Geophysical Profiles

The geophysical records collected give a subbottom profile of depth of sediment filling the pre-marine transgression valley. The record was used to determine the long-term rate of sediment filling and the depth of sediment cover over the underlying bedrock, in this case Purisima Formation. Interpretation of the geophysical records collected support the findings of McCulloch (1984) that the buried subbottom channels he found in Drakes Bay extend onshore and align with topographic features of Drakes Estero, Estero de Limantour, Horseshoe Pond (which lies to the west of the mouth of Drakes Estero), and the valley where the Drakes Beach Visitor Information Center is located (fig. 15).

The records collected in Drakes Estero are somewhat discontinuous because of numerous groundings due to the shallow depths. Nonetheless subbottom features inside the estero suggest a large buried valley with smaller buried channels that aligns with one of the buried channels suggested by McCulloch in the offshore area adjacent to Drakes Estero. Many of the subbottom features found in Drakes Estero align with small valleys and the branching bays

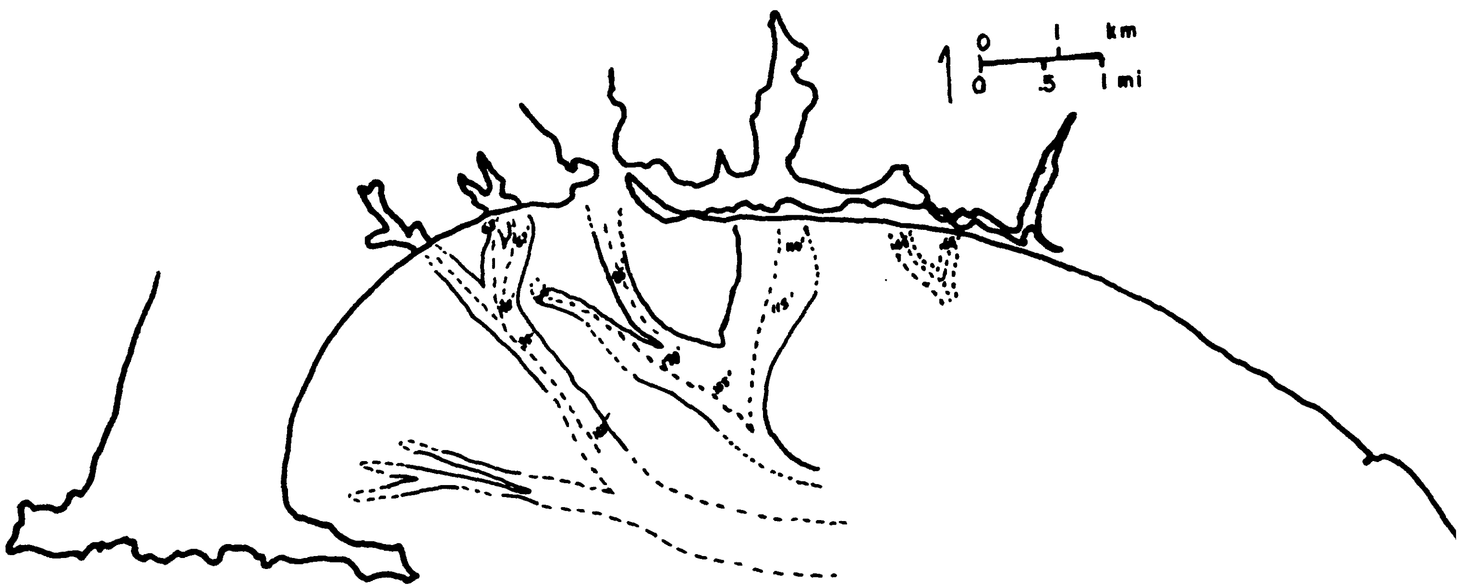


Figure 15. Paleodrainage channels cut into bedrock in Drakes bay, adjacent to Drakes Estero (from McCulloch, 1984)

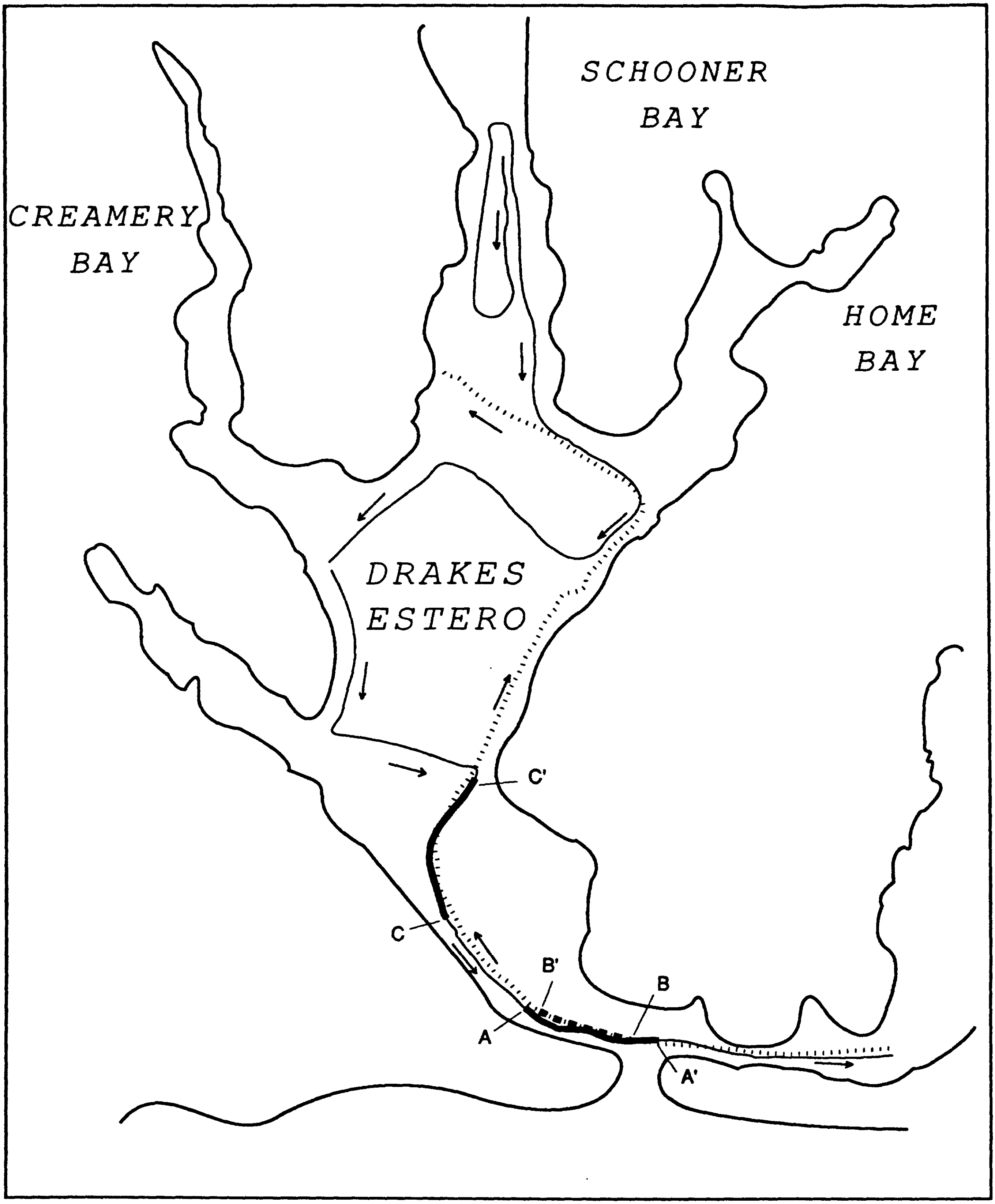
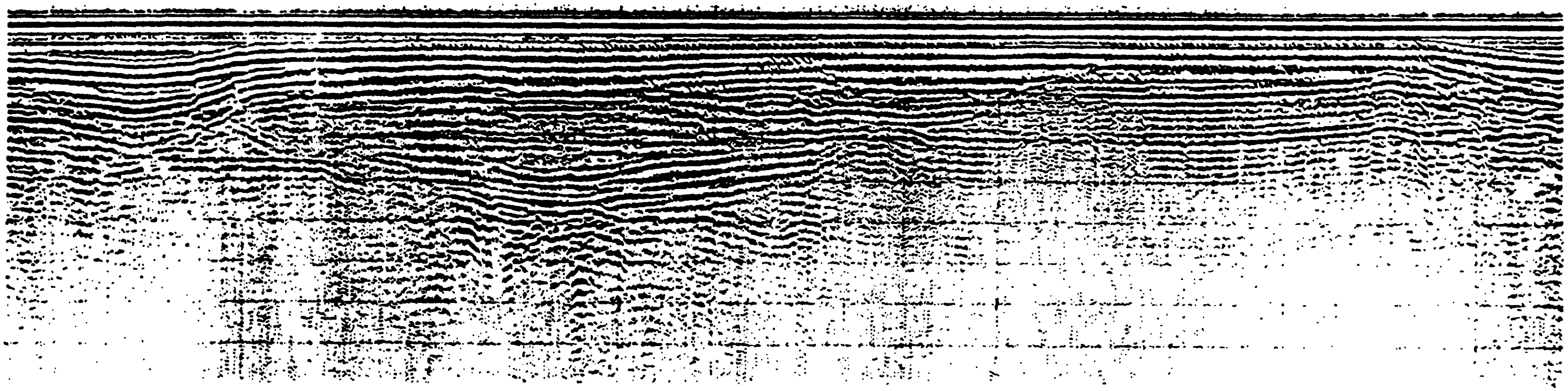


Figure 16. Geophysical trackline map showing location of sections of lines interpreted on figures 17, 18,and 19.



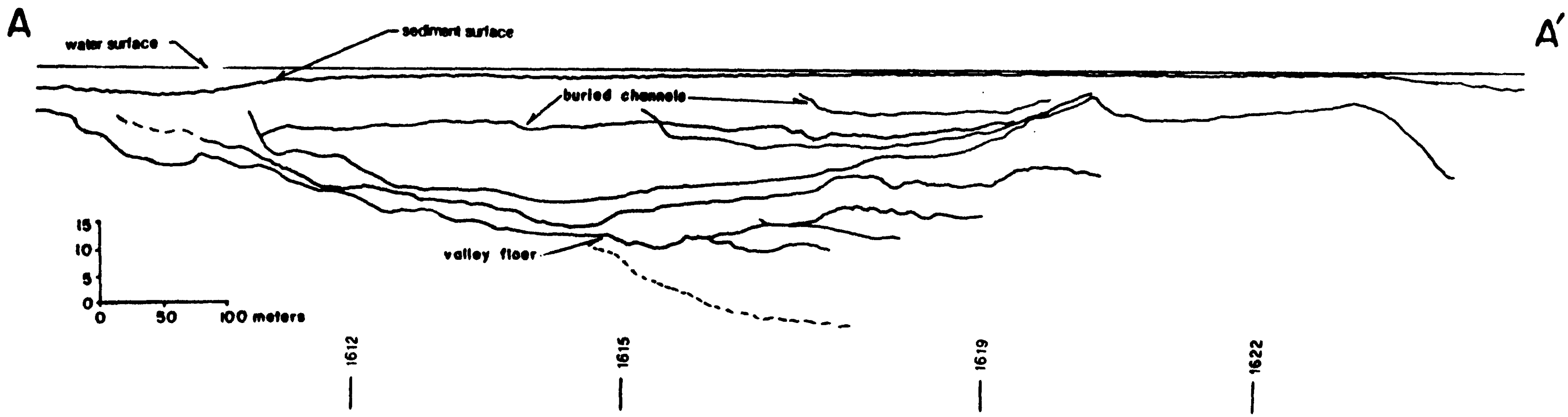


Figure 17. Geophysical record and interpretation of line A-A'.

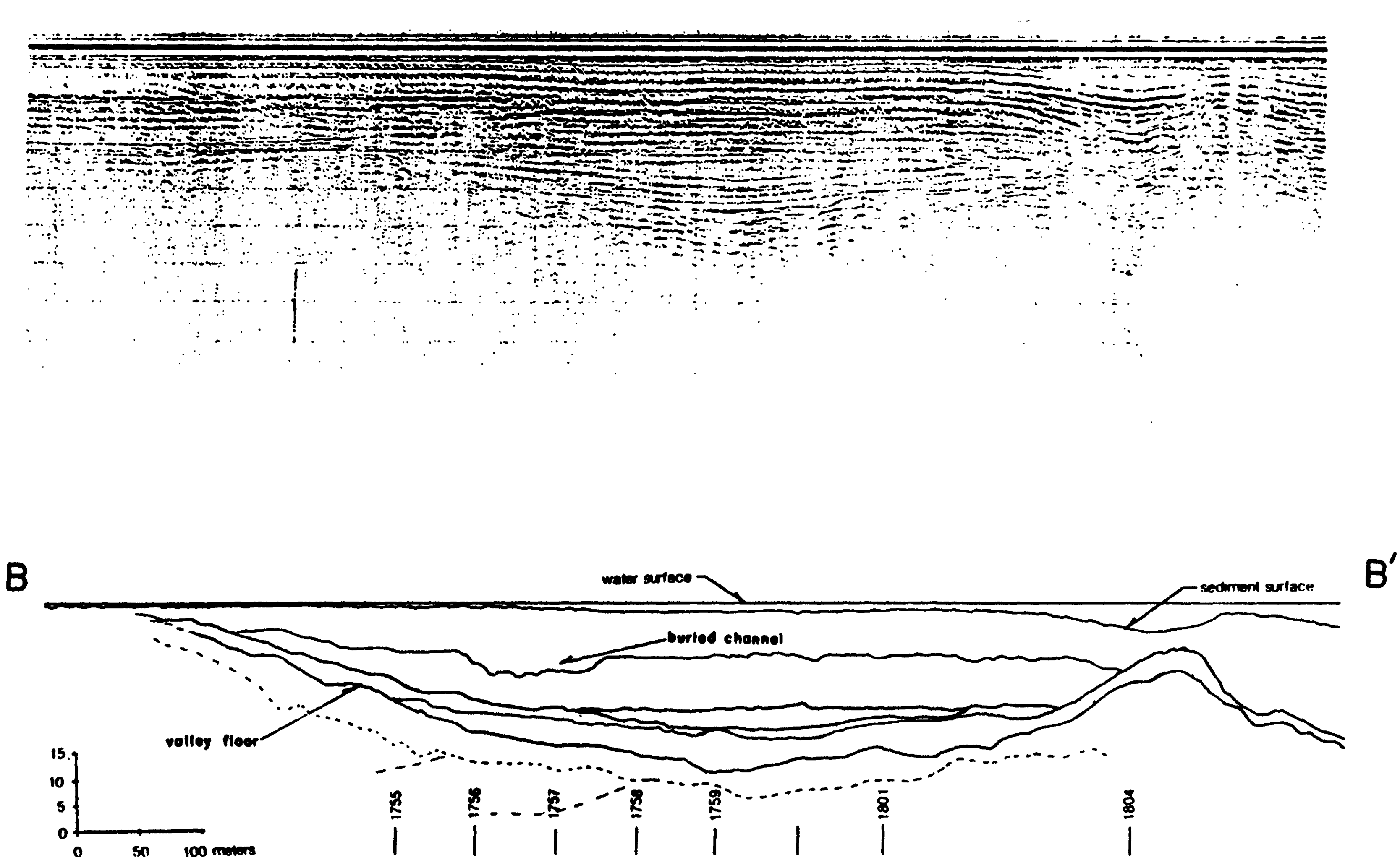


Figure 18. Geophysical record and interpretation of line B-B'.

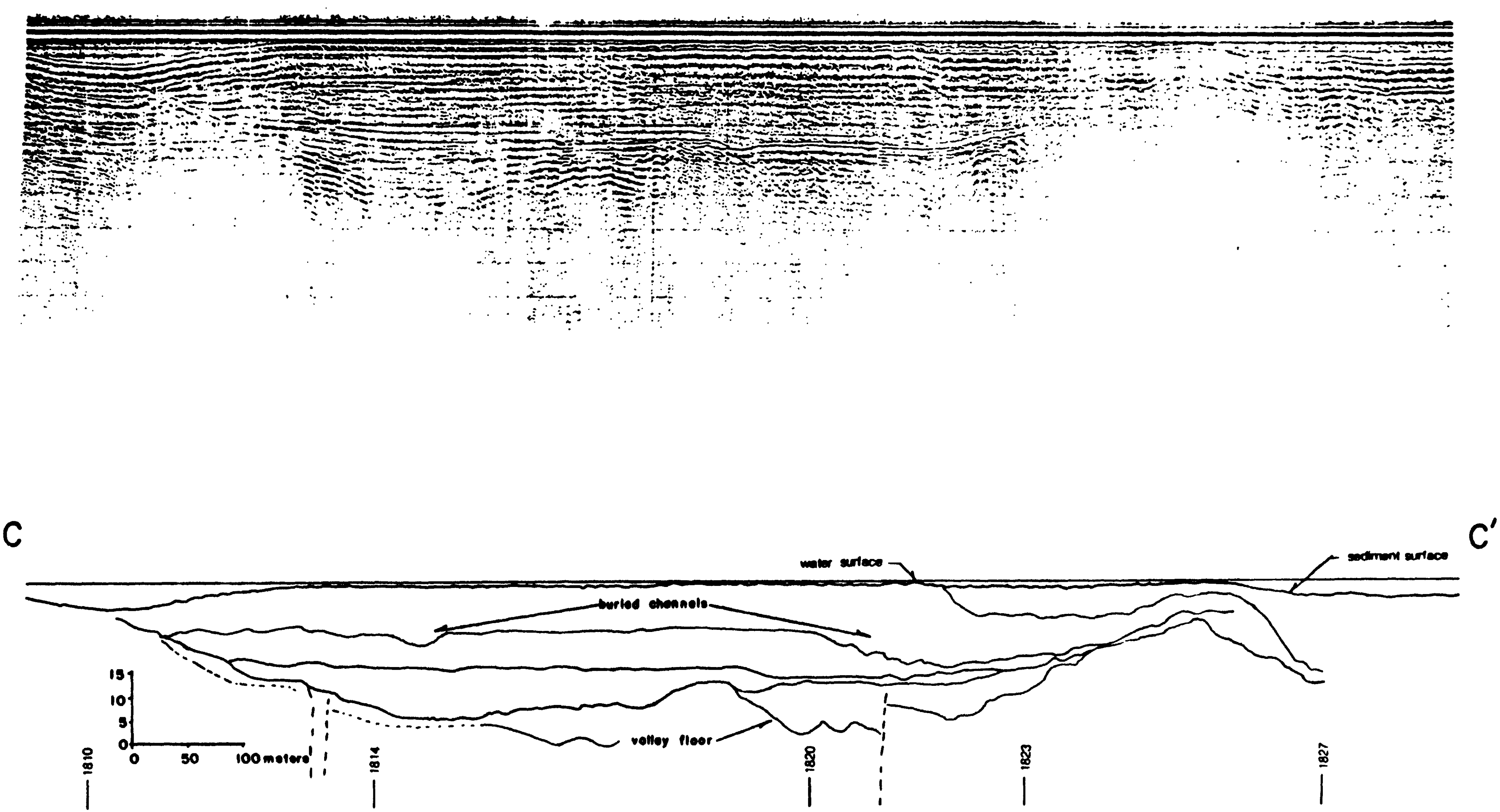


Figure 19. Geophysical Record and interpretation of line C-C'.

themselves. The records could not be run within the bays themselves, except Schooner Bay, because of the shallow depths, but the profiles were run across the mouths of the bays where possible. Figure 16 shows selected tracklines and figures 17, 18, 19, show the bottoms of the buried valleys with the thickness of sediment fill. Visible in the figures are buried tidal channels that are analogous to the modern tidal channel system of the estero. These features were probably deposited in an earlier upper intertidal flat or supratidal marsh environment which developed as the sea level began to fill the old stream valley to its present height. The interpretation of the depth of sediment infilling is consistent with that proposed by McCulloch in his work.

The geophysical records suggest that approximately 30 meters of sediment has filled the valley occupied by Drakes Estero near the entrance. The sea level curve suggested by Milliman and Emery (1968) (fig. 20) was used as a measure of the last marine transgression, which began at 15-18,000 yrs. B.P. The sea-level curve suggest that the time of the onset of valley filling at a depth of 30 m was 8,000 yrs B.P. Dividing the depth of valley fill by the time of onset of filling suggest a long-term sedimentation rate of 37.5 cm/100 yrs. Table 17 shows the results of similar calculations using acoustic and Sonoprobe surveys for Tomales Bay and Bolinas Lagoon. Drakes Estero sedimentation rates are well

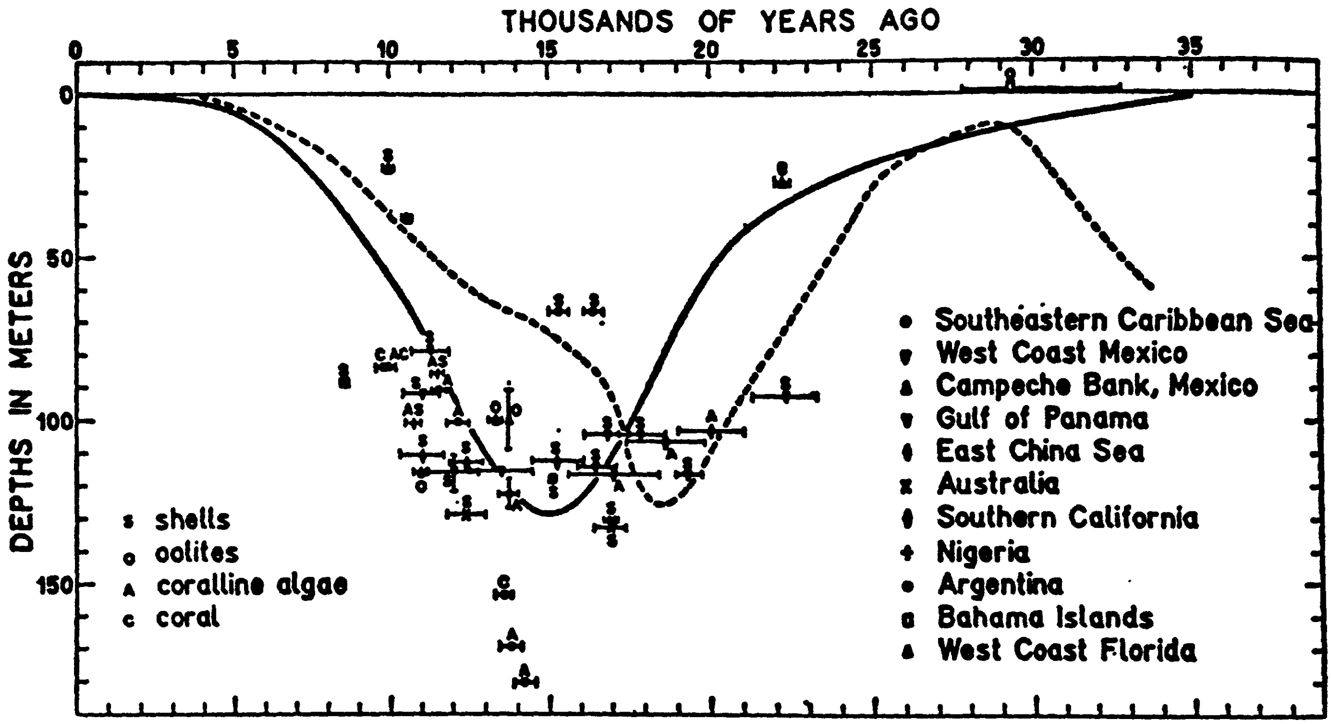


Figure 20. Sea level fluctuation over the last 35,000 years B.P. Depths and ages of sea-level indicators throughout the world. The solid line is the sea-level curve for the Atlantic continental shelf. The dotted line is the sea-level curve for the Texas shelf, from Milliman and Emery (1968).

Table 17. Deposition Rates in Central California Estuar based on acoustic survey interpretations, sediment sediment correlation, and bathymetric surveys.

Worker	Location	Method	Sedimentatior Rate cm/100 yr
Daetwyler, (1965	Tomales Bay, CA	Sonoprobe surveys	22.8
Rowntree, 1973	Bolinas Lagoon, CA	Acoustic surveys	39.9
Anima (this study)	Drakes Estero, CA	Uniboom surveys	35.5
Stevenson, and Emery, 1958	Newport Bay, CA	correlate old tidal flat sediments with change in hydraulics of the estuary.	45.7
Wahrhaftig, 1970	Bolinas Lagoon, CA	pre transgressive beach deposits	30.5 - 7.6
Ritter, 1973	Bolinas Lagoon, CA	1939-1968 surveys	45.7

within the same range of rates. Comparison with bathymetric surveys and sediment correlations by other workers show similar results.

6. Nutrient Study (Hagar, 1990, written communication)

The purpose of the nutrient study was to ascertain the influence of land use on the nutrient inputs to Drakes Estero and Abbotts Lagoon. The study gathered data on the chemical composition of the water of creeks flowing into Drakes Estero and Abbotts Lagoon from October, 1987 to September, 1988 (fig. 21). The study began with a reconnaissance of ten creeks, and subsequently focussed on five creeks chosen to represent a range of land uses. Water samples were collected primarily during storm events. The properties measured were temperature, electrical conductivity, dissolved nitrate, nitrite, reactive phosphate, silica and ammonium, total dissolved nitrogen and phosphorus, particulate nitrogen and carbon, total phosphorus, and suspended particulate material. At most sampling times, flow rates were estimated and evidence of previous water levels noted (Hagar, 1990).

Descriptions of sampling sites, with estimated watershed areas, the methods used to sample the study streams and the laboratory analysis procedures used are described in Hagar, 1990.

The original strategy of this study was to test two hypotheses: First, that the ratio of dissolved inorganic nitrogen or phosphorus to total dissolved inorganic

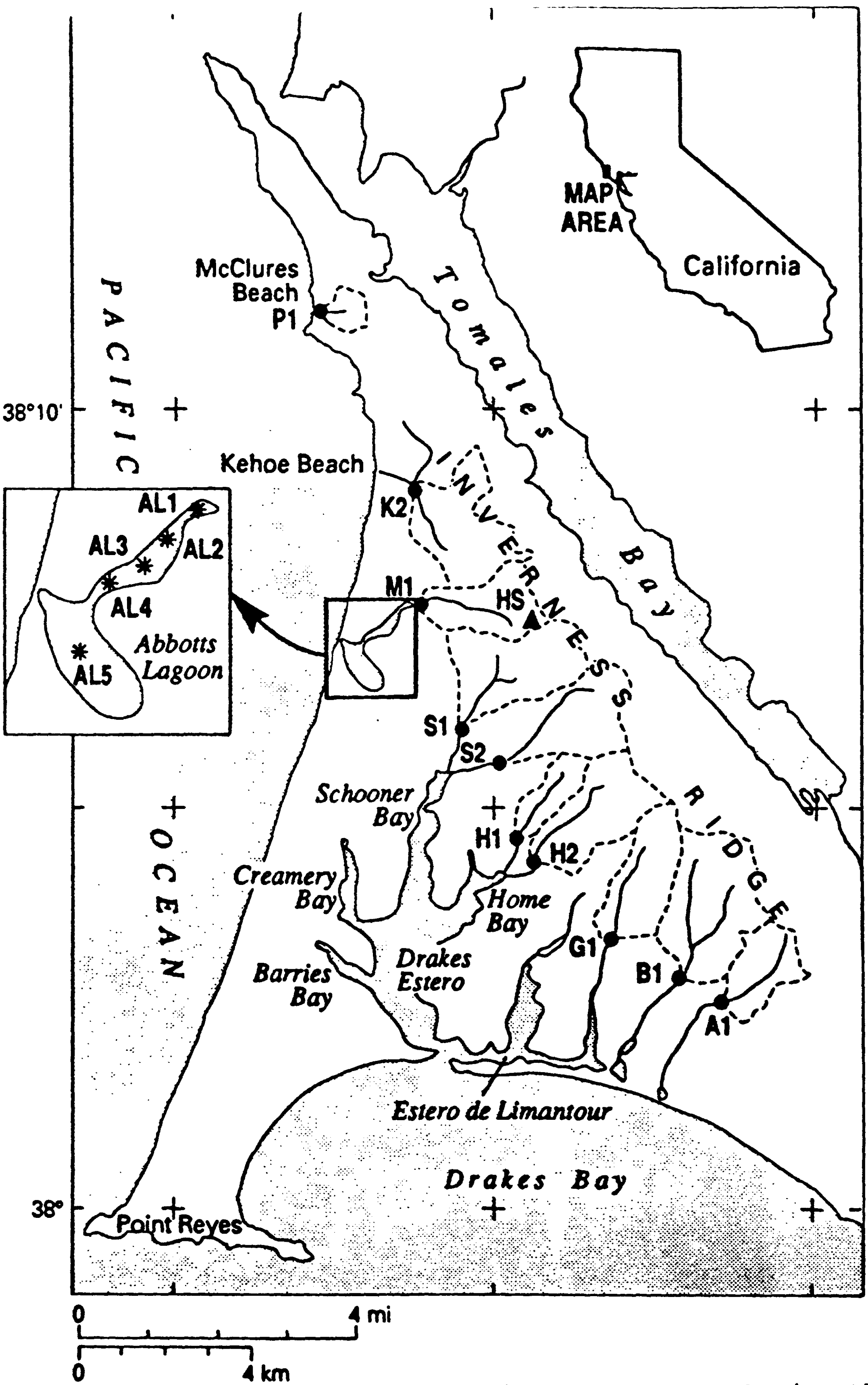


Figure 21. Map of Point Reyes National Seashore showing the sites used for nutrient analysis sampling (from Hagar, 1990)

concentration, aliased by the electrical conductivity, would be significantly higher in the creeks draining agriculturally utilized watersheds, and would be highest in the most intensely utilized watersheds. Second, that the ratio of particulate nitrogen or phosphorus to (total) suspended particulate material would also be higher. By showing consistent enrichment of the dissolved and particulate loads of these creeks, it was anticipated that the difficult and costly task of establishing yearly nutrient budgets would be circumvented. However, the highest nitrate plus nitrite (water year median 312 uM) and total dissolved nitrogen concentrations (340 uM) were seen in a "control" creek, one supposedly outside of the area of agricultural influence. Consistently high nitrate plus nitrite levels (164-165 uM) were also seen in an incidentally sampled spring in the upper part of a watershed with relatively intense agricultural use in the lower parts. Although no firm conclusions can be reached as to the quantitative impact of agricultural land use, it seems unlikely that surface nutrient inputs to Drakes Estero are of concern. Inputs to Abbotts Lagoon should be further studied, since the lagoon is not regularly flushed, and there are significant above-ground and presumably groundwater supplies of nutrients to the lagoon. Because of the limited rainfall during this winter, it was impossible to establish the degree to which the washout of nutrients occurred, and thus the applicability of these results to other, wetter years (Hagar, 1990).

Section IV. Conclusions

1. Drakes Estero

The results of this study indicate that Drakes Estero is a slowly filling system that is being supplied with sediment from the open marine environment, streams, aeolian deposition, biological reworking, and erosion of the surrounding bedrock. Tidal action is playing the dominant role in sediment distribution, erosion of surrounding bedrock, and overall flushing of the system. The rate of sedimentary filling has varied since the onset of the last marine transgression which began 8,000 yrs. B.P. based on the depth of sediment fill at the entrance of the lagoon, Pb^{210}, and C^{14} analyses. The depth of fill suggests the sedimentation rate was approximately 37.5 cm/100 yrs from 8,000 yrs. B.P. until approximately 3,000 yrs. B.P., when according to the results of the C^{14} analysis it decreased to between 3.8 to 6.4 cm/100 yrs. and increased again to between 5.7 to 11.7 cm/100 yr over 1,200 to 1,700 yrs B.P. The early high sedimentation rate may reflect the rapid rise of the sea during the early stages of the marine transgression. The Pb^{210} analyses suggest a continued increase in sedimentation rates to the levels similar to the post transgressive sea level rise. Comparing the results of this study to that of other workers suggests that both the long-term and short-term sedimentation rates follow a similar pattern and that discrepancies that may exist may be due to sampling errors or the resolution of the dating medium in the different studies. Comparison of Pb^{210} age dates and those of C^{14} (Appendix E) suggest that sedimentation has increased in the last 150 yrs. The increase in sedimentation could be attributed to increased land use as the population of the area increased, i.e., trail and road use, road building, increase in the paved areas that would increase the amount of surface runoff of rain water as opposed to ground absorption. But to relate the increase in sediment input to increased cattle grazing alone is very difficult to substantiate based on the change in population and overall land use of the area over the last 150 years. Based on geophysical record interpretations the lagoon has undergone 10-35 m of infilling in the past 8,000 years. Based on rates of sediment filling calculated using the three methods mentioned and comparing these rates of filling to other areas along the west coast, Drakes Estero and Abbotts appear to be filling at a rate like other west coast lagoons.

The results of both herbicides and pesticides analyses indicate that input into the two study areas are near or below the detection limits of the analytical methods used. Comparing the results of this study to studies conducted in the San Joaquin River and San Francisco Bay show that the amounts detected in the this study are very low.

The effects of range land use are not discernable from the nutrient monitoring program of the streams that flow into Drakes Estero and Abbotts Lagoon. A complete and detailed report on the methods and results of the nutrient analysis is available in Hagar, 1990.

In Drakes Estero, open-coast processes have a direct influence on the morphology of the lagoon entrance and subsequently on the distribution of sediment inside the lagoon. When the entrance is to the extreme west as it was in 1953 and again in 1974, oceanic wave and tidal approach is nearly aligned with the main arm of the tidal channel that trends north-south so that sediment being carried in suspension is carried further into the lagoon. Compared to the configuration with the entrance to the east, where wave and tidal currents dissipate their energy on the adjacent cliffs, the sediment would not be transported the same distance into the lagoon, but instead be deposited along the shore of the adjacent margins or as small ebb tidal features near the channels. The tidal flats just north of the main channel (fig. 5) are a relic flood tidal delta feature of when the mouth is in a west side configuration. When the entrance is located to the east , incoming waves and tides attack the adjacent cliffs of Purisima Formation, probably accounting for periods of increased erosion in this area.

The fluvial input of sediment into the system is important to the overall sediment supply and is mainly impacting lagoonal filling in upper parts of the branching bays, most notably in Schooner Bay and in the upper part of Estero de Limantour where sedimentation rates were the highest in the lagoon system. Streams that flow into the lagoon are eroding the underlying bedrock from higher in the watershed and introducing the sediment to the estero, where it is deposited mostly in marshes and deltas adjacent to the stream mouths. Where the drainage basins are not large, as in the case of Barries and Creamery Bays, the deltas are comparatively small and the marsh areas not as extensive.

Because they are filter feeders, the oysters being grown and harvested in the estero play an important role in the deposition of fine grained sediment. Haven and Morales-Alamo, (1966) in their study on the quantities of suspended matter removed by oysters(*Crassostrea virginica*) and deposited as feces and pseudofeces (material taken in by an organism but not digested, and expelled as pellets resembling feces), concluded that the amount of feces and pseudofeces (biodeposition) always greatly exceeded the deposition of solids by gravity or settling from suspension. Ito and Imai (1955) calculated that in Japanese waters a raft of oysters 60 m square would annually produce 0.6 to 1.0 metric tons (dry weight) of fecal material. In laboratory experiments (Haven, D. S., and Morales-Alamo, R., 1966), oysters were found to filter seston from the water and deposit it as feces or pseudofeces about seven times faster than it would settle by gravity. It was also determined that the amount of biodeposition differed between warm water and cold water conditions and that oyster ranked second in the amount of feces and pseudofeces produced only to the tunicate *Mogula manhattensis,* based on weight per unit of tissue weight. The

Haven Morales-Alamo report points out that the biodeposition rate of other common species of invertebrates equals or exceeds that of the oyster. The combination of abundant native filter feeders and the introduced oyster raises questions of the impact the industry is having to the sedimentation rate of the lagoon.

Other work carried out by Haven and Morales-Alamo (1972) reported on the settling velocities of feces and pseudofeces, compared with velocities of naturally settling suspended sediment, support the idea that fine grained sediment in suspension tends to be deposited on the substrate surface more rapidly after having passed through the body of a filter feeder than by natural means. The quiet water environment of the upper middle part of the estero, where most of the oyster racks are found, could allow for the deposition of silt-sized material in the form of feces and pseudofeces produced by the oysters. Once deposited, the material is resistant to erosion. Because the areas of greatest abundance of oysters are well into the lagoon, where tidal flushing is limited, the feces are not being transported out of the system with the tides. Areas adjacent to staked oyster beds have been observed to have higher accumulations of silt and clay sized material on the leeward and/or a down current direction from the beds. Studies mentioned on the production of silt-sized material by Atlantic oysters indicate that the amounts produced are significant. More research is needed to ascertain what amount of silt-sized material is being produced by oysters in the lagoon.

2. Abbotts Lagoon

Abbotts Lagoon is also a filling system, but the rate of filling (between 8.0 to 19.0 cm/100 yrs.) is slower than that of Drakes Estero. Sediment supply is mostly from aeolian dune encroachment, open coast processes (berm overwash, and wave erosion), and stream input. Abbotts Lagoon has the Monterey Formation as its basement rock, which is more resistant to erosion than the Purisima Formation found underlying Drakes Estero, so that the input of sediment from cliff erosion is minimal. However, as mentioned earlier, there is some erosion of bedrock between the two arms of the lagoon and along the east side of the main arm. Scuba diving observations made in the lower or ocean side of the Abbotts Lagoon system found that there are very few organisms living in the lagoon other than arthropods and microorganisms. The system lacks significant numbers of bivalves or other filter feeders that would fix fine-grained sediment and redeposit it as silt-sized material. The system is not tidally influenced, so that constant sediment input or flushing is not a factor.

Both the herbicide and pesticide analysis indicate that the amounts of the two compounds is the same as that found in Drakes Estero, albeit the lack of good circulation by tides would be conducive to preservation of the compounds.

Section V Recommendations

Although there is very little input of herbicide and pesticides into the Drakes Estero and Abbotts Lagoon systems, the use of either of these two agents should not be increased without a detailed re-sampling of the sediments and streams to evaluate the effects of their increased use. This is to insure that the levels of pesticides and herbicides be kept at or below the existing levels.

The methods used by the oyster industry in Drakes Estero appear to be serving as a baffle to tidal currents in those locations where rack density is highest i.e., mouth of Creamery Bay, Schooner Bay, and Home Bay. What the results of this current baffling might be needs further study. It has been observed that silt-sized material accumulates on the leeward and/or down-current side of the staked oyster beds. Further study isneeded to ascertain what effects the methods and the large numbers of oysters, oyster racks, and staked oyster beds are having on the sedimentological makeup of the estero. The oyster industry has left much debris in the estero over the years related to their operation. A cleanup effort to remove debris from the intertidal flats, subtidal channels, surrounding shoreline, and marsh areas would be beneficial to the esthetics of the estero. Also, consideration should be given to removing abandoned structures and devices not used by the operation.

Recommended Future Work

1. Conduct experimental studies on the production of fine-grained material from the various filter feeders that live in the lagoon to determine the effects the fine grained material on the deposition rate into the lagoon. Does this production of fines have an impact on the filling of the lagoon?

2. Continue to monitor the rate of migration of the inlet and what its position has to do with the deposition of sand in the central part of the estero. What is the effect of the inlet position to the sedimentation pattern inside the estero? Periodically monitor the bar across Abbotts Lagoon, especially during periods of high tides and storms, to study the erosion of and rebuilding of the barrier.

3. Run more geophysical profiles in the lagoon to determine the amount of sediment that has already infilled the lagoon. This could aid in a better understanding of the infilling characteristics of the lagoon.

4. What has been the effect of damming of the streams in the overall sedimentation picture of the lagoon. By vibracoring the ponds developed behind the dams and attaining Pb^{210} dates, the amount of sedimentation into these ponds can be determined. What is the rate of filling? Will they eventually fill and begin depositing sediment into the lagoons? How long before this occurs?

5. Conduct a detailed identification of the fossil mammal remains found along the margins of Drakes Estero and collect samples large enough to display at the Visitor Information at Bear Valley, (fig. 22).

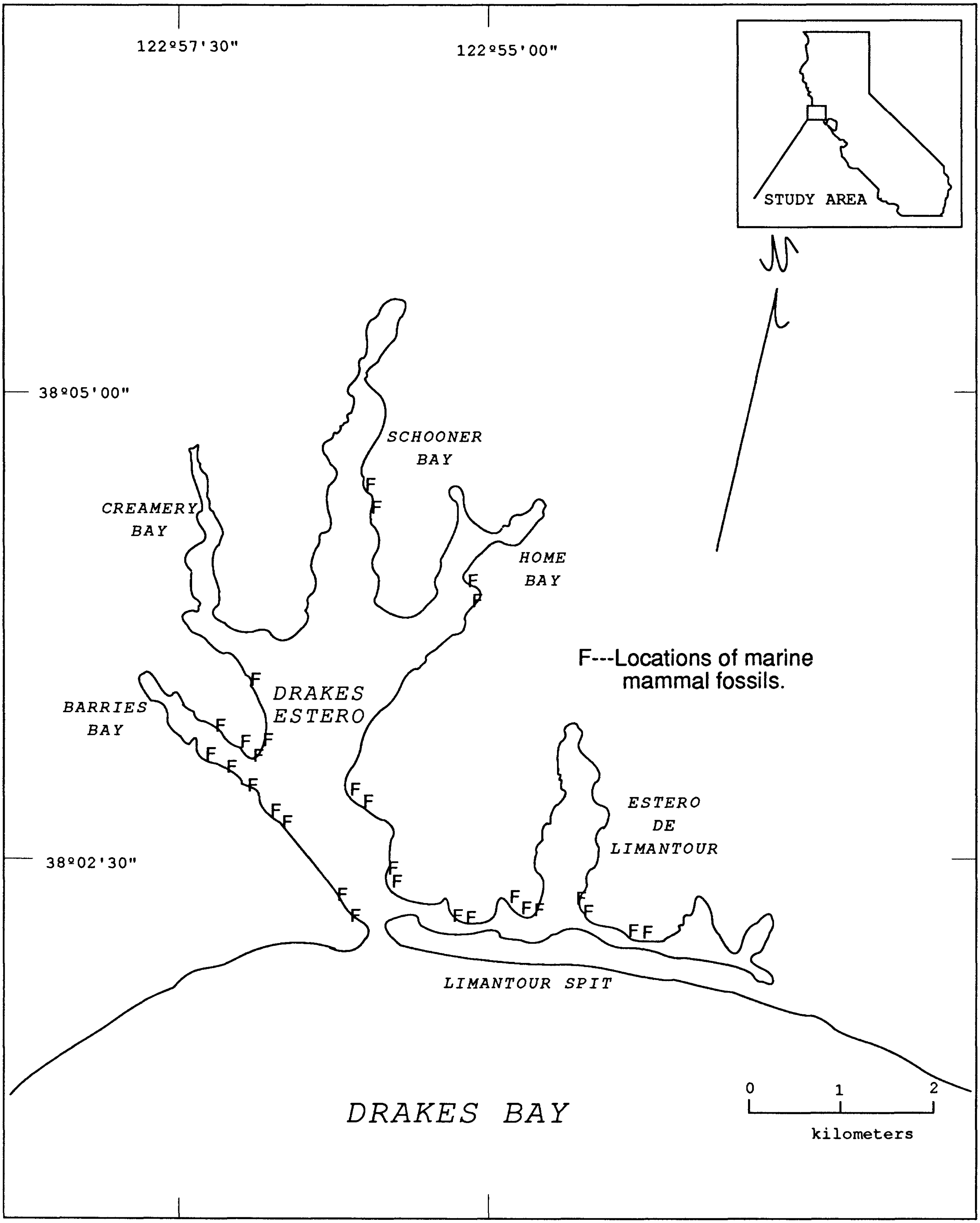


Figure 22. Map showing the location of fossils exposures surrounding Drakes Estero.

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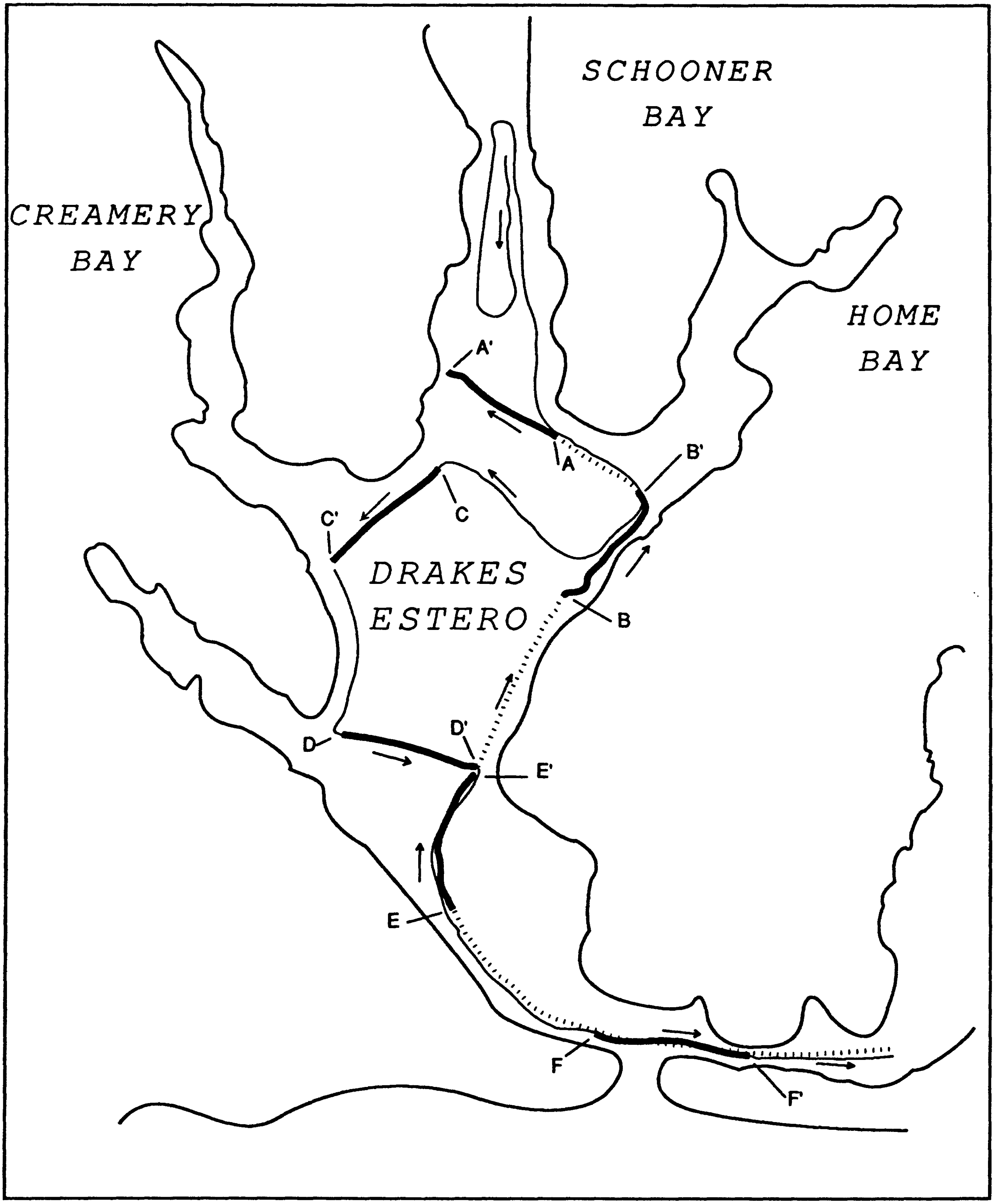
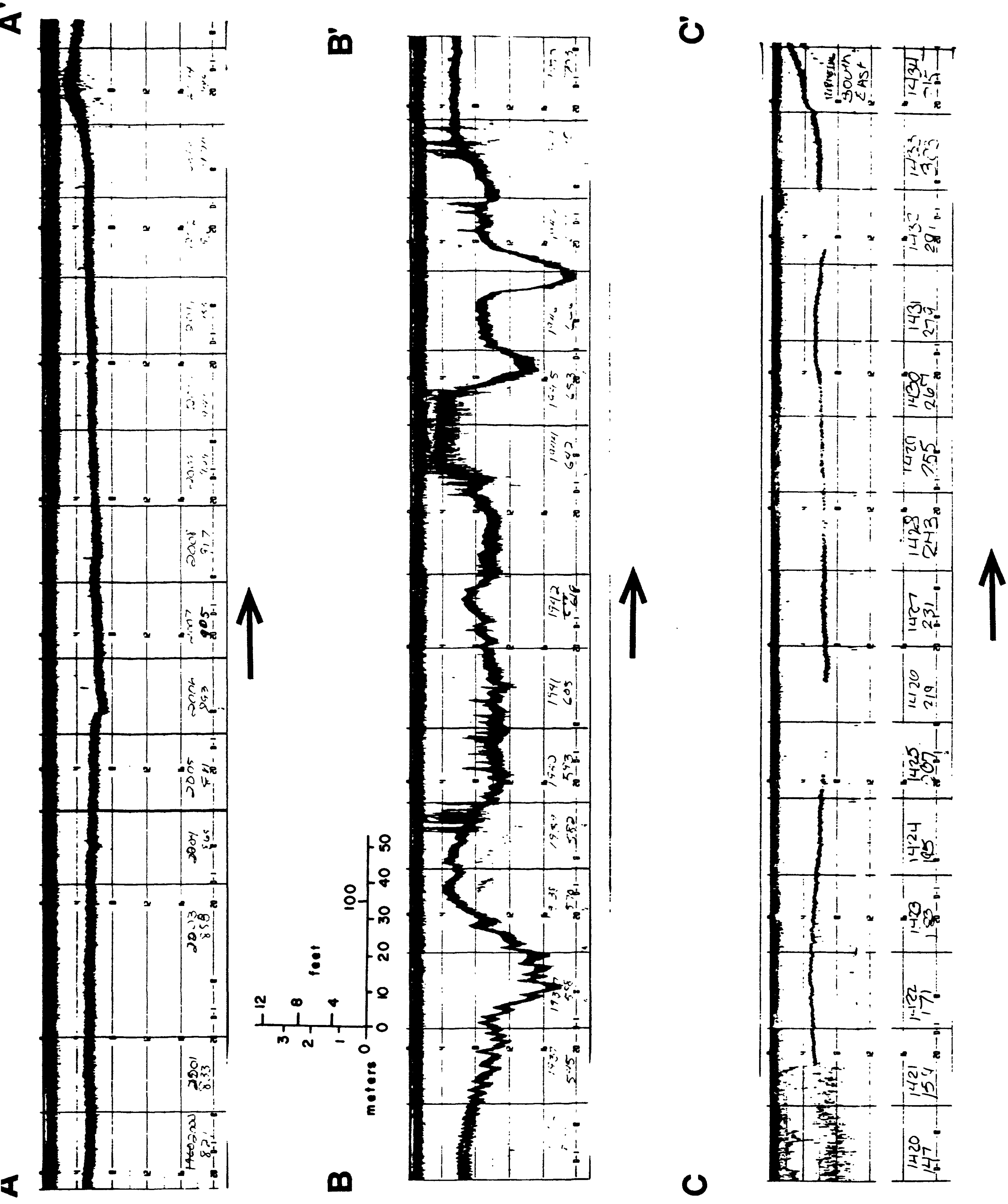
Appendix A1

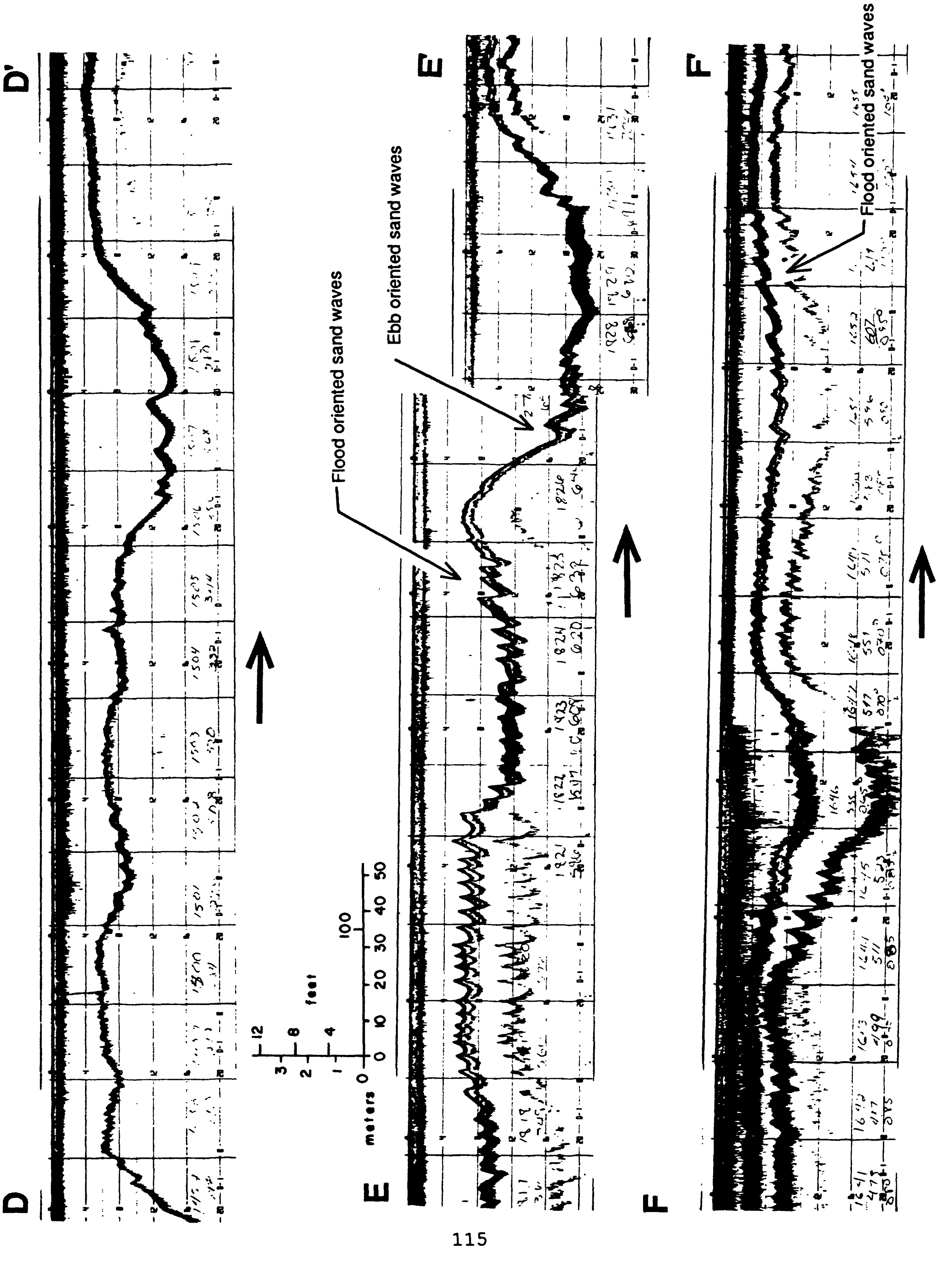


Map showing bathymetric tracklines run in Drakes Estero .
Letters correspond to profile lines (dark lines).
Arrows indicate boat direction.

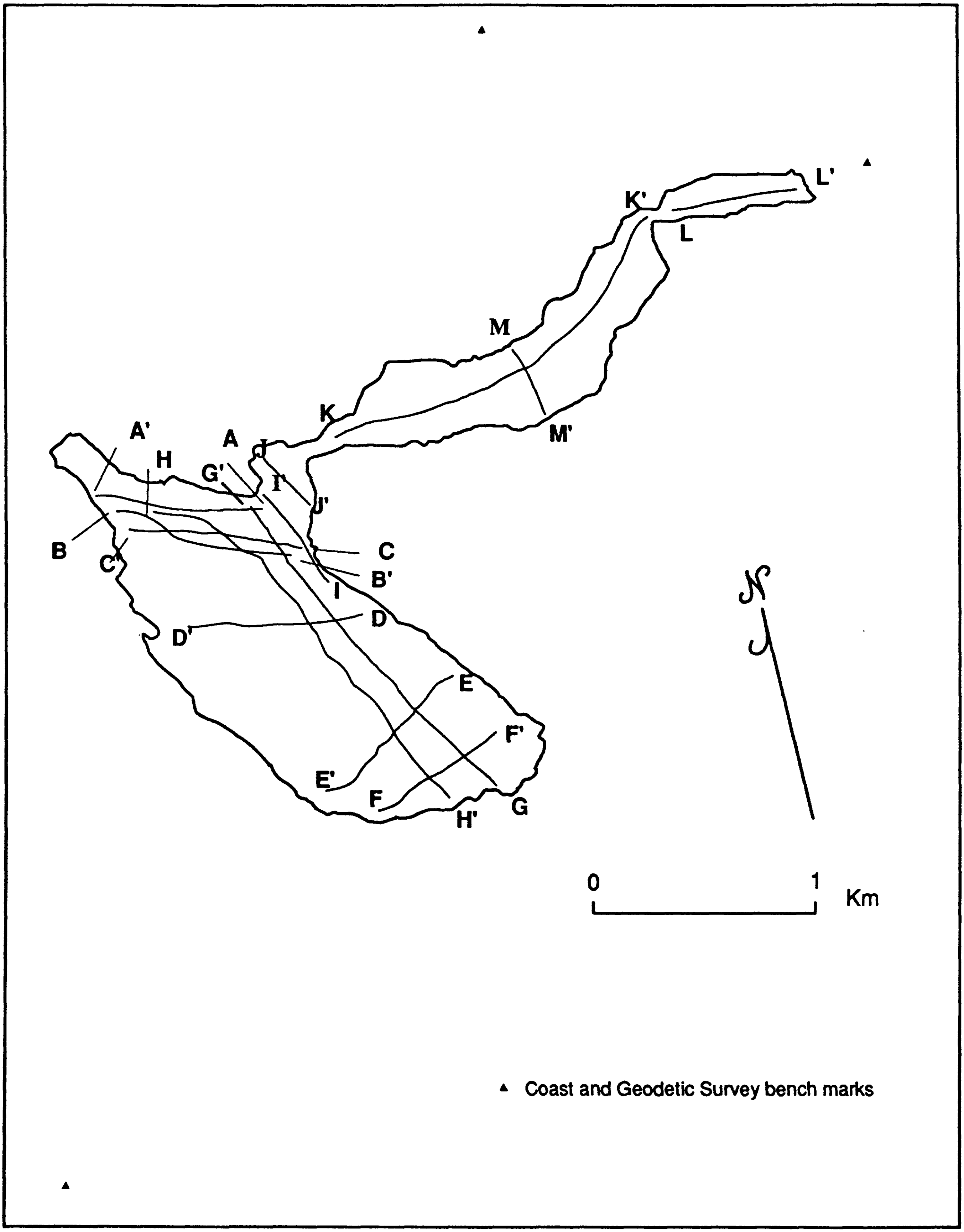
A1b. Bathymetry records taken in Drakes Estero along tracklines A-A', B-B', and C-C'.


A
A'
B
B'
C
C'
meters
feet

A1c. Bathymetric records taken in Drakes Estero along tracklines D-D', E-E', and F-F'.

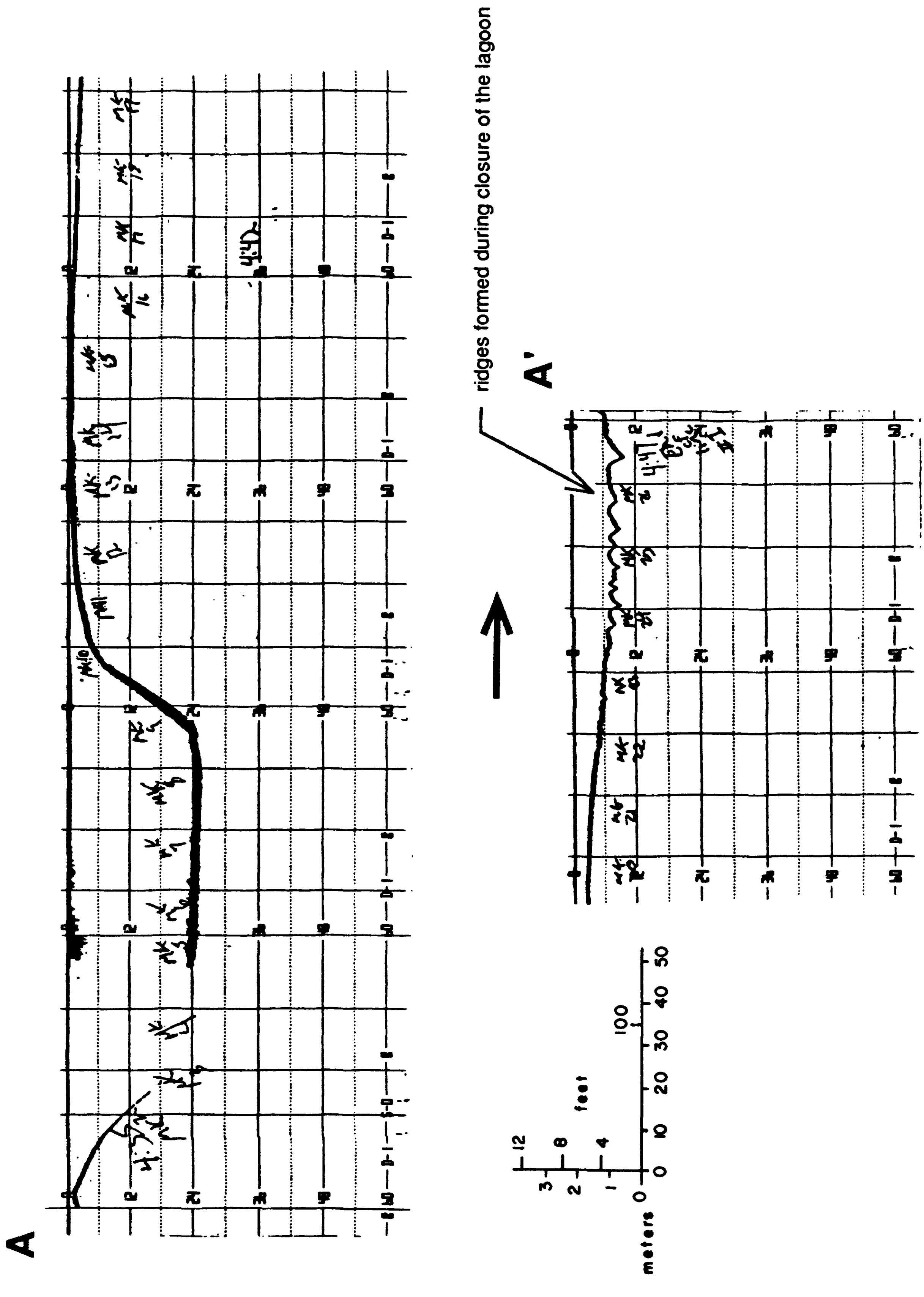

D
D'
E
E'
F
F'
Flood oriented sand waves
Ebb oriented sand waves
Flood oriented sand waves
meters
feet
0
1
2
3
0
4
8
12
0
10
20
30
40
50
100

Appendix A2

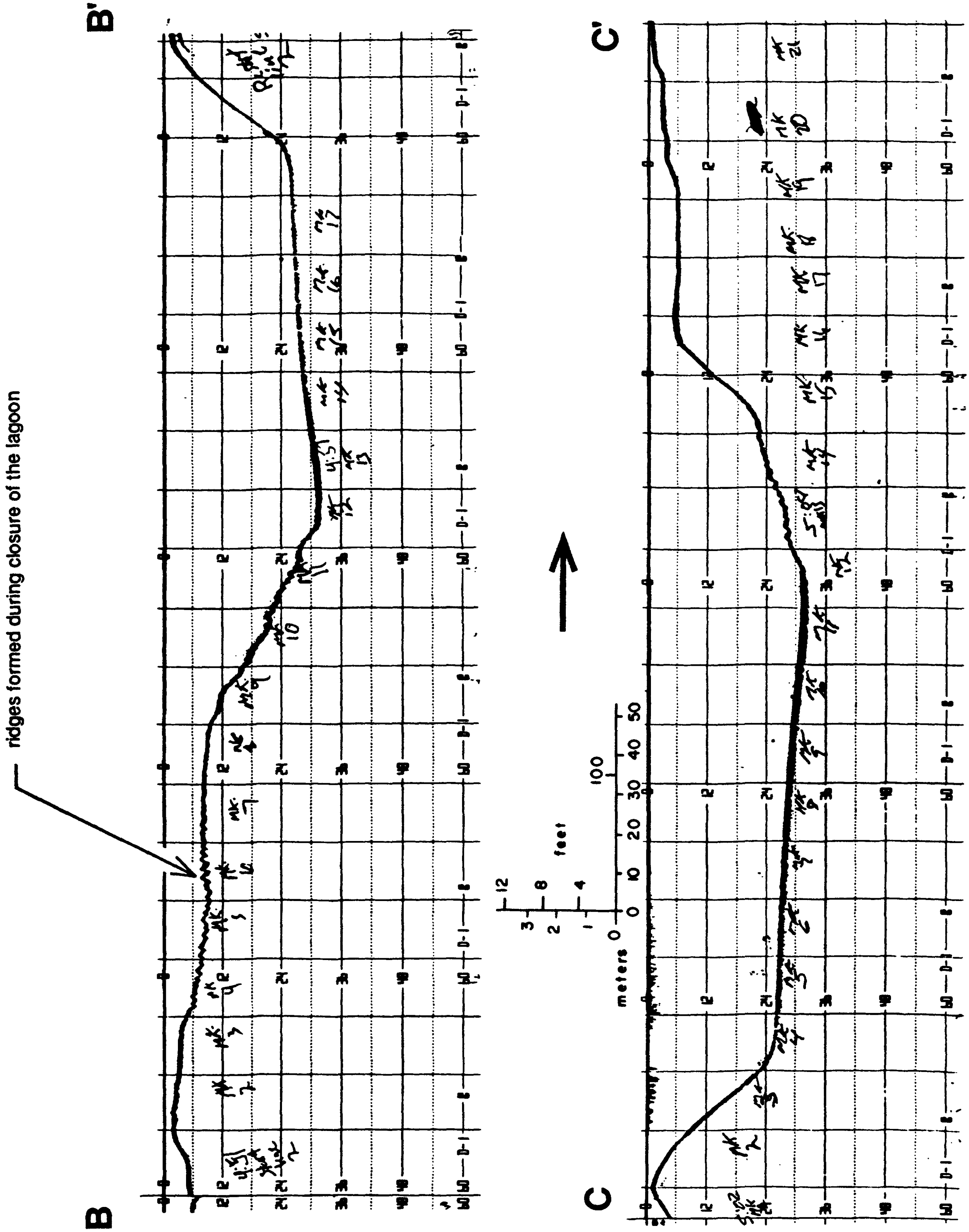


A2a. Map showing bathymetric tracklines in Abbotts Lagoon.

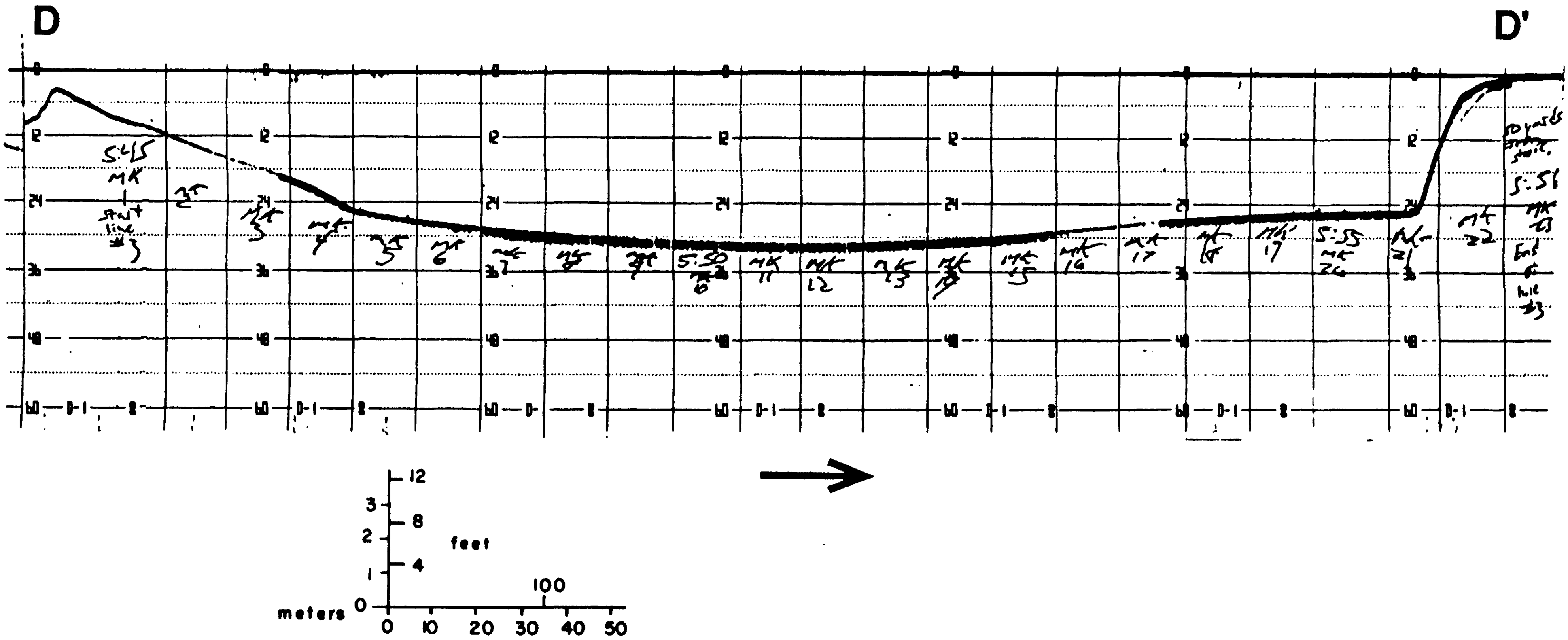
A2b. Bathymetric records collected along track line A-A' in Abbotts Lagoon. Note ridges that formed during closure of the lagoon.


A
A'
ridges formed during closure of the lagoon
meters
feet
0
1
2
3
4
8
12
0
10
20
30
40
50
100

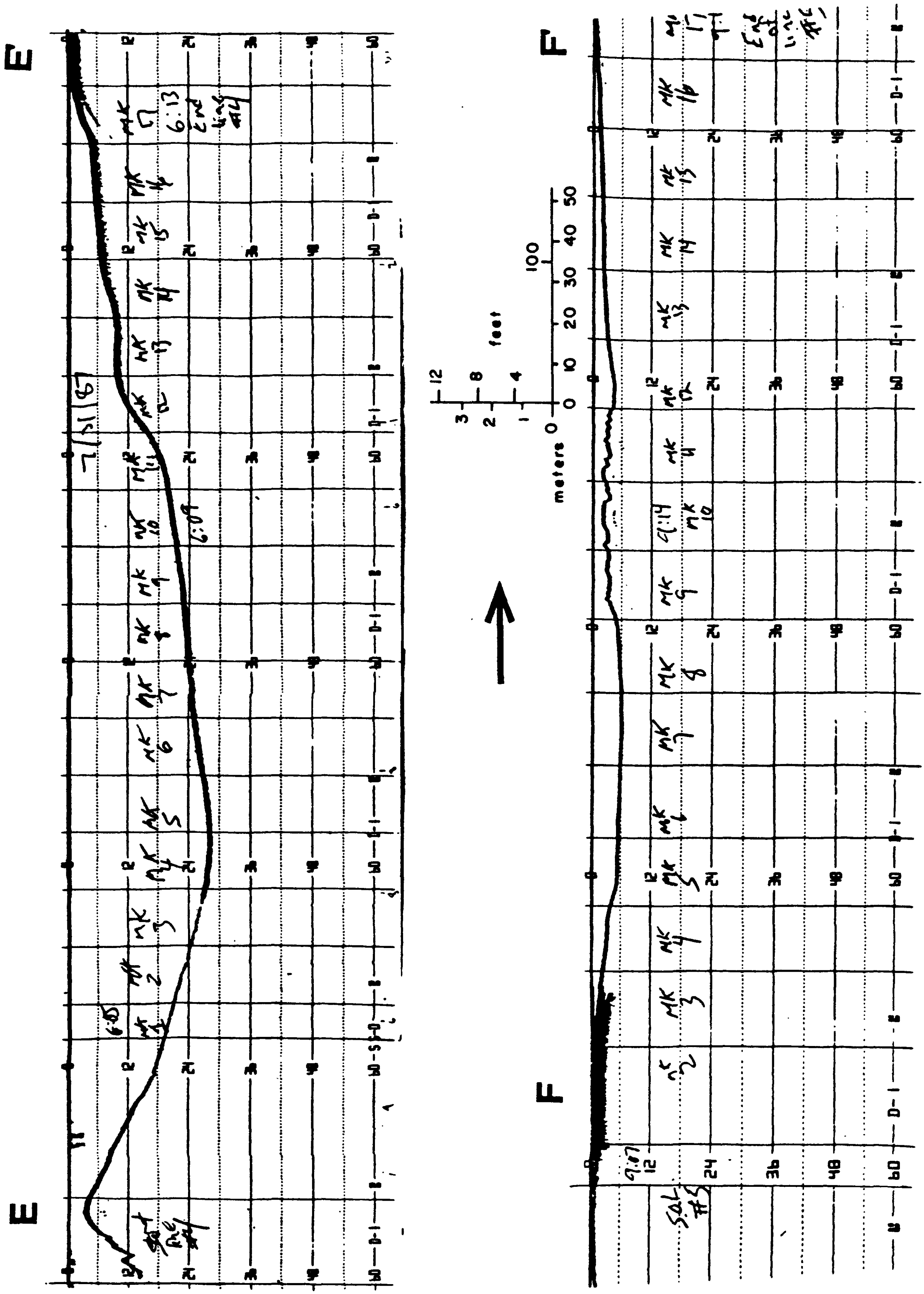
A2c. Bathymetric records collected along tracklines B-B', and C-C', in Abbotts Lagoon. Note ridges along both tracklines that formed during closure of the lagoon


B
B'
C
C'
ridges formed during closure of the lagoon
meters
feet
0
1
2
3
4
8
12
10
20
30
40
50
100

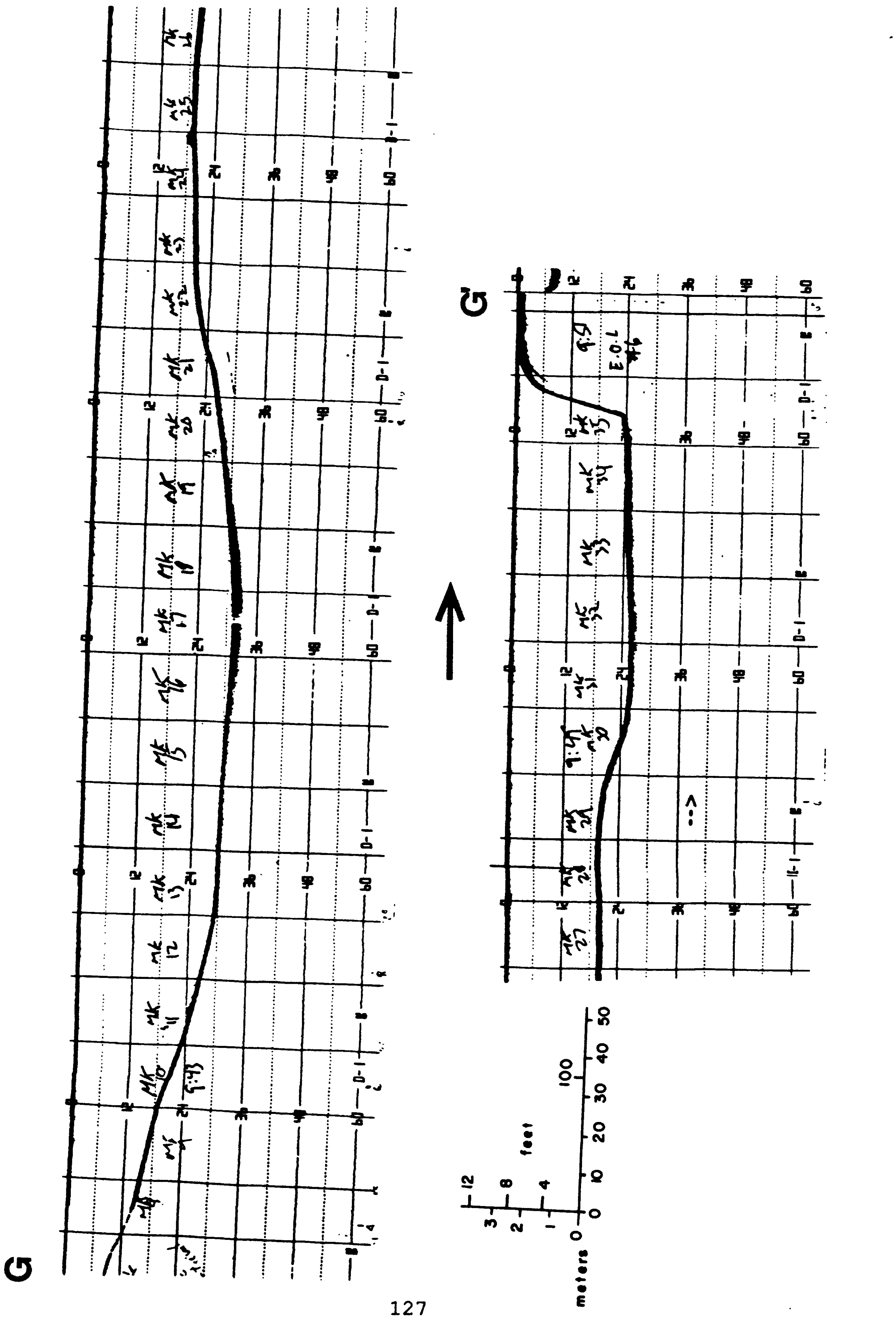
A2d. Bathymetric records collected along trackline D-D' in Abbotts Lagoon. Note steep west bank of the lagoon.


D
D'
meters
feet
100

A2e. Bathymetric records collected along tracklines E-E', and F-F' in Abbotts Lagoon.

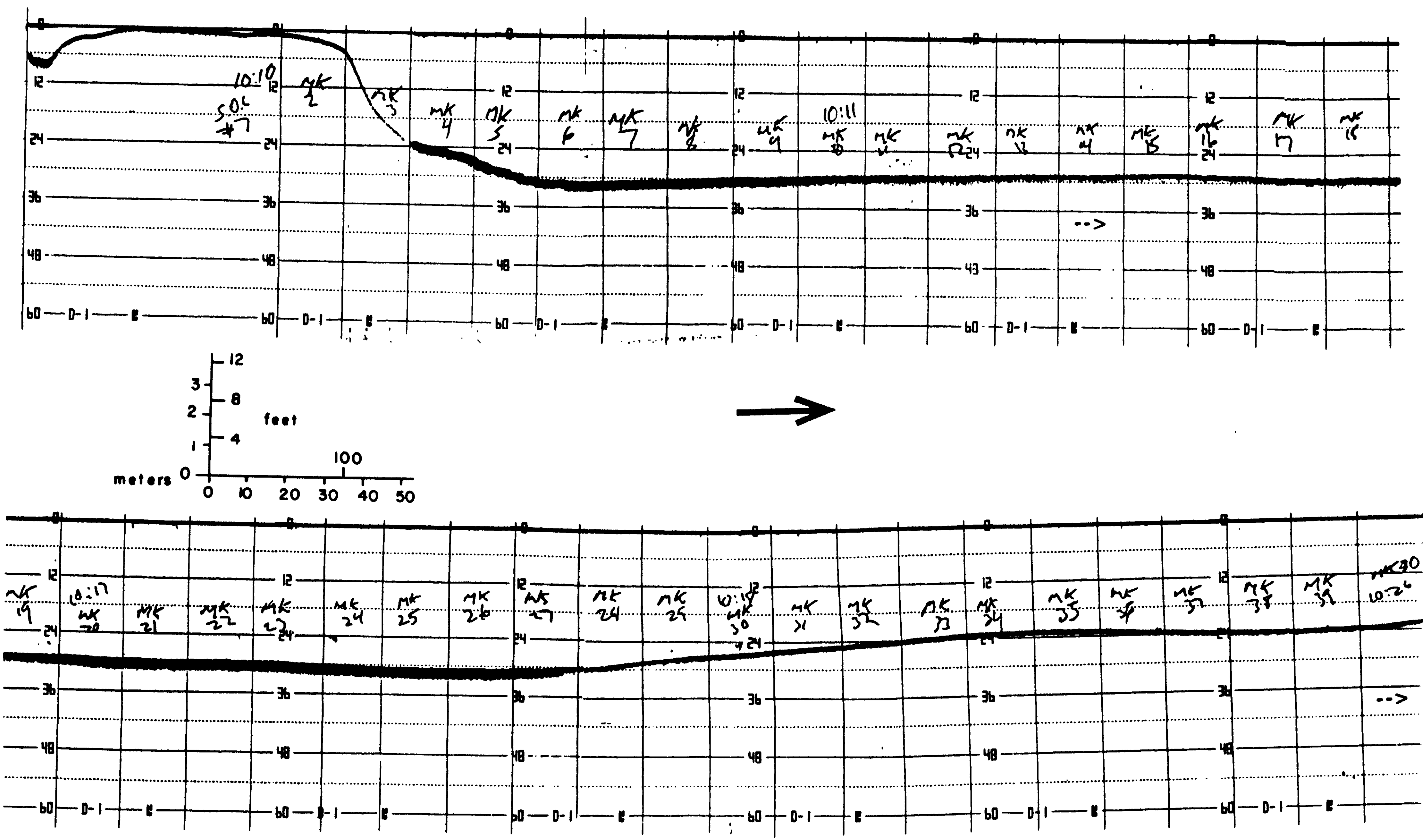

E
E'
F
F'
meters
feet
0
1
2
3
4
8
12
10
20
30
40
50
100

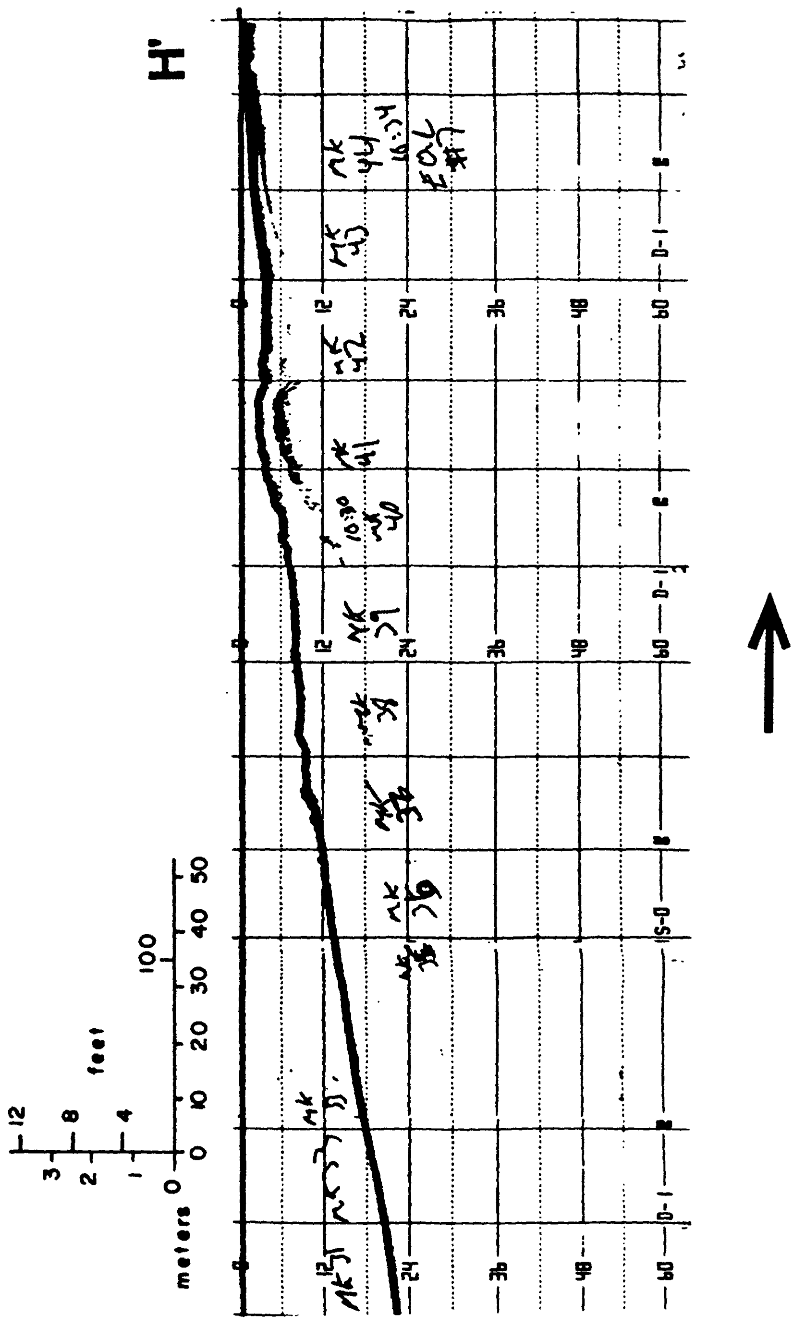
A2f. Bathymetric records collected along trackline G-G' in Abbotts Lagoon. This trackline was run from south to north along the center of the lagoon.


G
G'
feet
meters
E.O.L

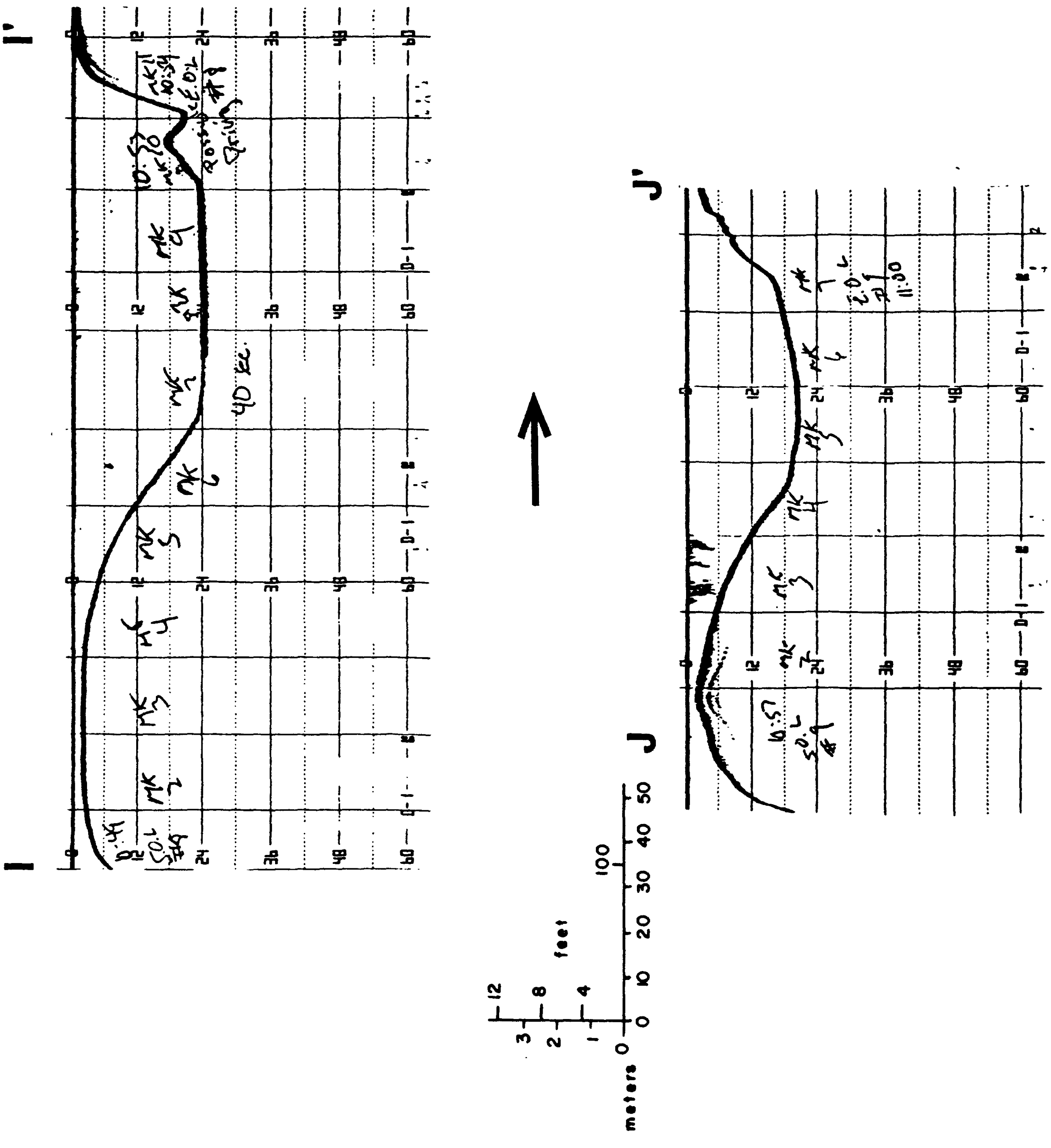
A2g. Bathymetric records collected along trackline H-H' in Abbotts Lagoon. This trackline was run from the north to the south west of trackline G-G'.

H

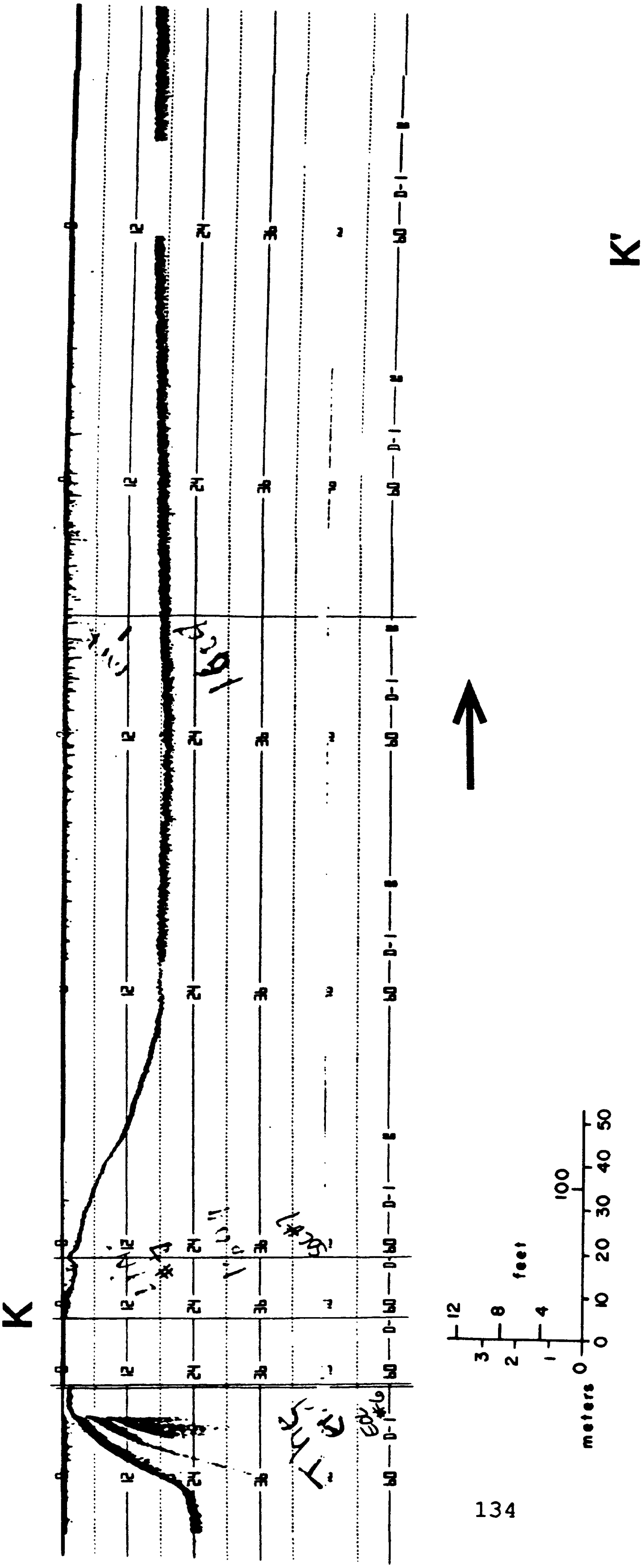


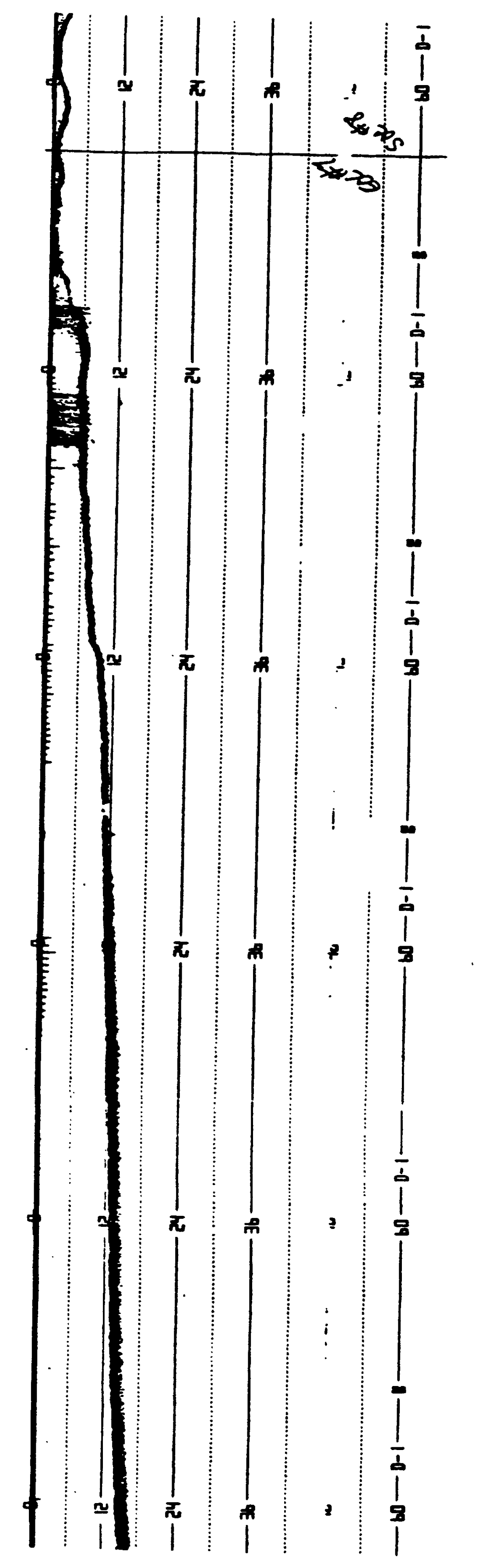

H'
meters
feet

A2h. Bathymetric records collected along tracklines I-I', and J-J' at the northern part of Abbotts Lagoon.

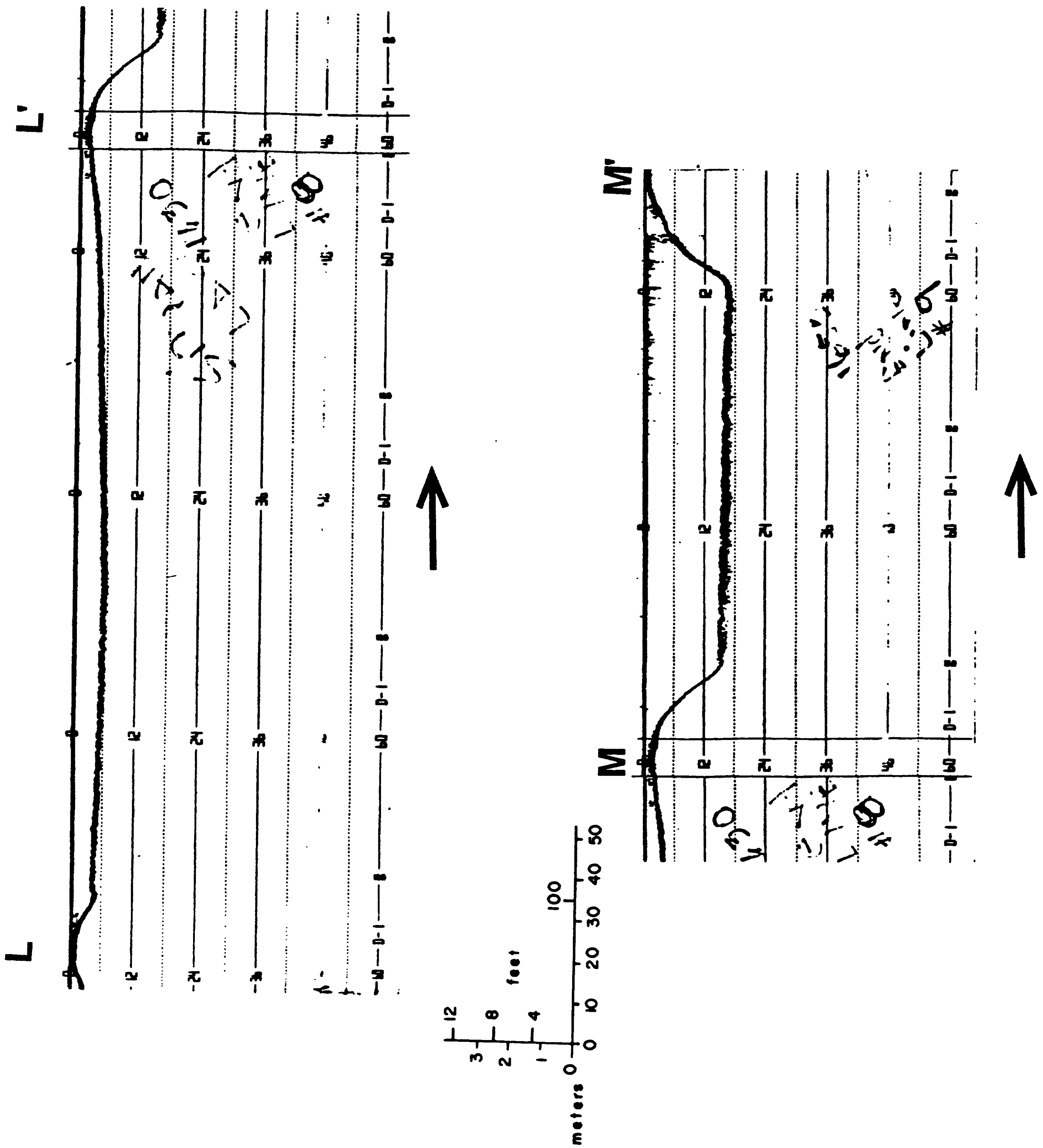

I
I'
J
J'
feet
meters

A2i. Bathymetric records collected along trackline K-K'
in the eastern arm of Abbotts Lagoon


K
feet
meters


K'

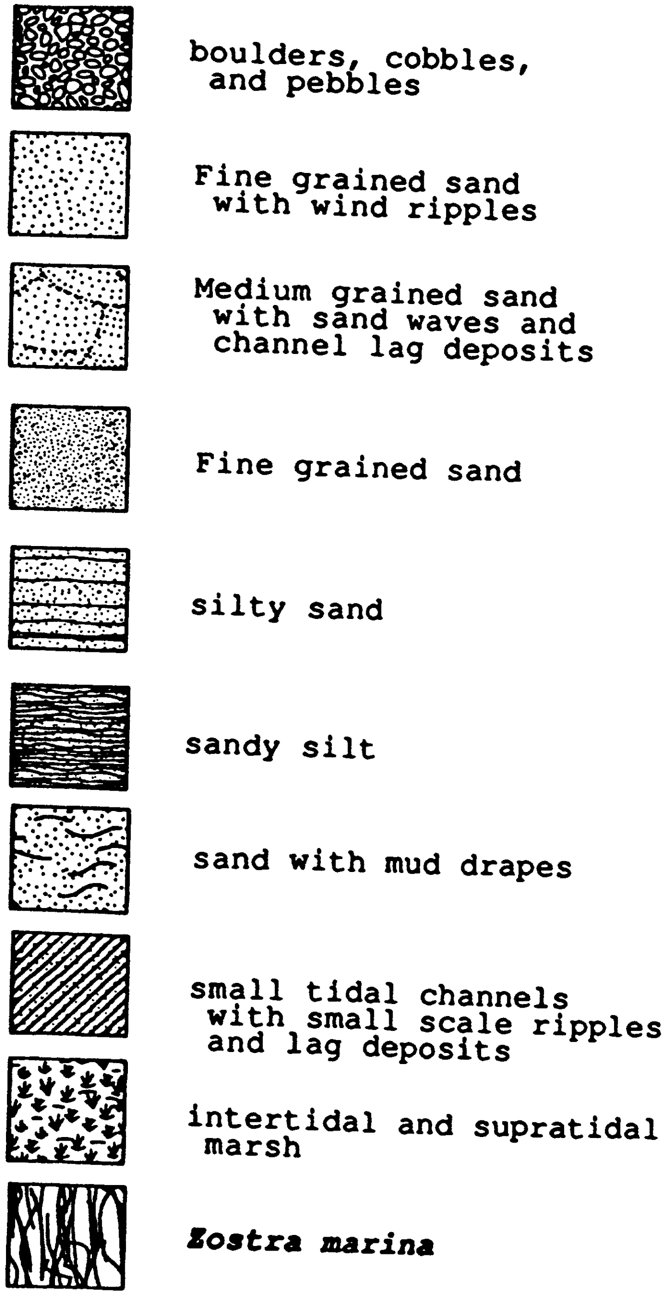
A2j. Bathymetric records collected along tracklines L-L', and M-M' in the eastern arm of Abbotts Lagoon



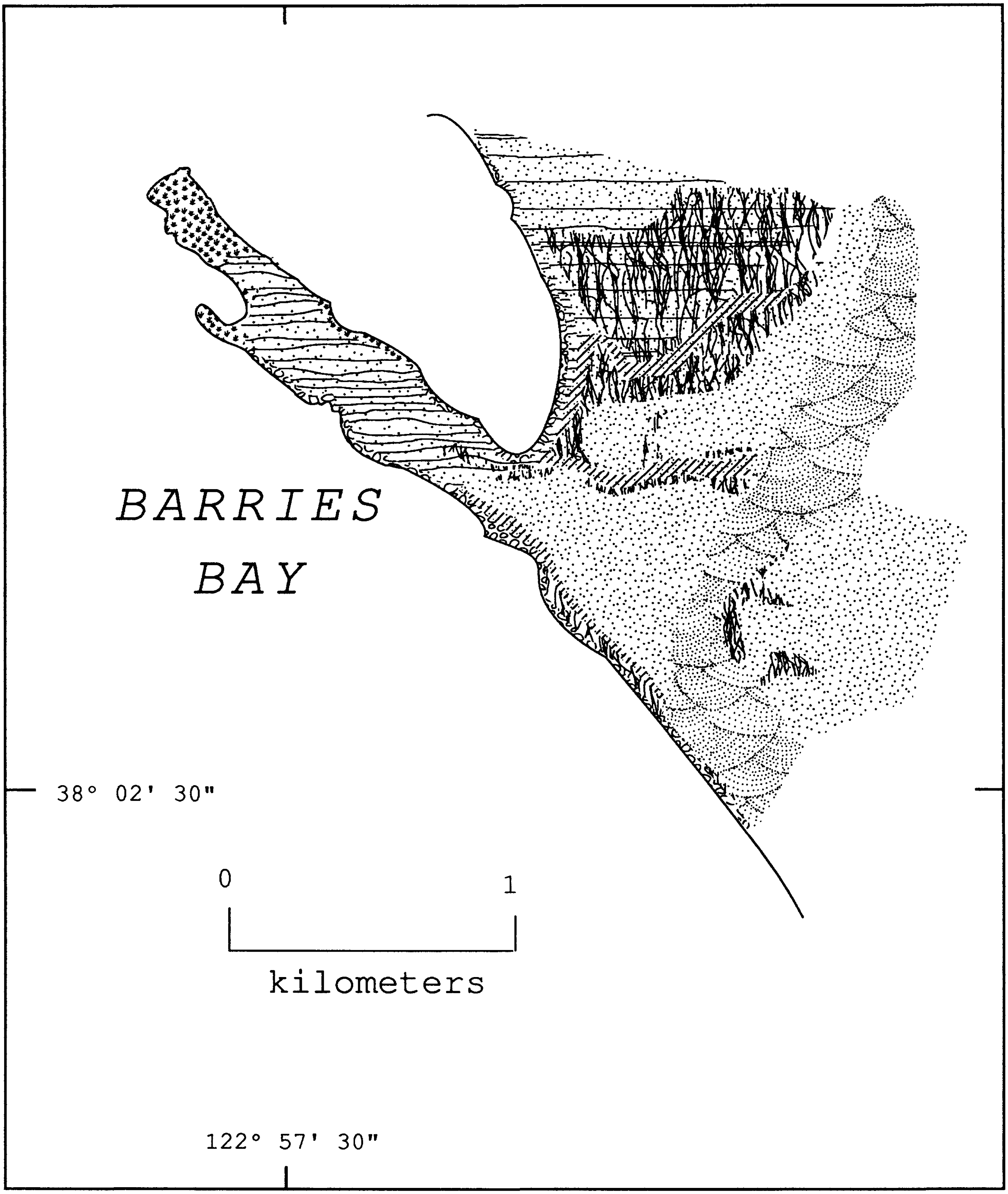
L
L'
M
M'
feet
meters

Appendix B Sediment Characteristics

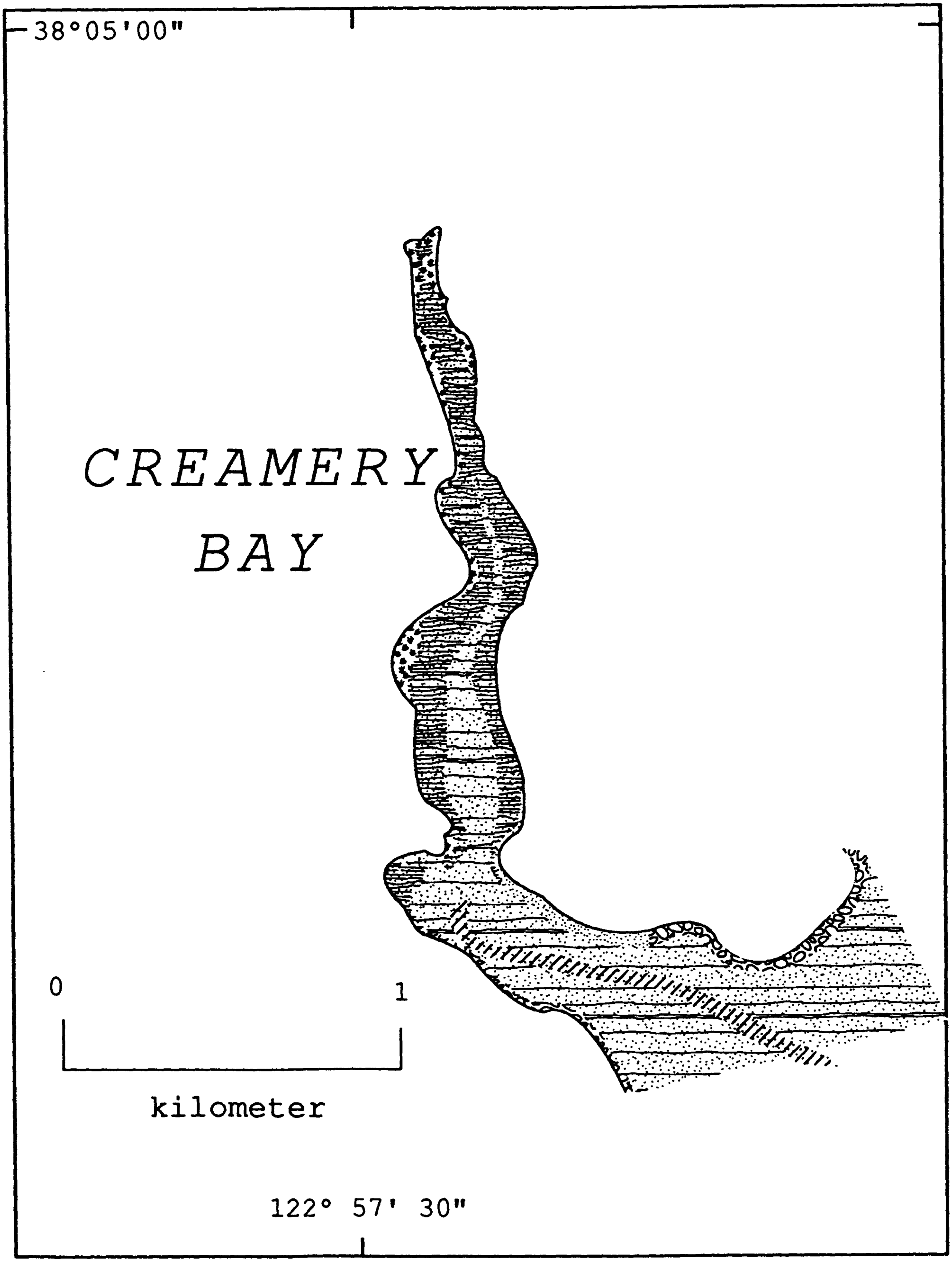
Key to Patterns and Texture



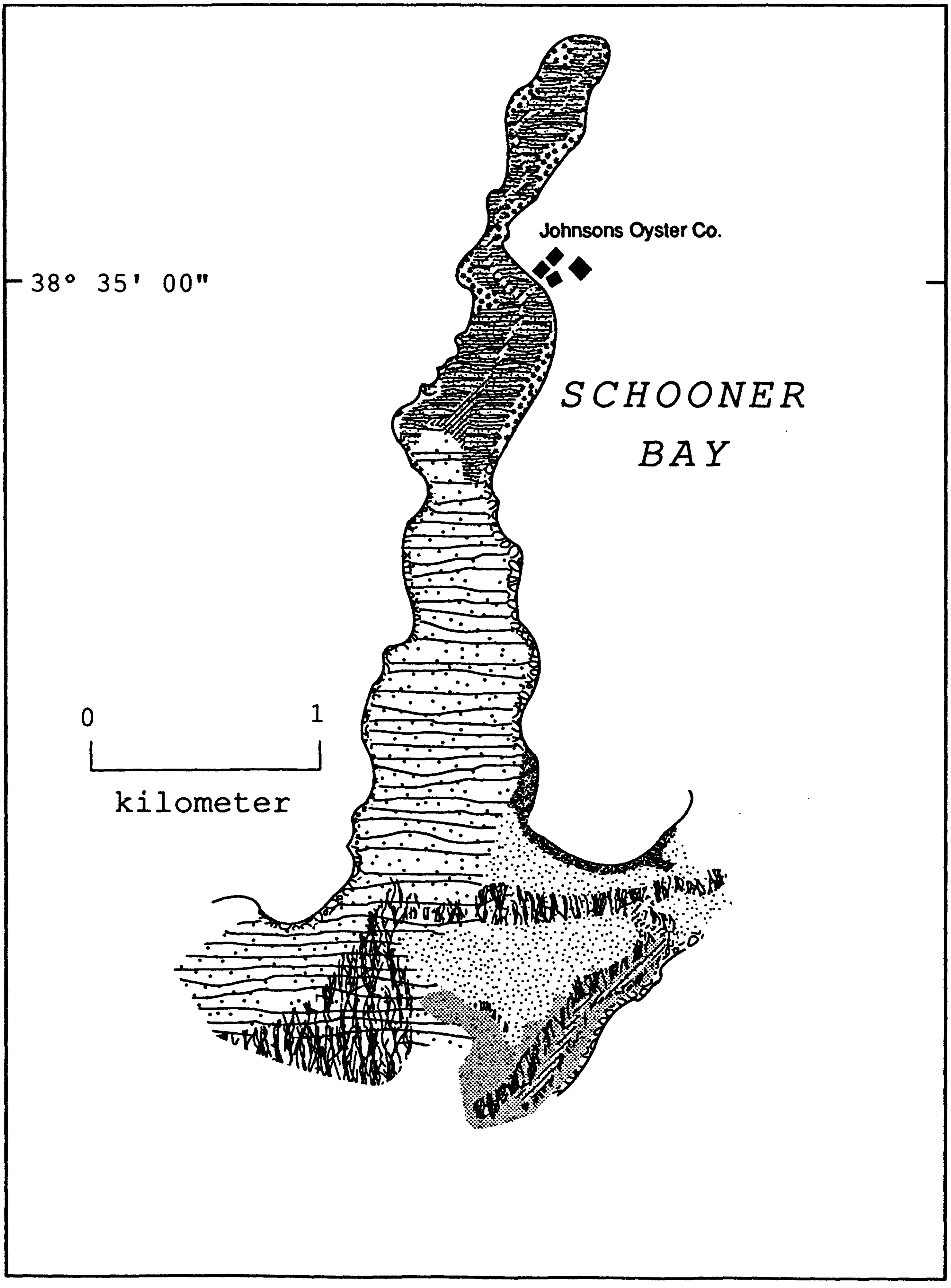
B1a. Key to patterns and textures used in figures B1b to B1g



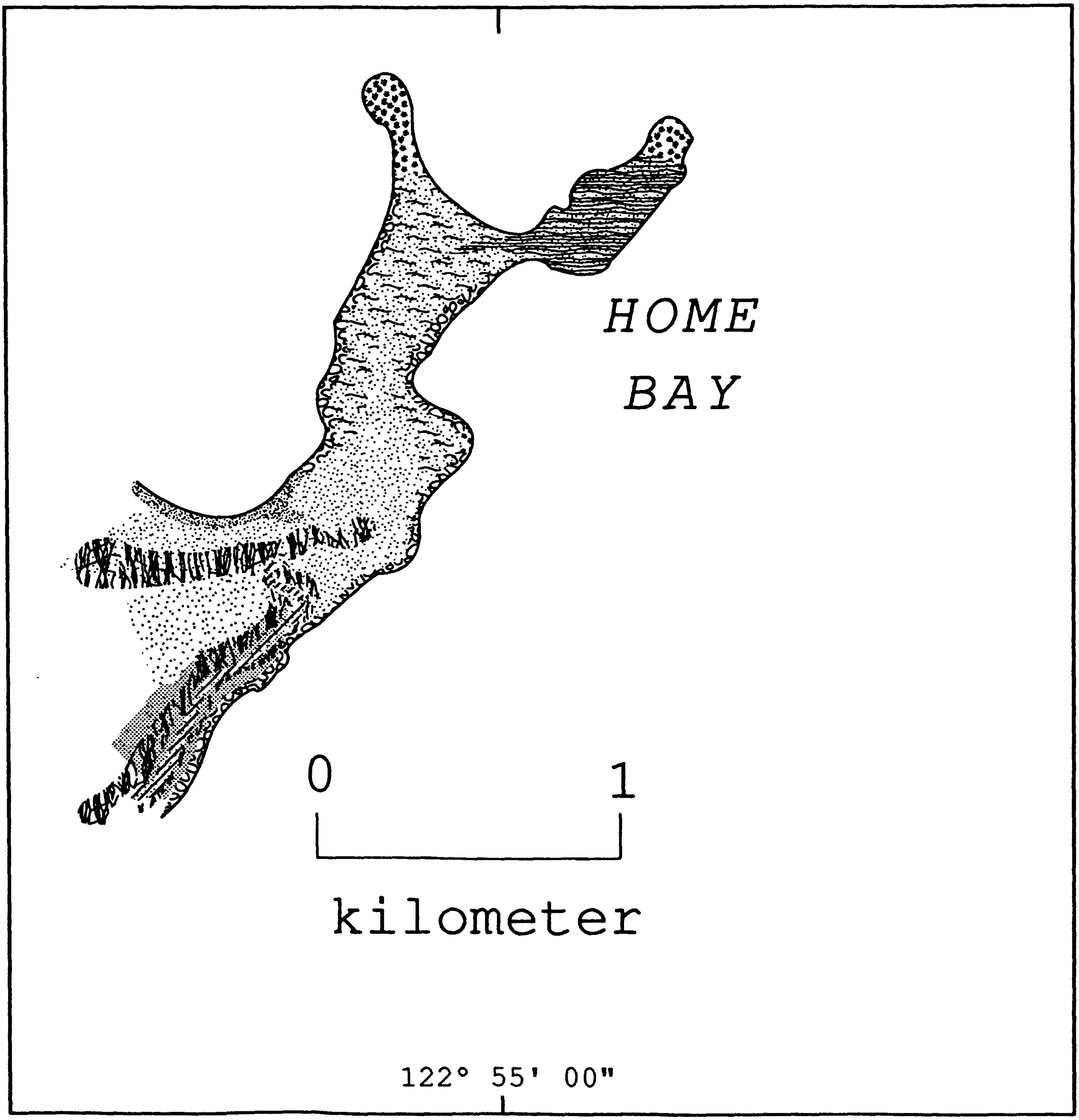
B1b. Sediment textures found in Barries Bay and portions of the central estero.



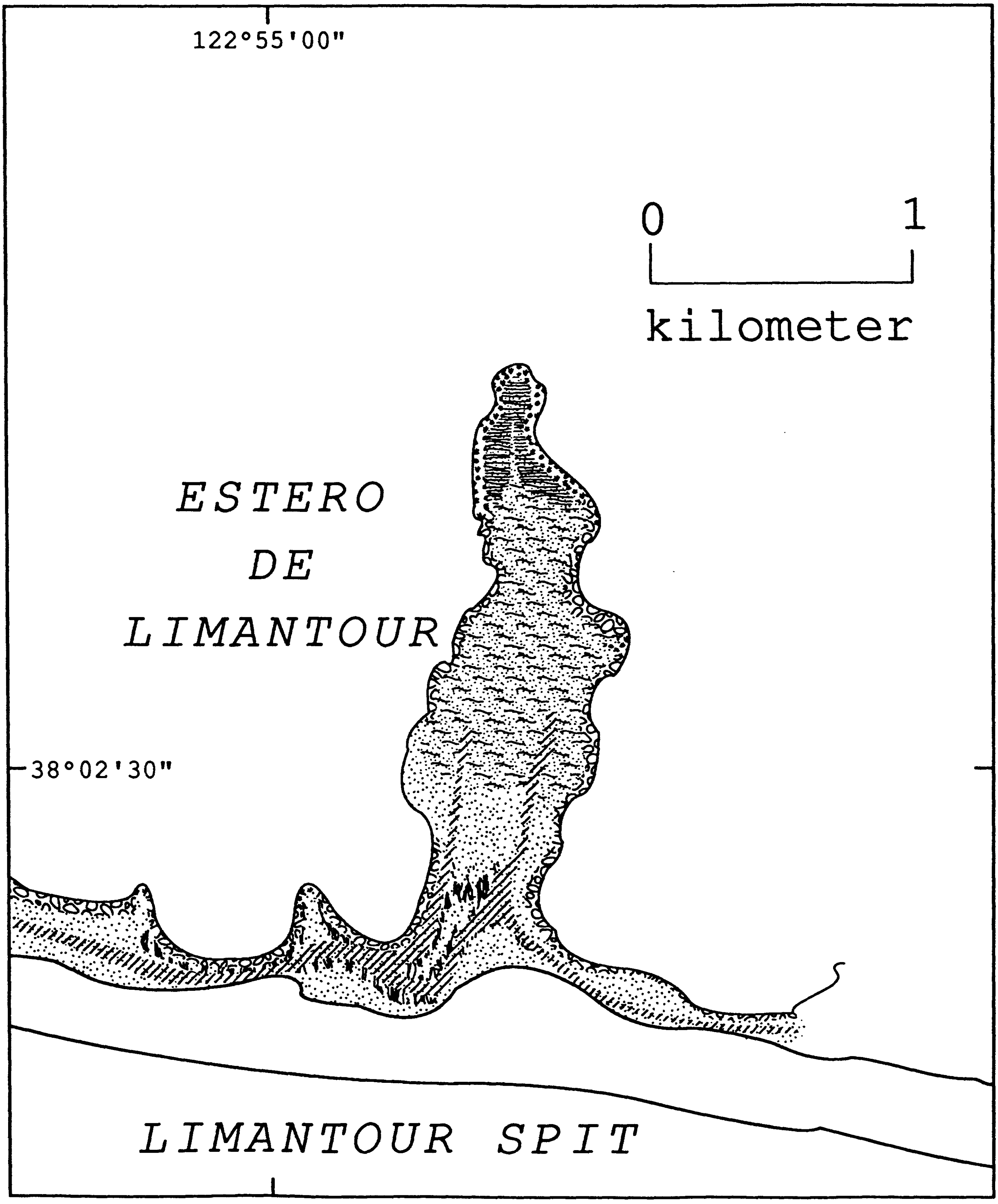
B1c. Sediment textures found in Creamery Bay



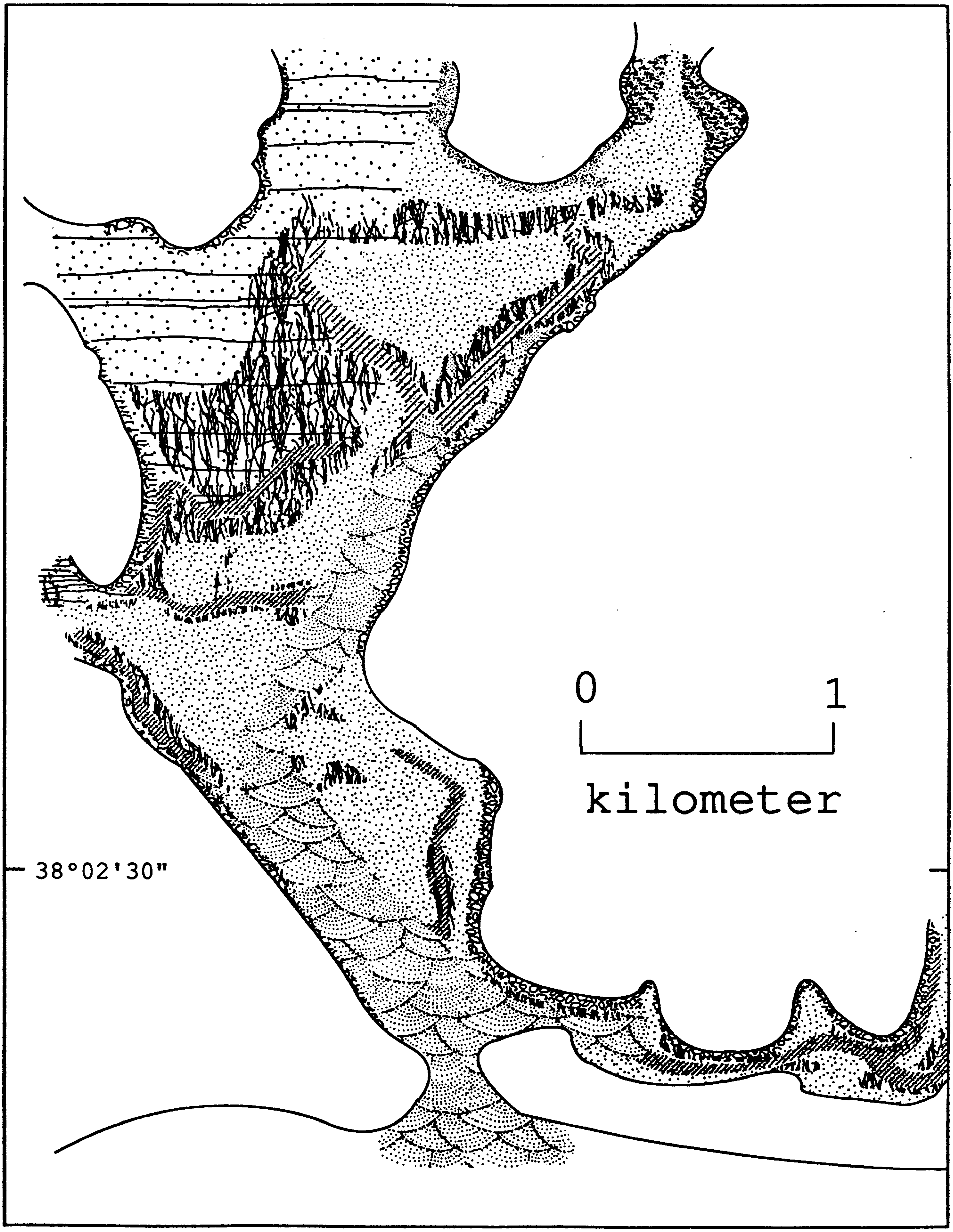
B1d. Sediment textures found in Schooner Bay, and northern portions of the central estero



B1e. Sediment textures found in Home Bay.



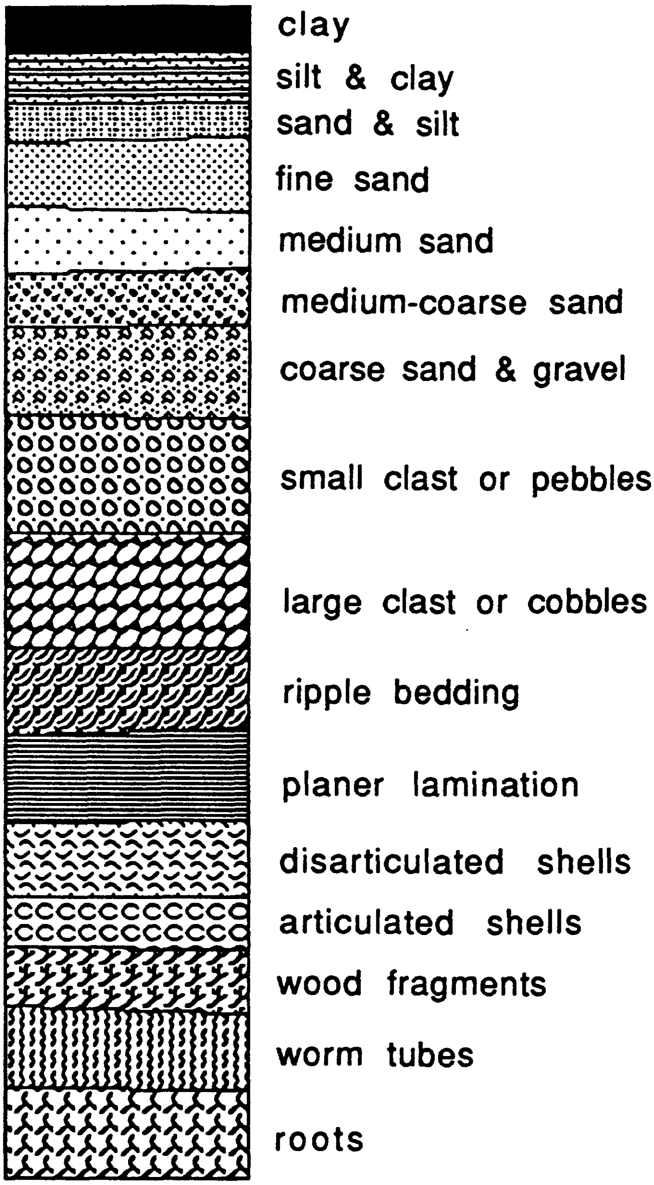
B1f. Sediment textures found in Estero de Limantour



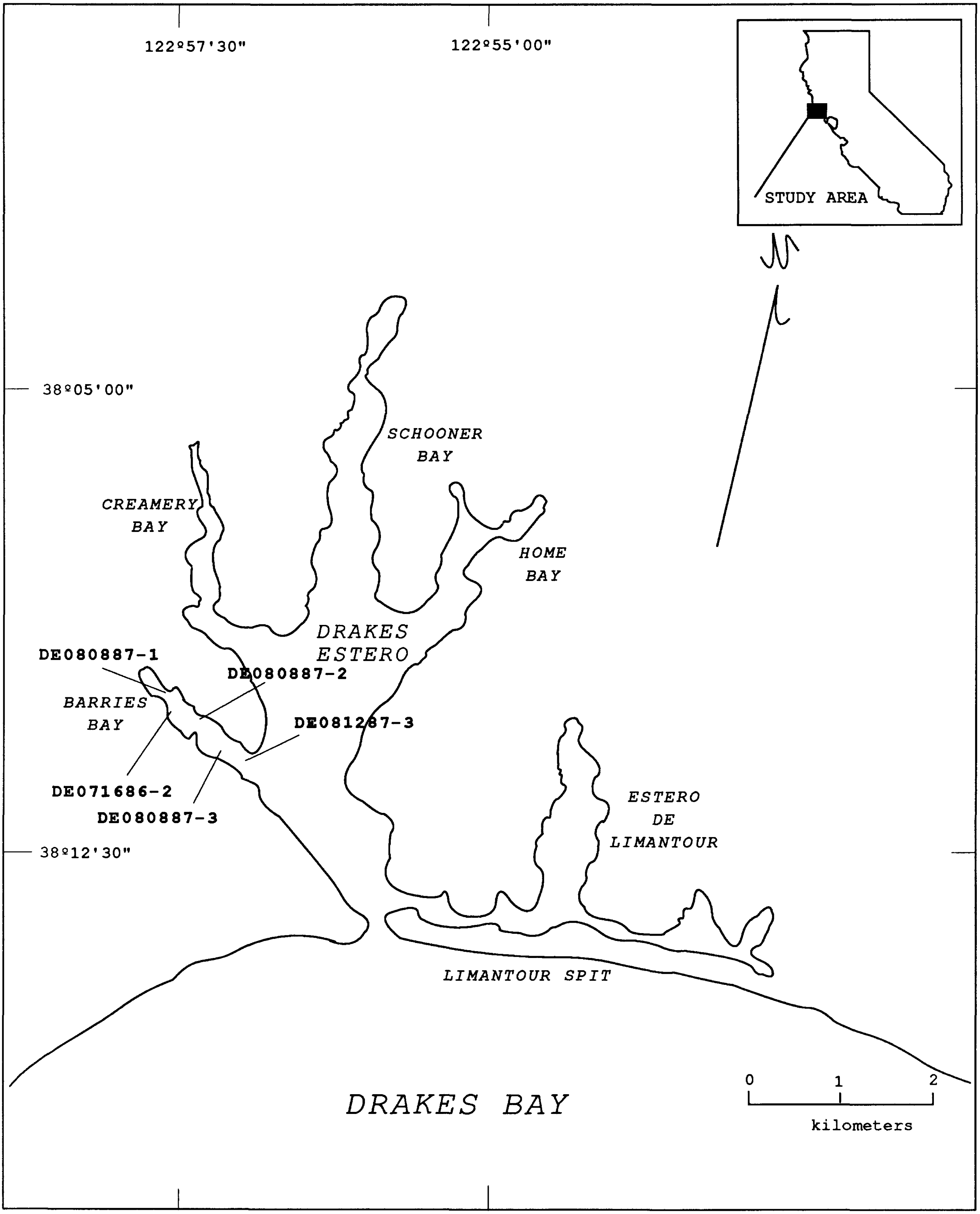
B1g. Sediment textures found in the central part of Drakes Estero.

Appendix C

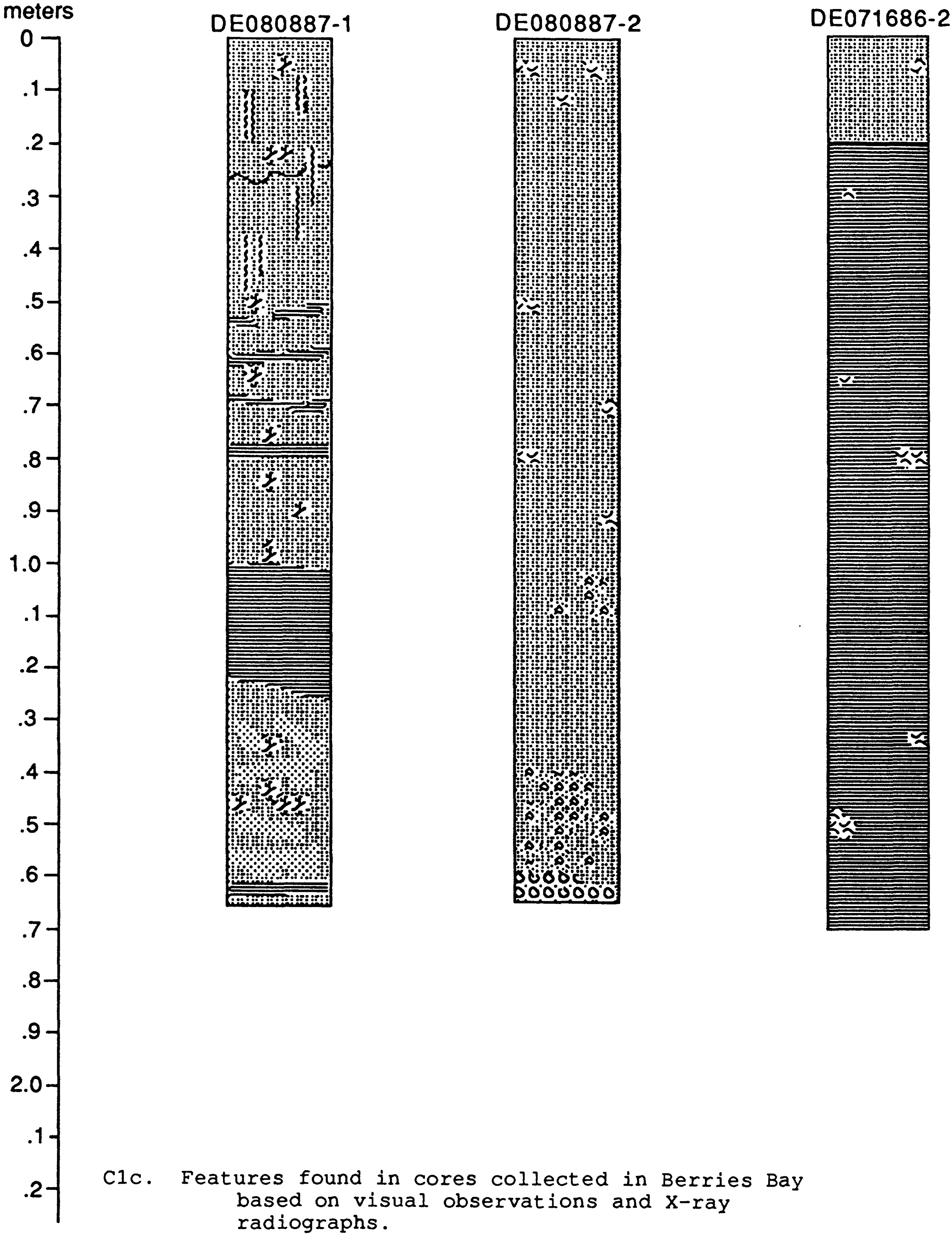
Key



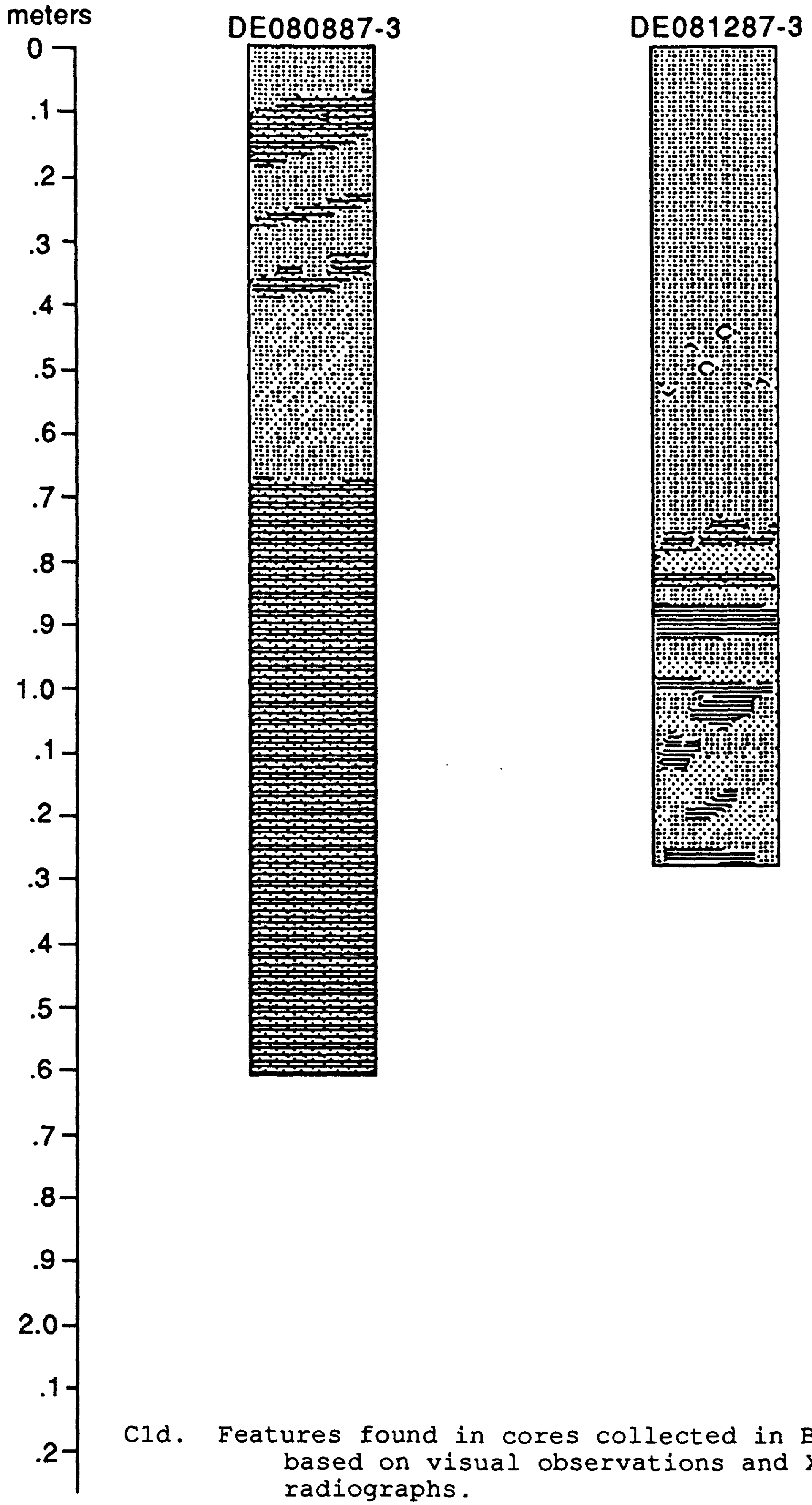
C1a. Key to textures and general features found in cores taken in Drakes Estero and Abbotts Lagoon.



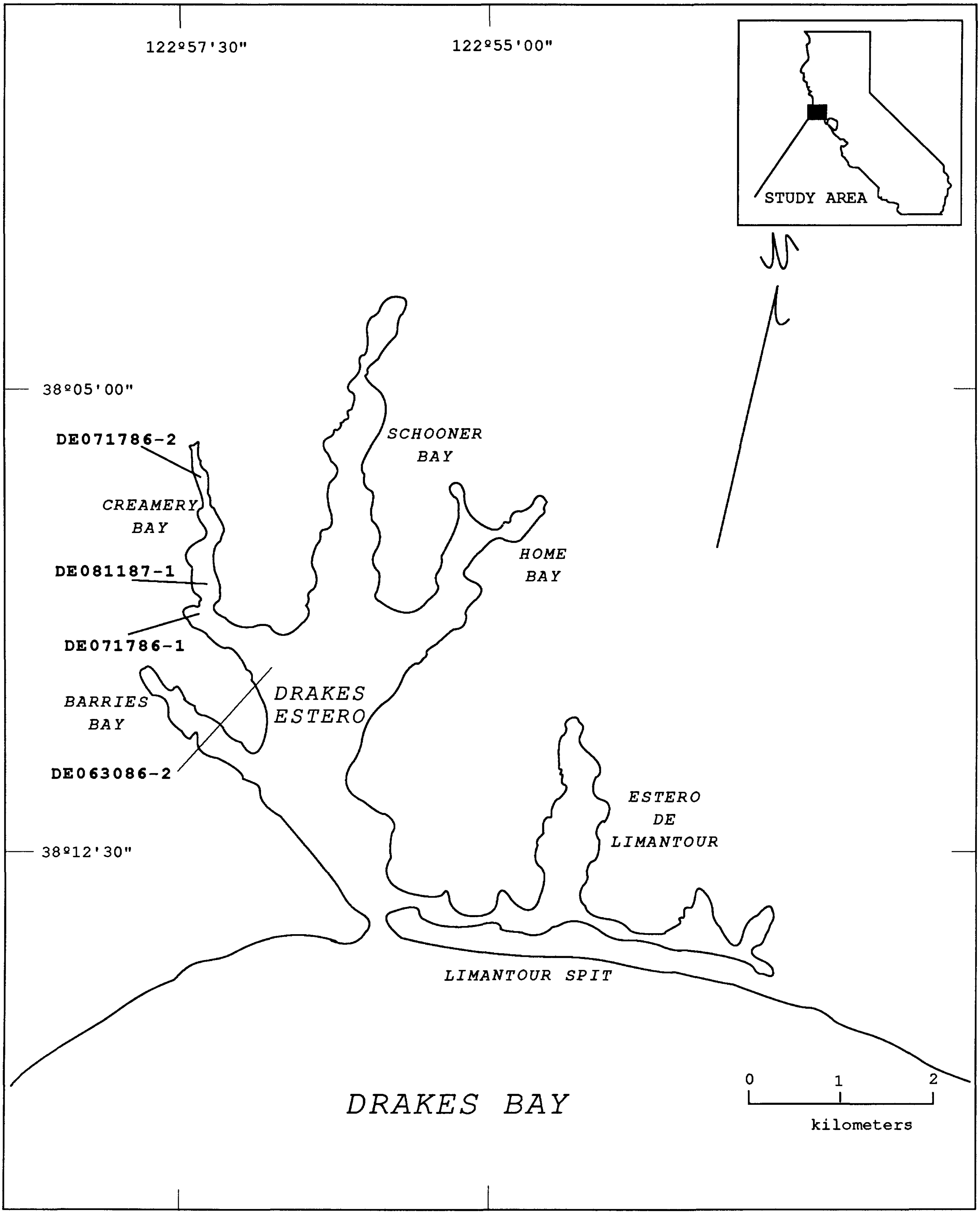
C1b. Map showing locations of cores collected in Barries Bay.



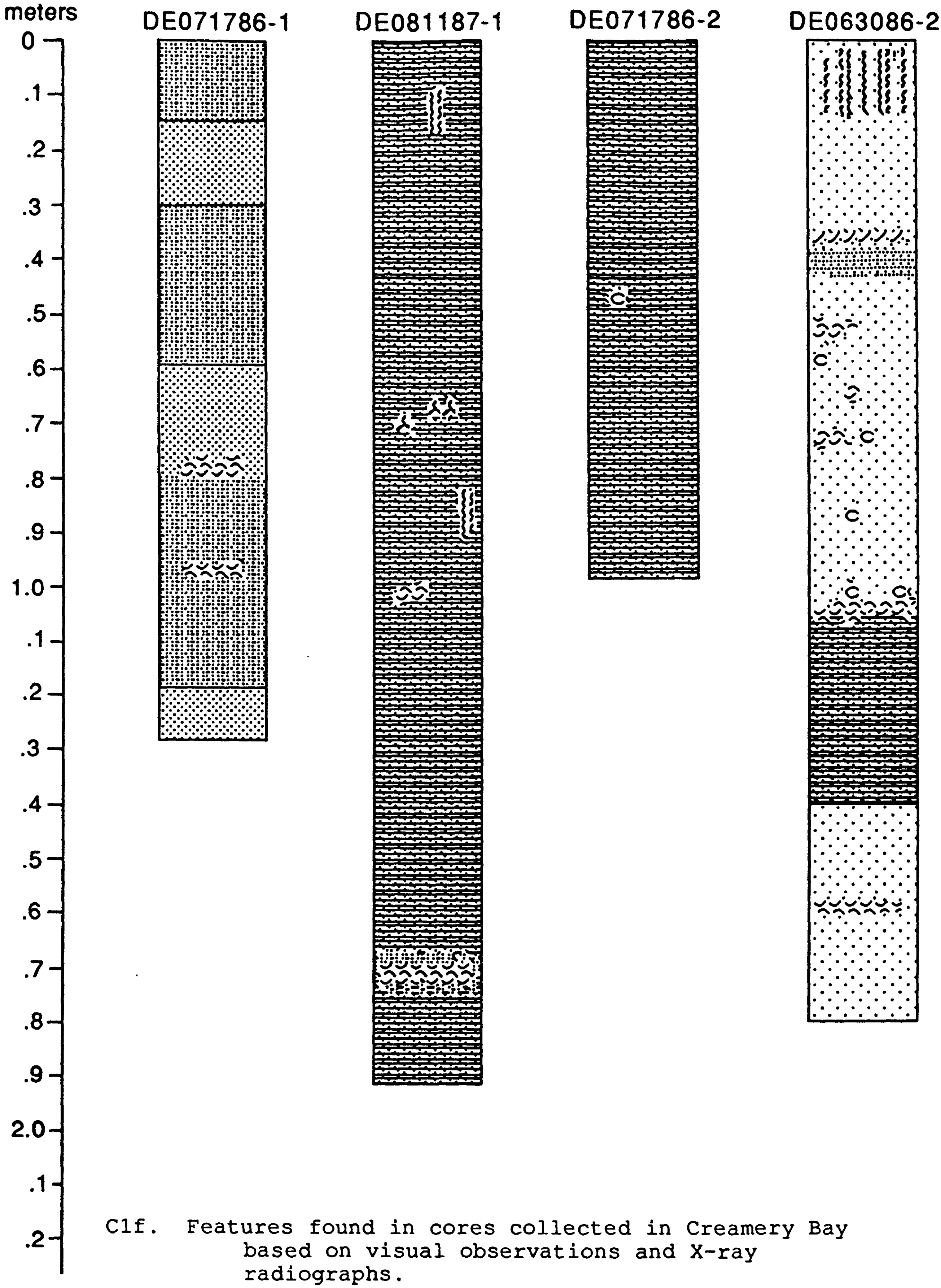
C1c. Features found in cores collected in Berries Bay based on visual observations and X-ray radiographs.



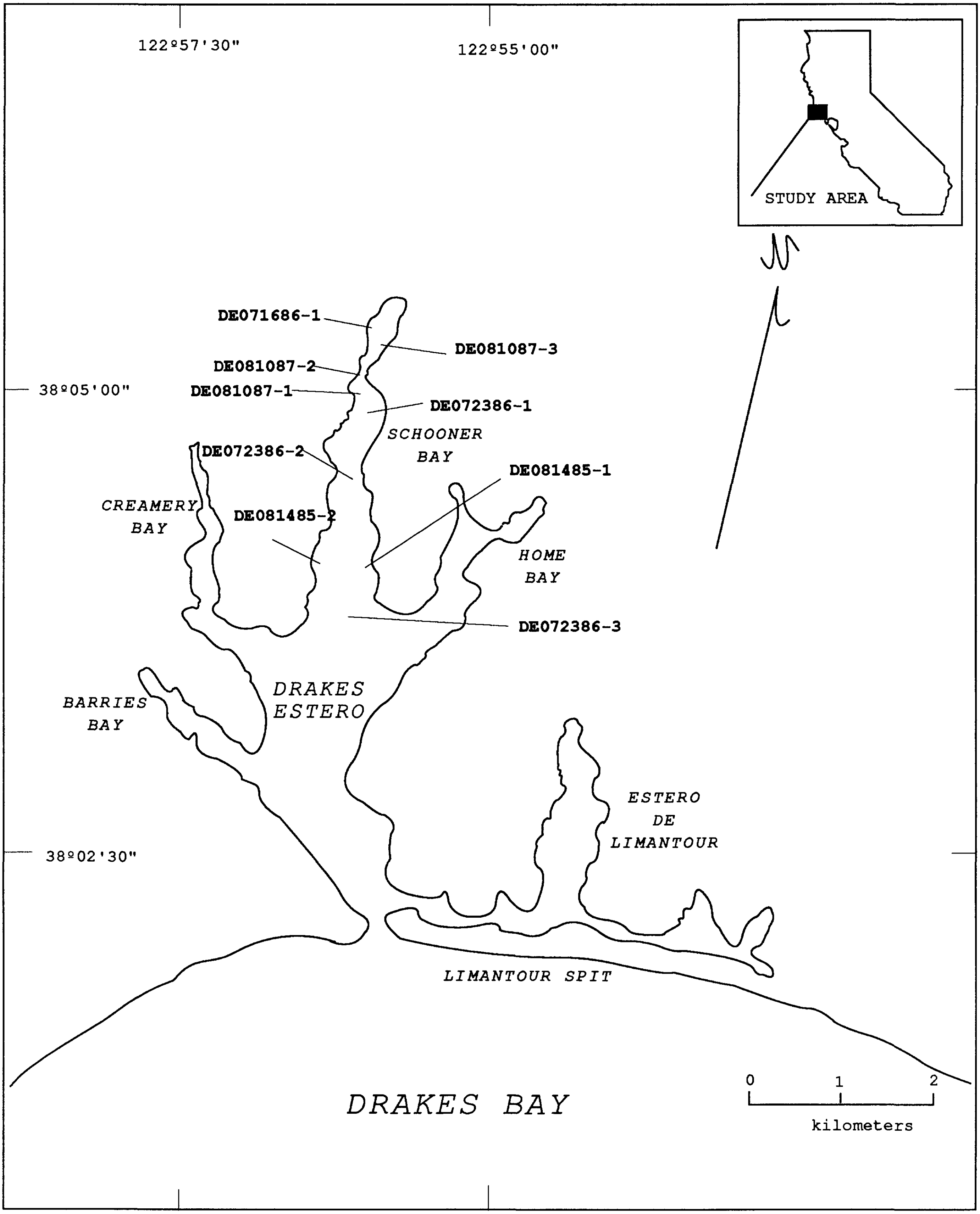
C1d. Features found in cores collected in Berries Bay based on visual observations and X-ray radiographs.



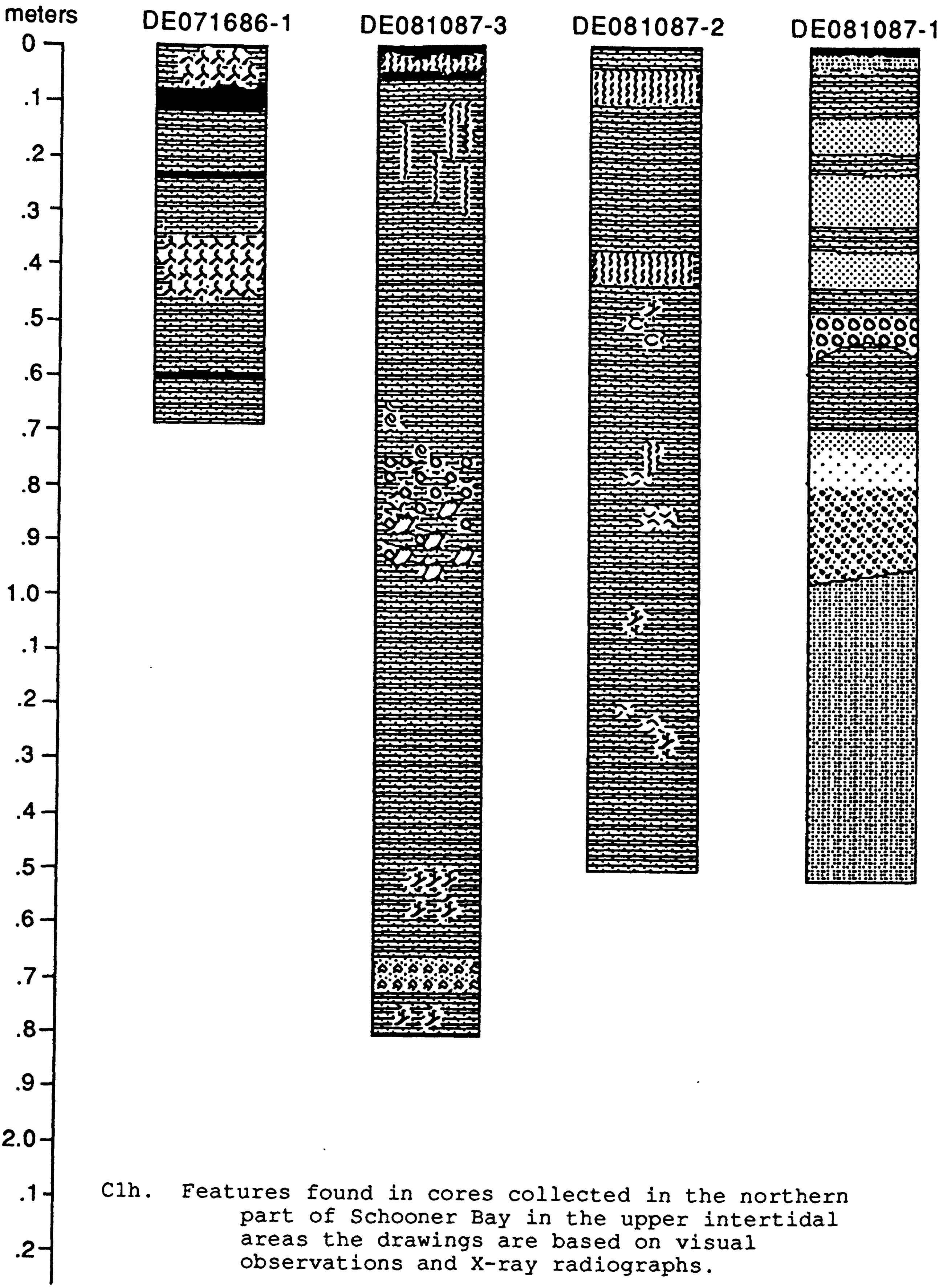
C1e. Map showing locations of cores collected in Creamery Bay.



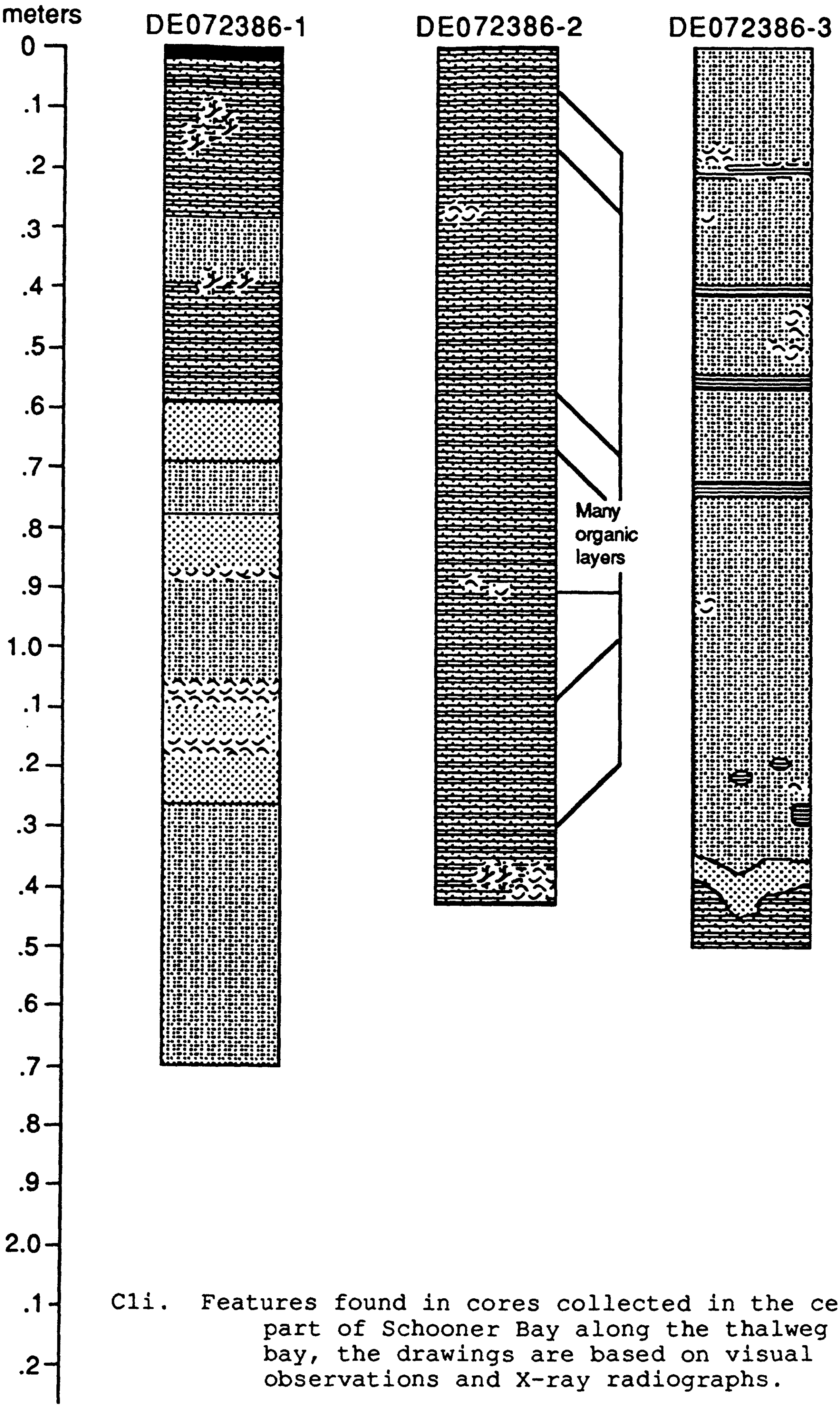
C1f. Features found in cores collected in Creamery Bay based on visual observations and X-ray radiographs.



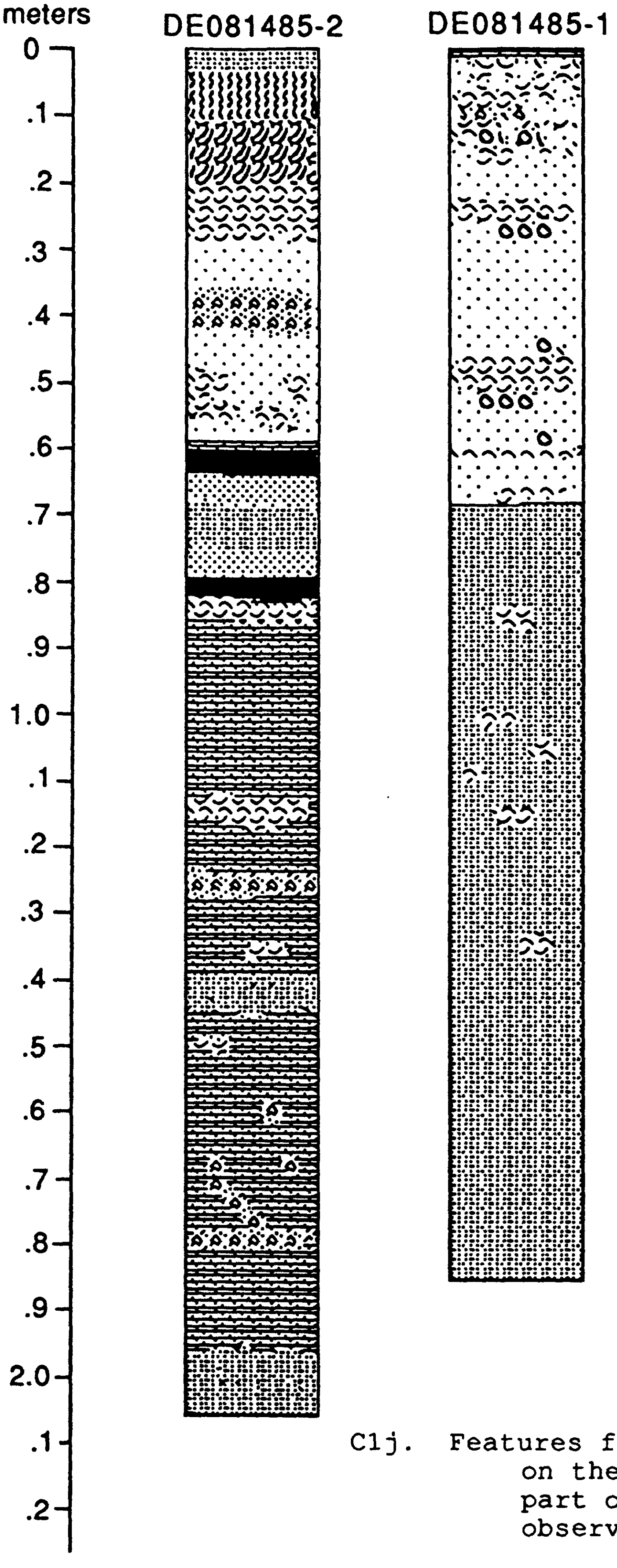
C1g. Map showing locations of cores collected in Schooner Bay.



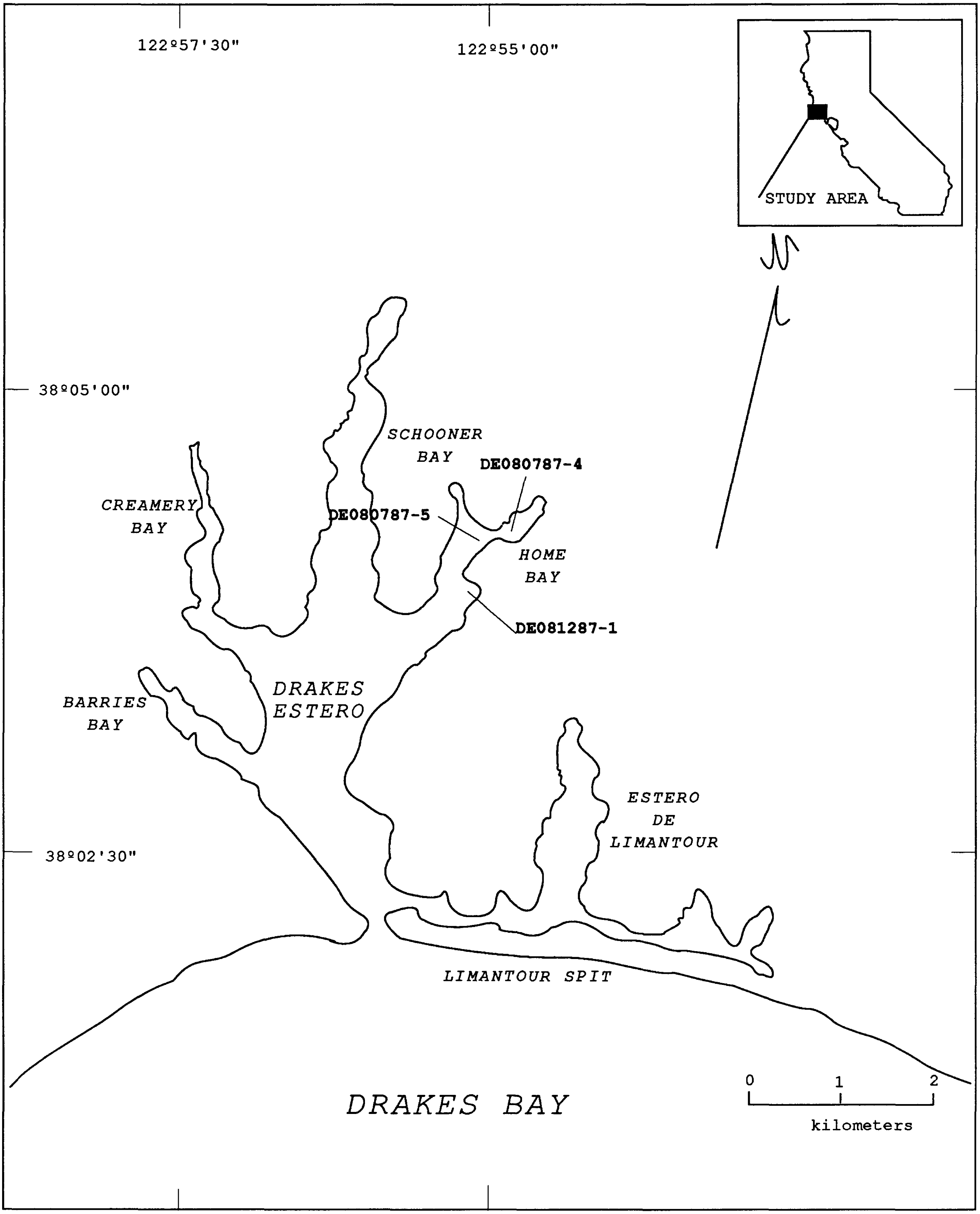
C1h. Features found in cores collected in the northern part of Schooner Bay in the upper intertidal areas the drawings are based on visual observations and X-ray radiographs.



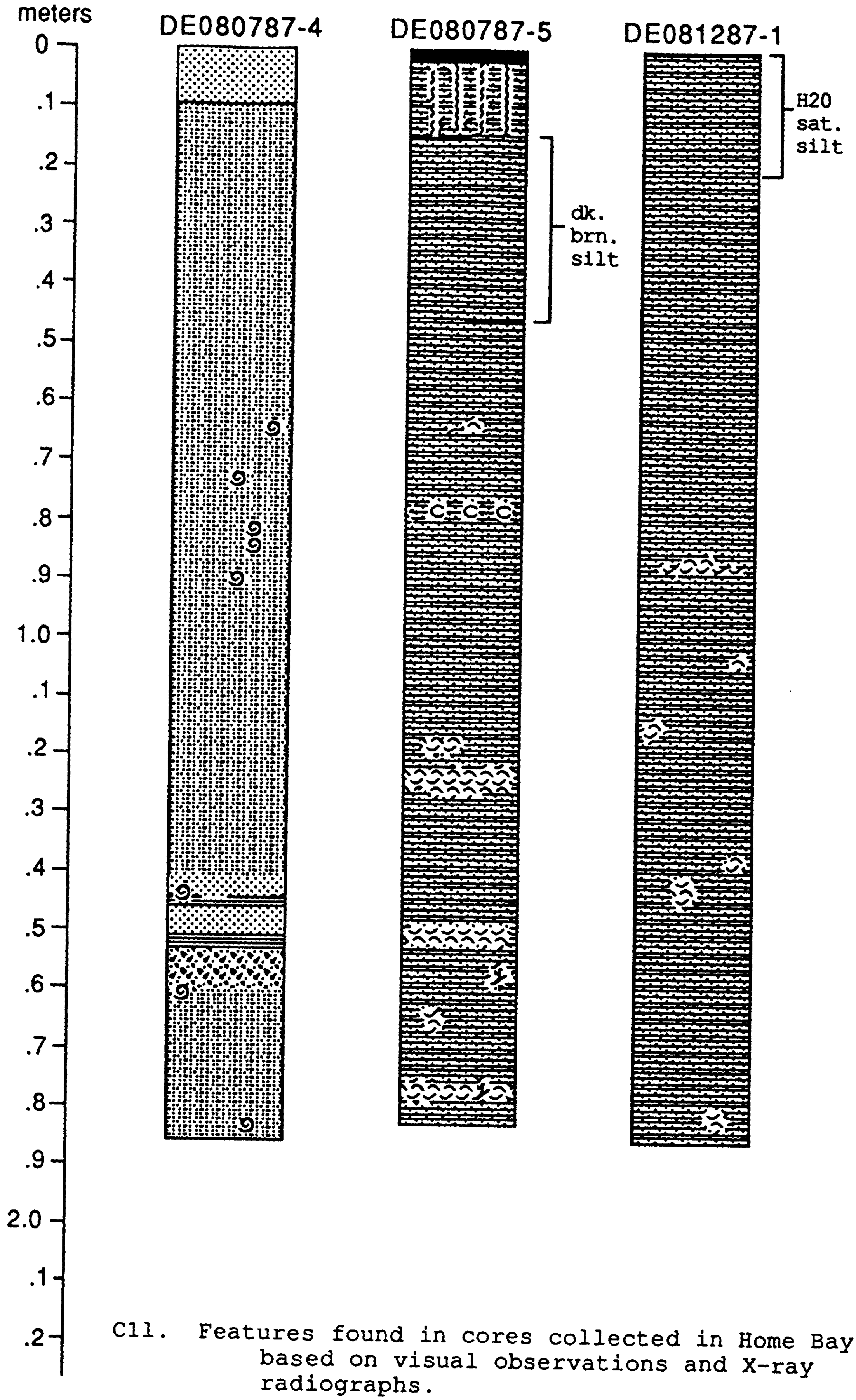
C1i. Features found in cores collected in the central part of Schooner Bay along the thalweg of the bay, the drawings are based on visual observations and X-ray radiographs.



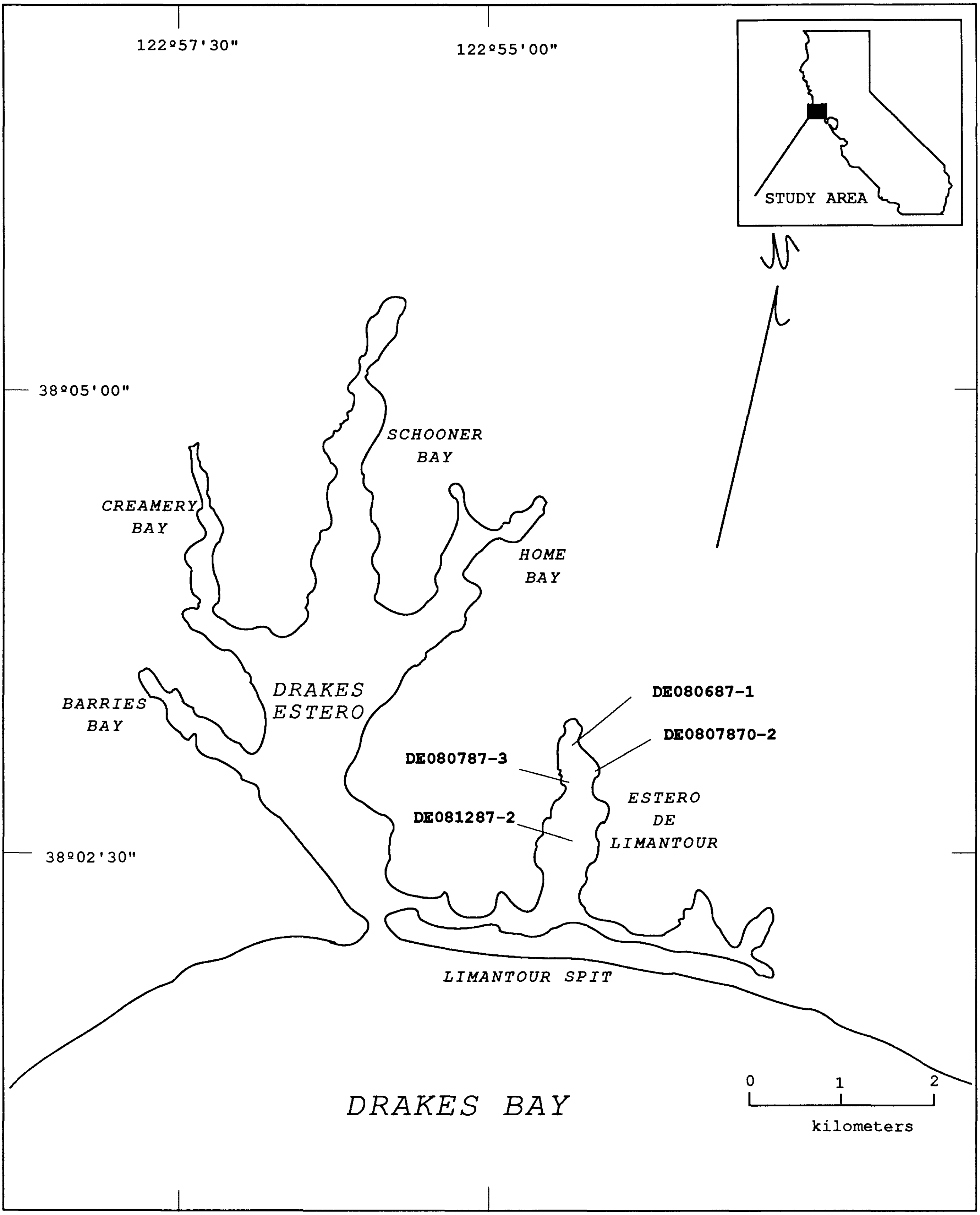
C1j. Features found in cores collected in Schooner Bay on the east and west sides of the southern part of bay, drawings are based on visual observations and X-ray radiographs.



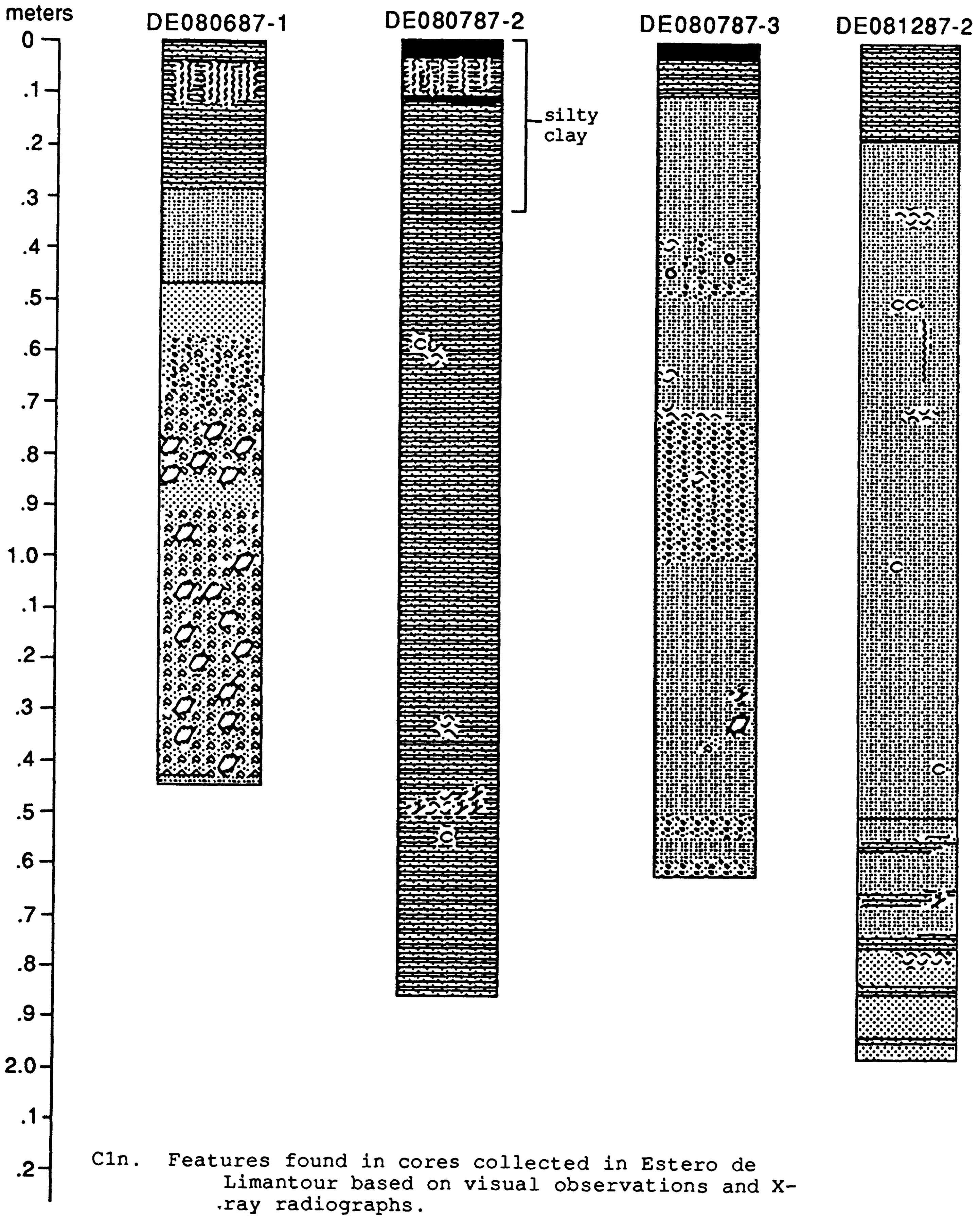
C1m. Map showing locations of cores collected in Home Bay.



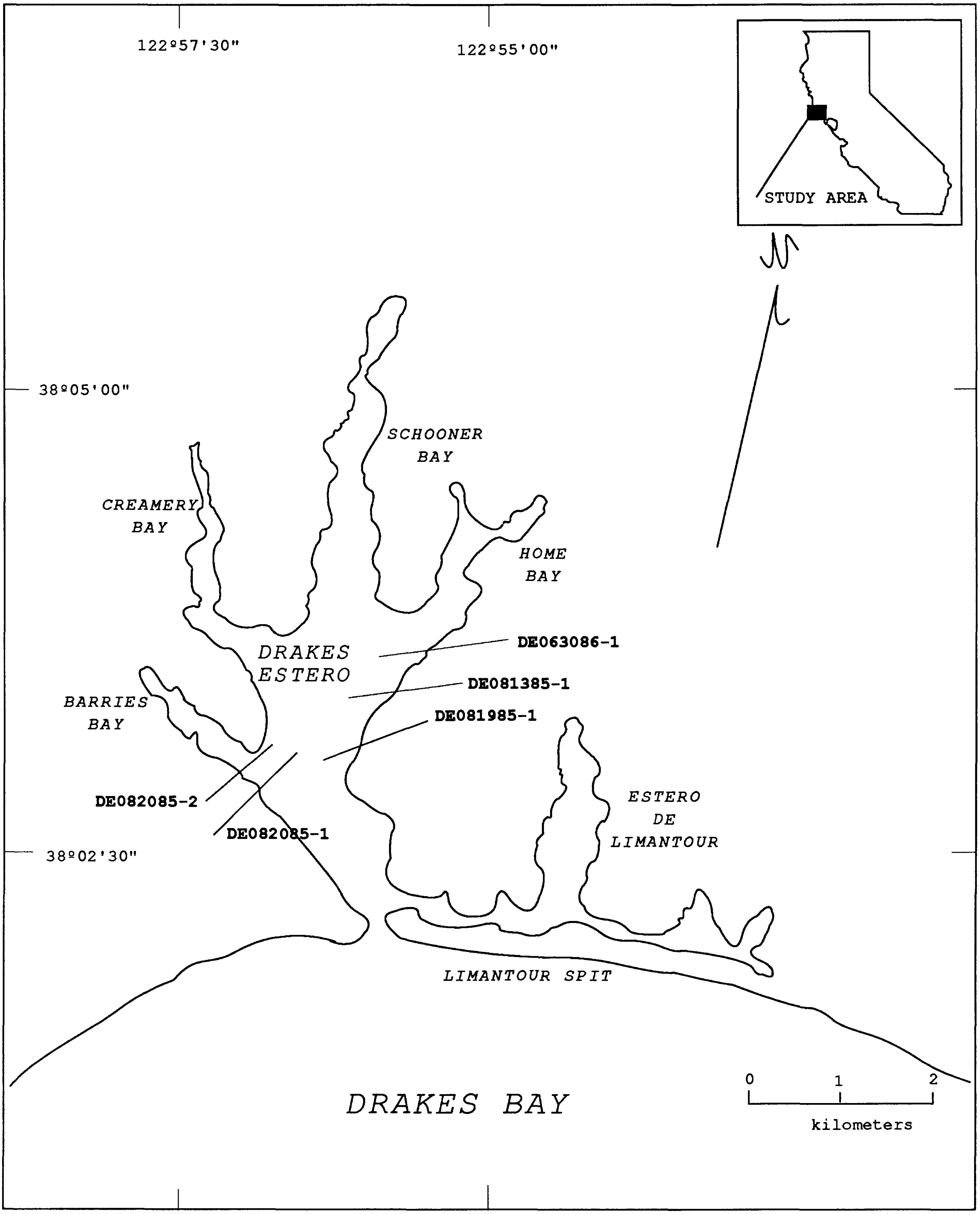
C11. Features found in cores collected in Home Bay based on visual observations and X-ray radiographs.



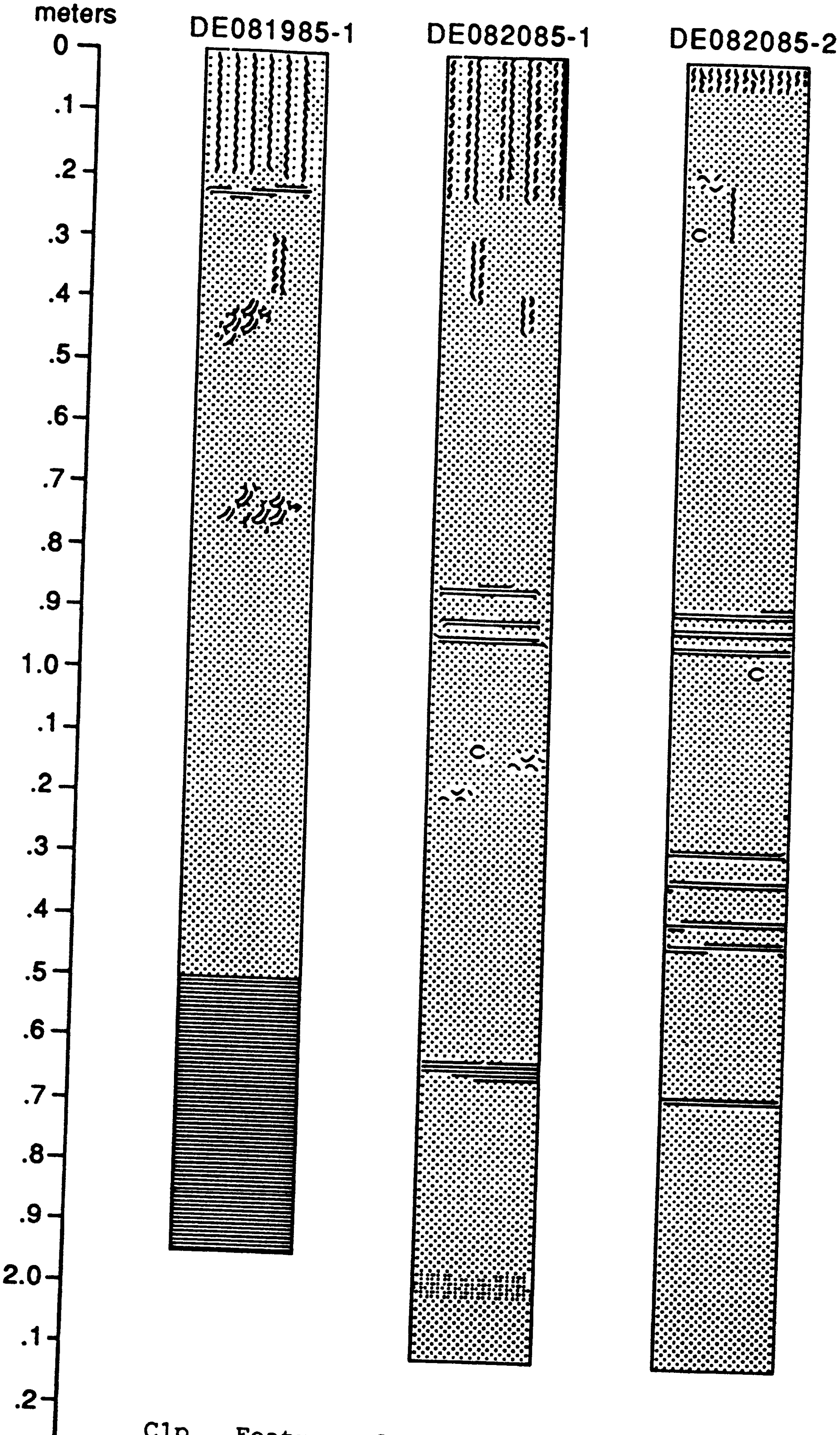
C1m. Map showing locations of cores collected in Estero de Limantour.



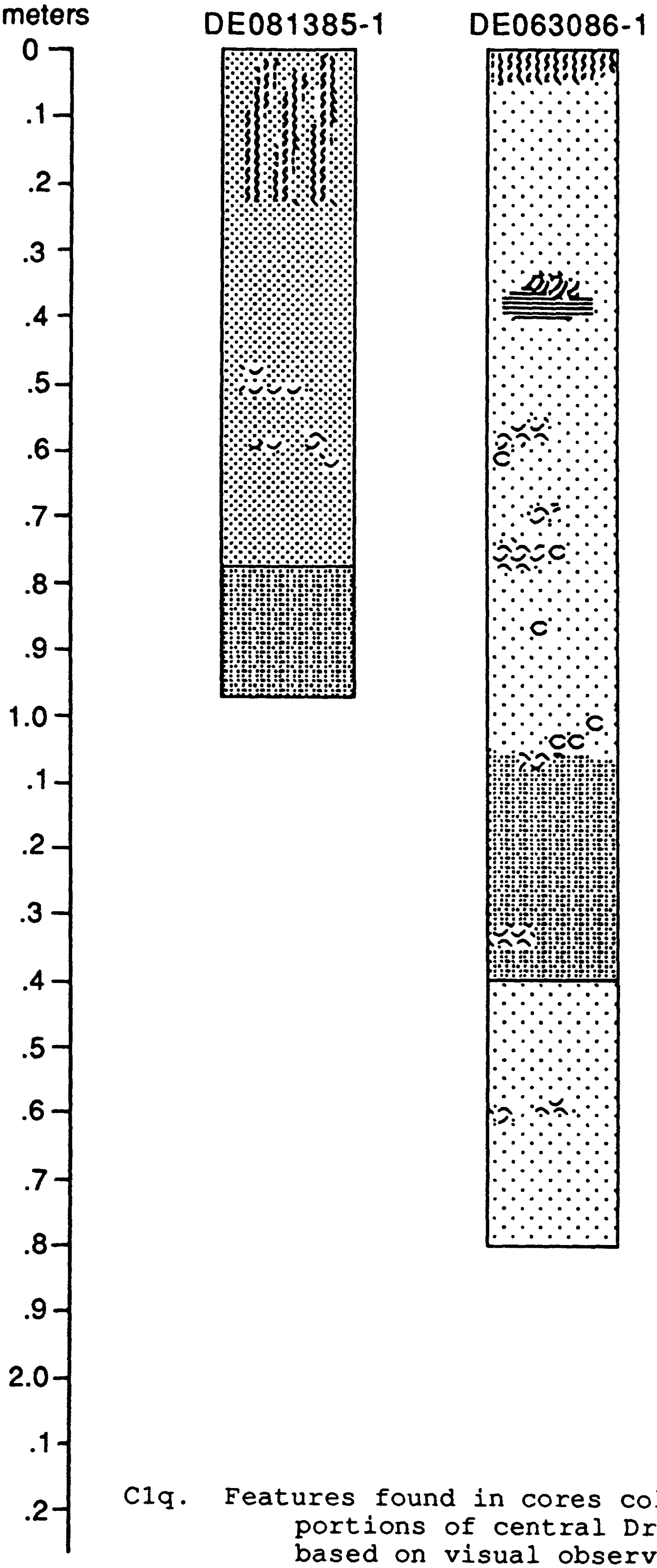
C1n. Features found in cores collected in Estero de Limantour based on visual observations and X-ray radiographs.



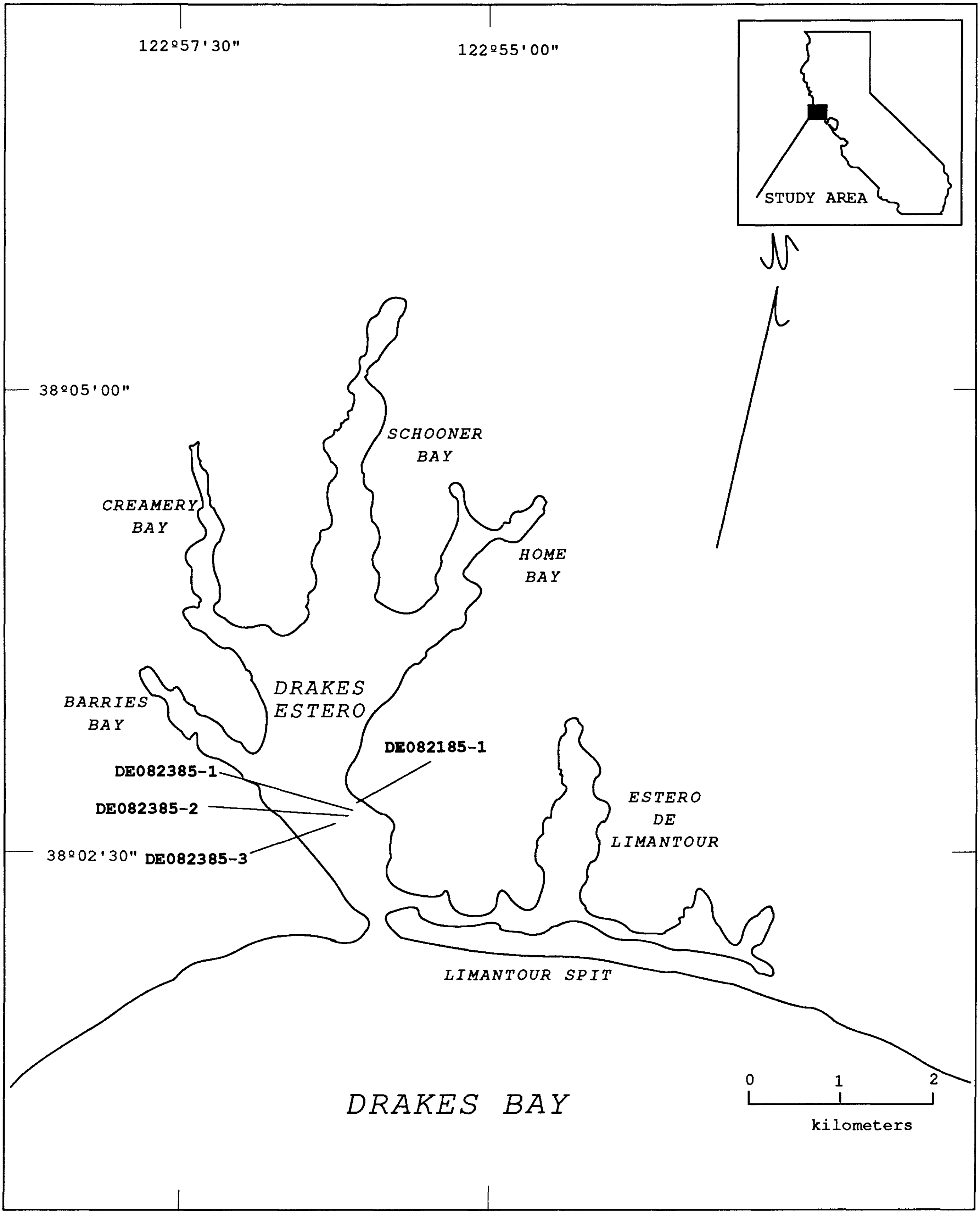
C1o. Map showing the locations of cores collected in the mid-portion of central Drakes Estero.



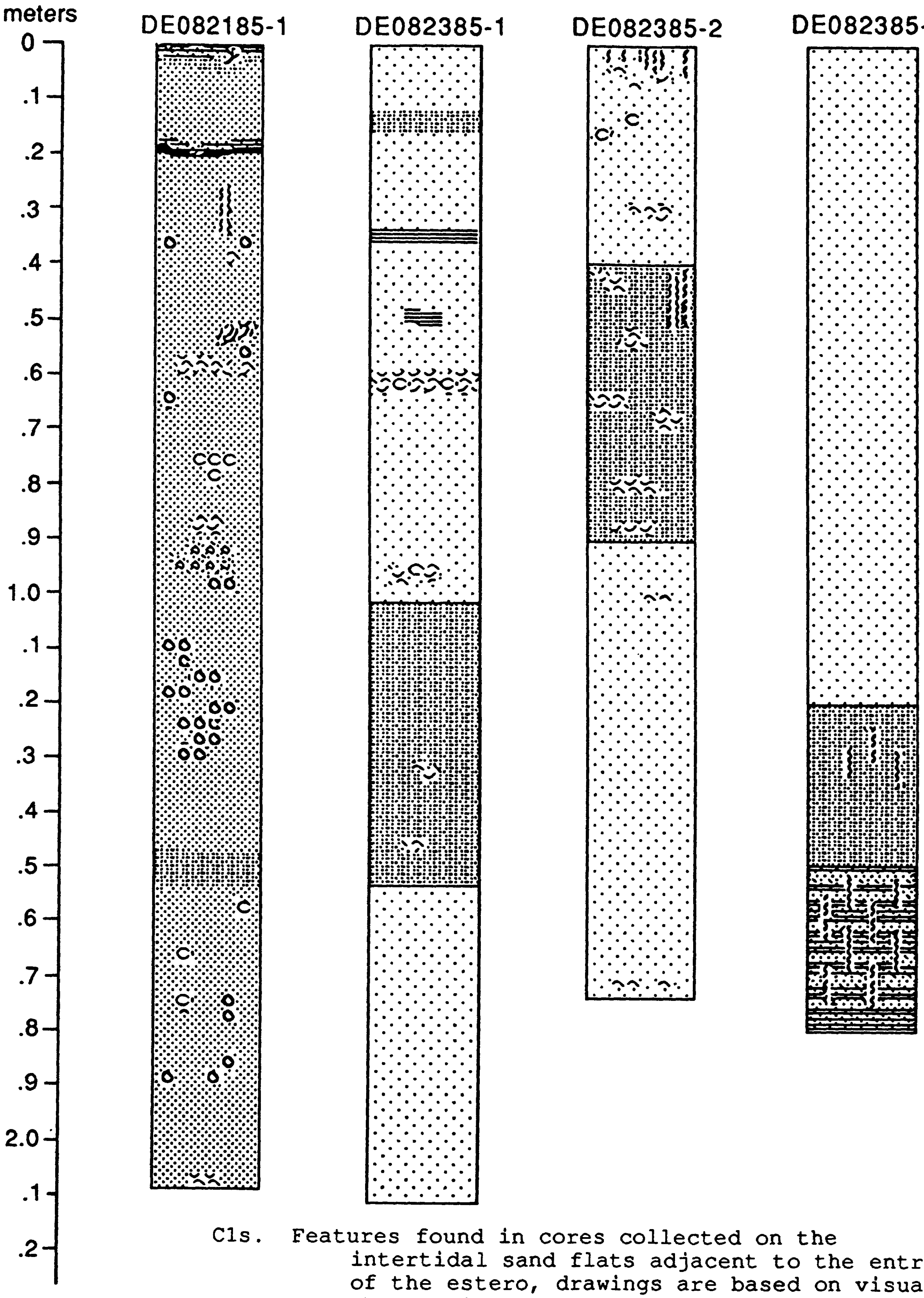
C1p. Features found in cores collected in the mid-portions of central Drakes Estero drawings are based on visual observations and X-ray radiographs.



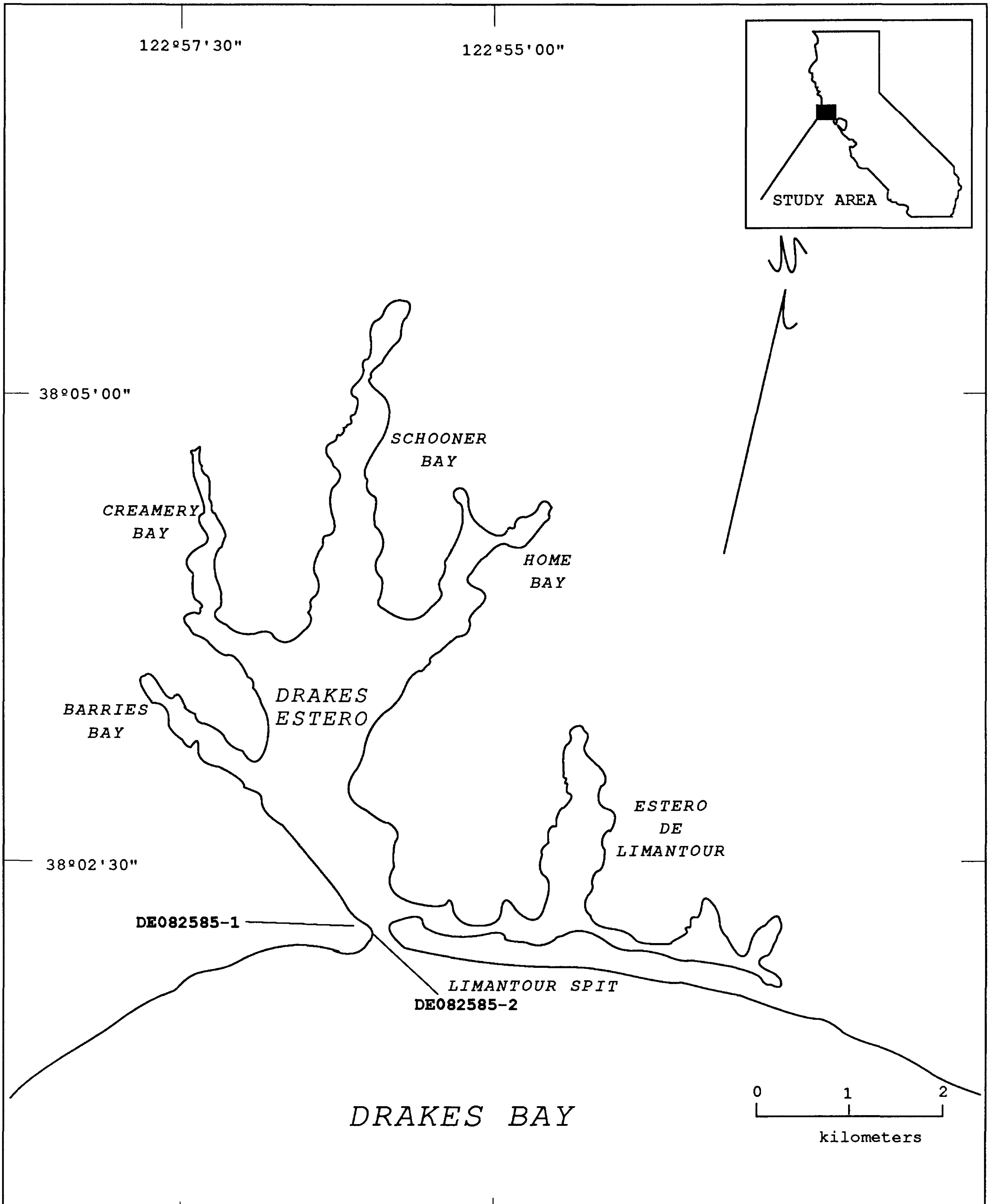
C1q. Features found in cores collected in the mid-portions of central Drakes Estero drawings are based on visual observations and X-ray radiographs.



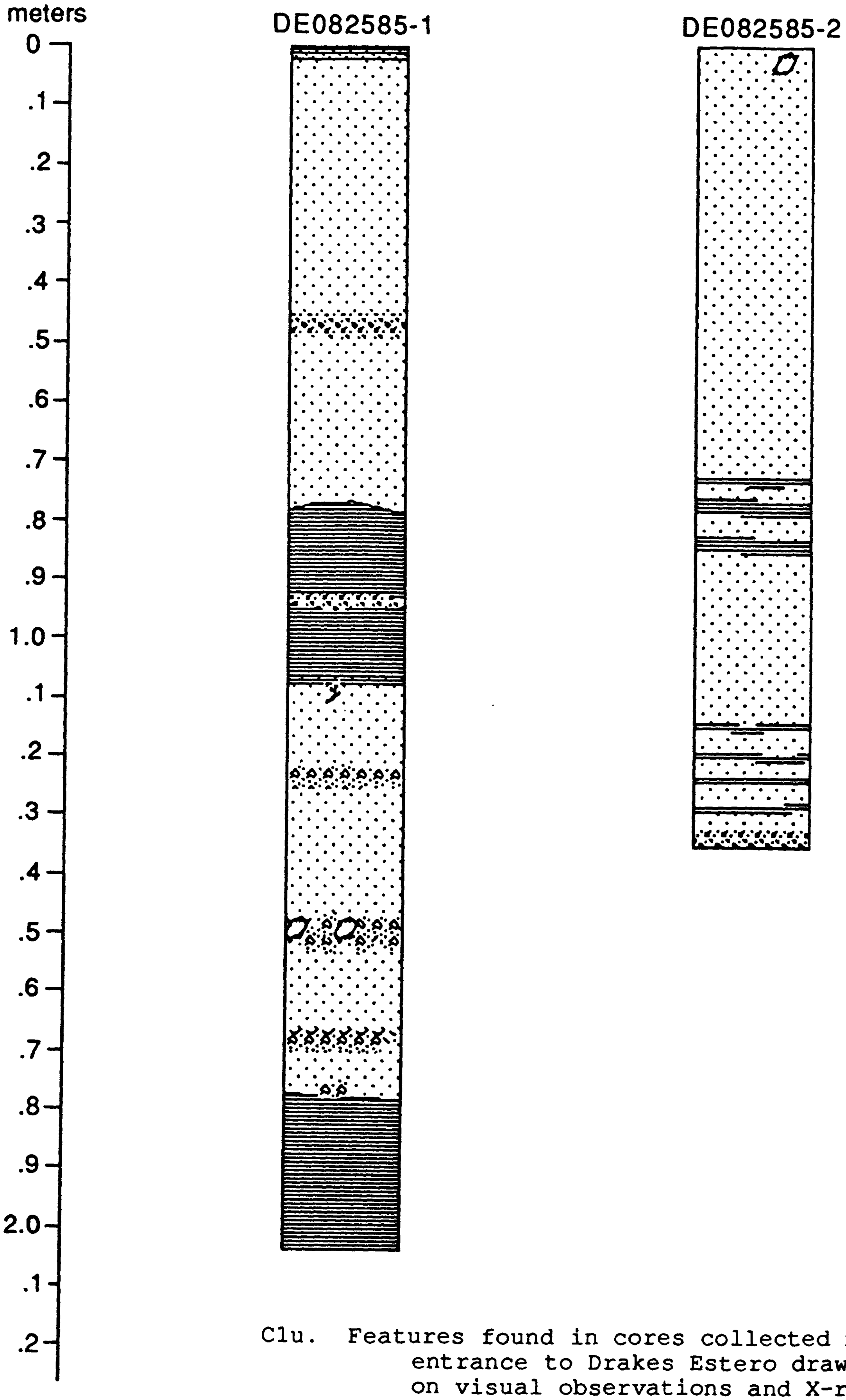
C1r. Map showing locations of cores collected on the intertidal sand flats adjacent to the entrance of the estero.



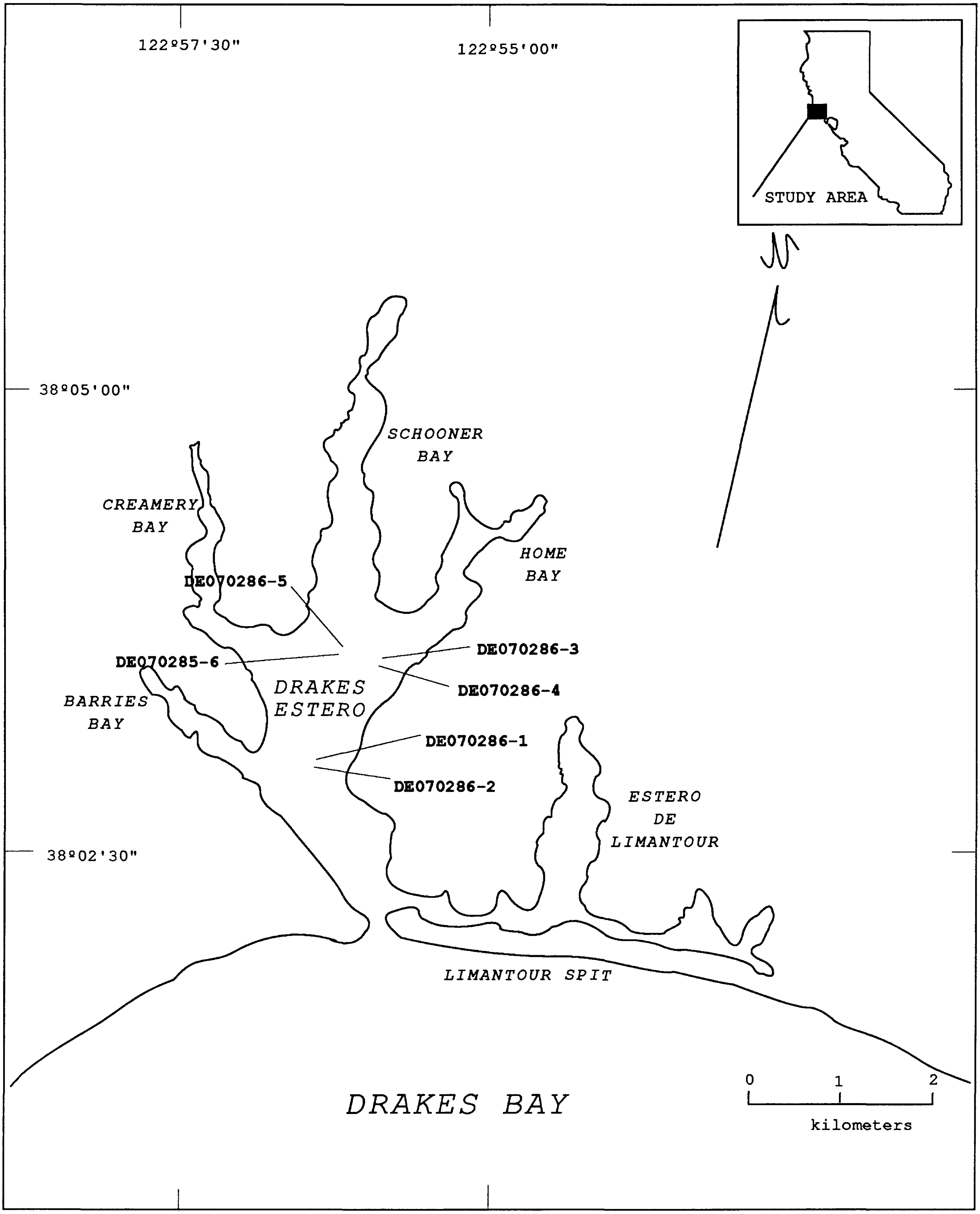
C1s. Features found in cores collected on the intertidal sand flats adjacent to the entrance of the estero, drawings are based on visual observations and X-ray radiographs.



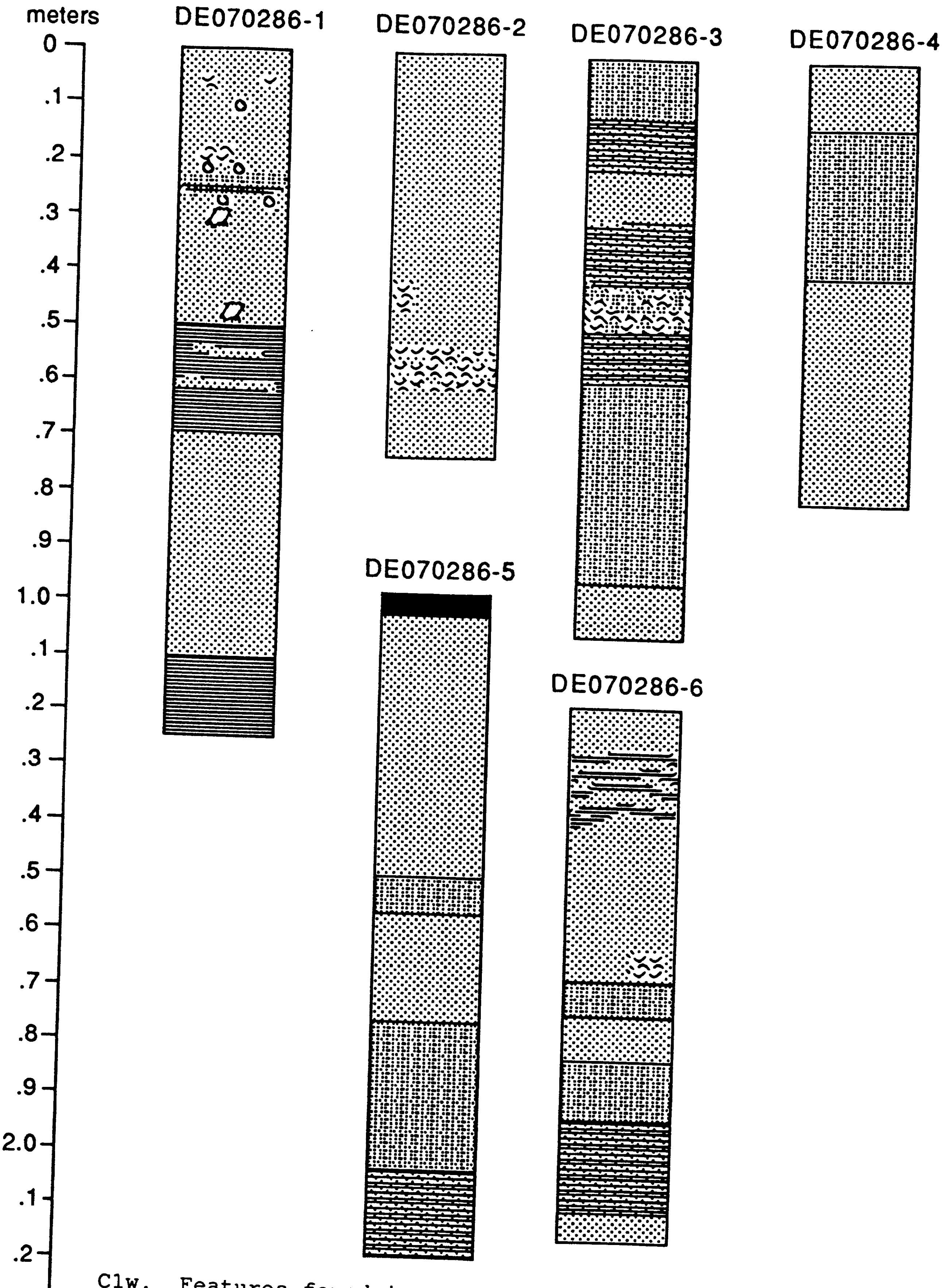
C1t. Map showing locations of cores collected near the entrance of Drakes Estero.



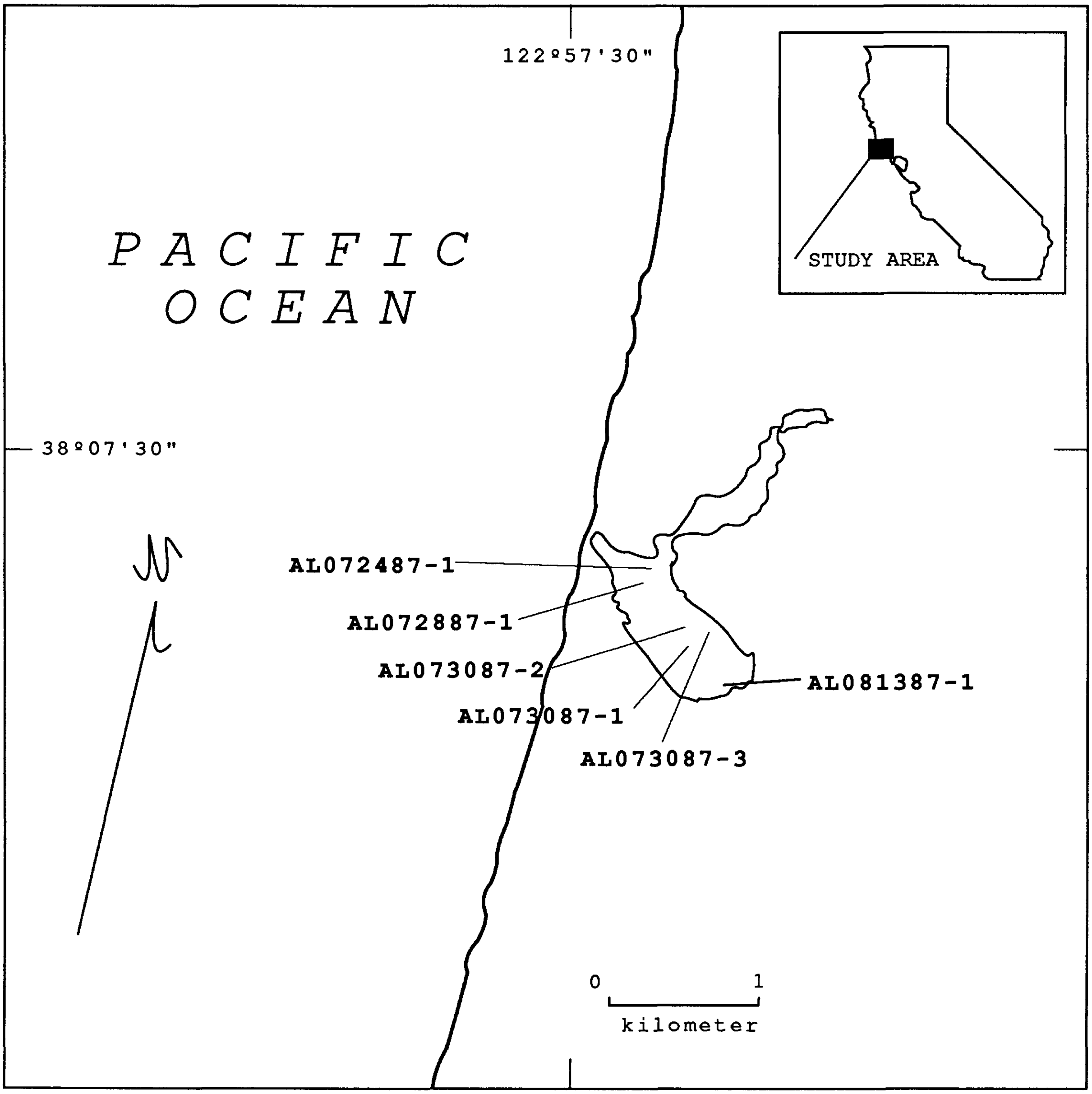
Clu. Features found in cores collected near the entrance to Drakes Estero drawings are based on visual observations and X-ray radiographs.



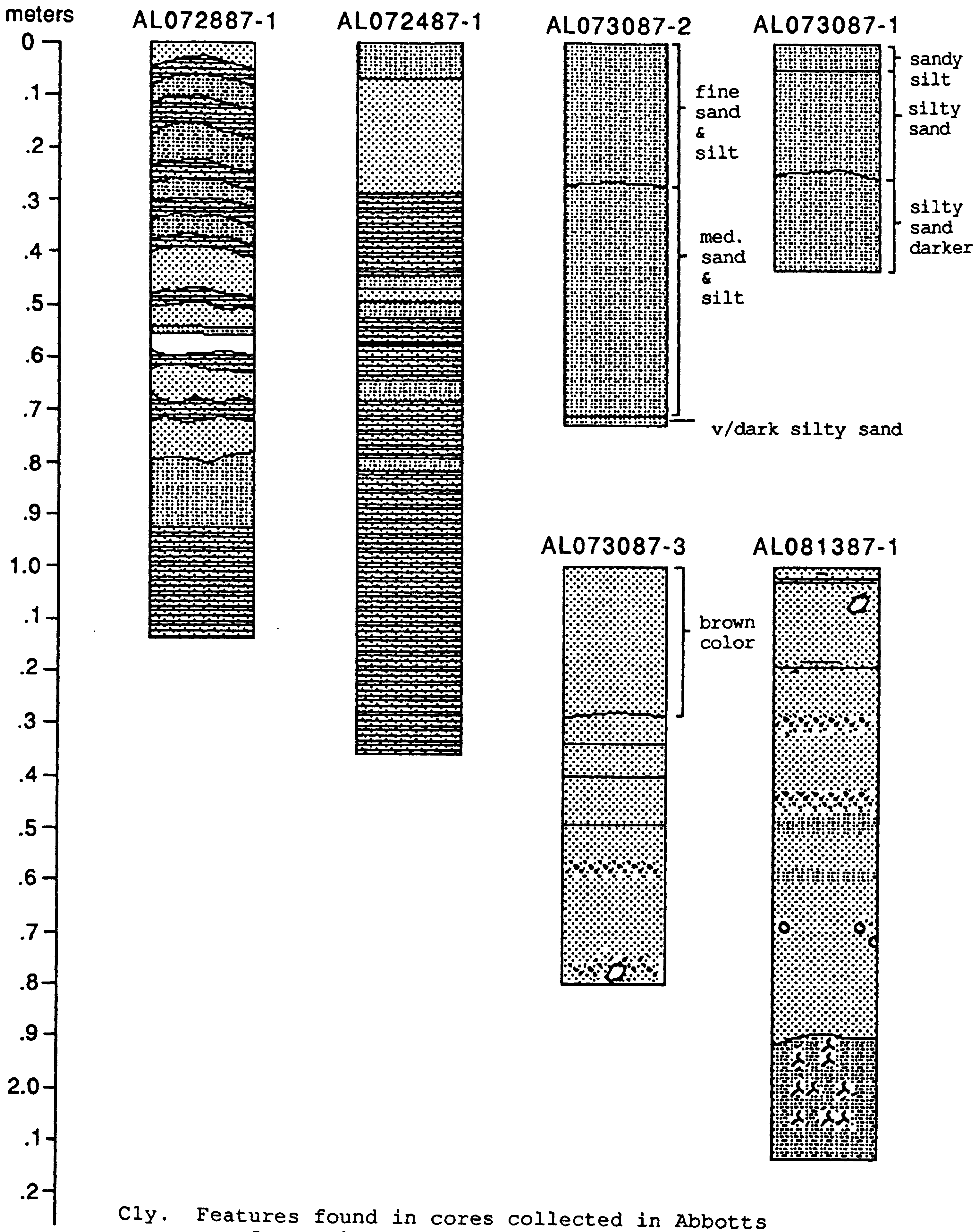
C1v. Map showing locations of cores collected in the tidal channels of the estero.



C1w. Features found in cores collected in the tidal channels of the estero, drawings are based on visual observations and X-ray radiographs.

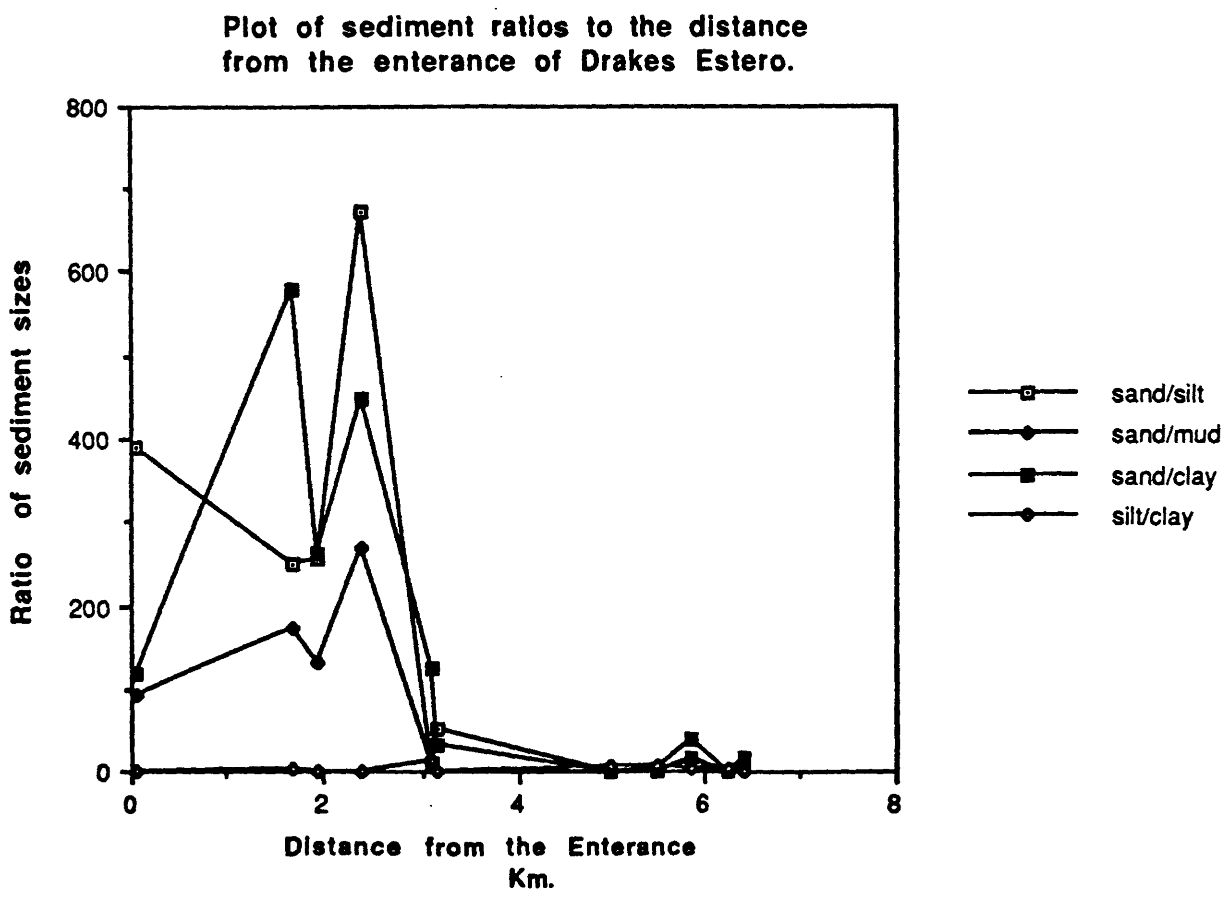


C1x. Map showing locations of cores collected in Abbotts Lagoon.

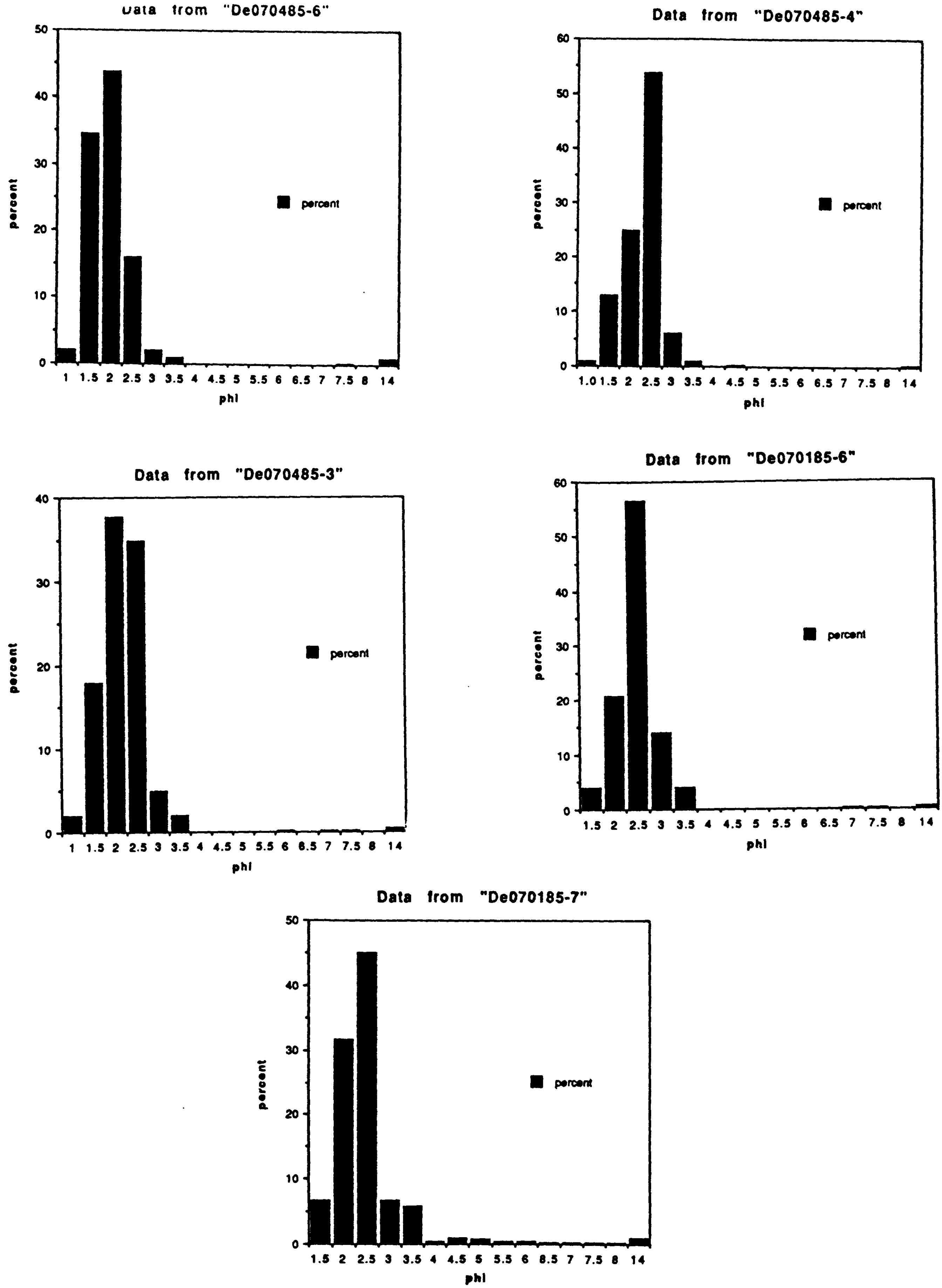


C1y. Features found in cores collected in Abbotts Lagoon based on visual observations and X-ray radiographs.

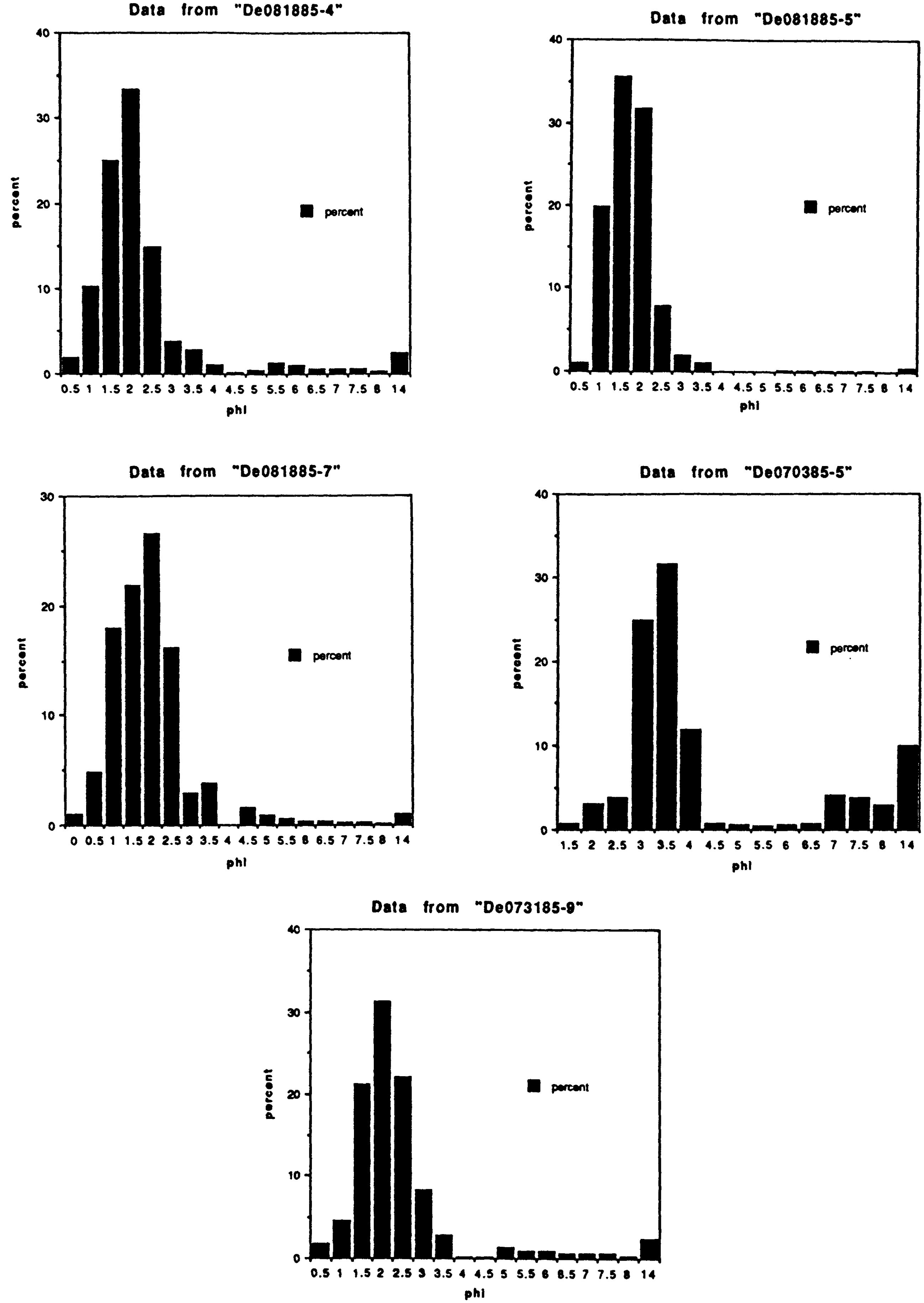
Appendix D Variability in Grain Sizes



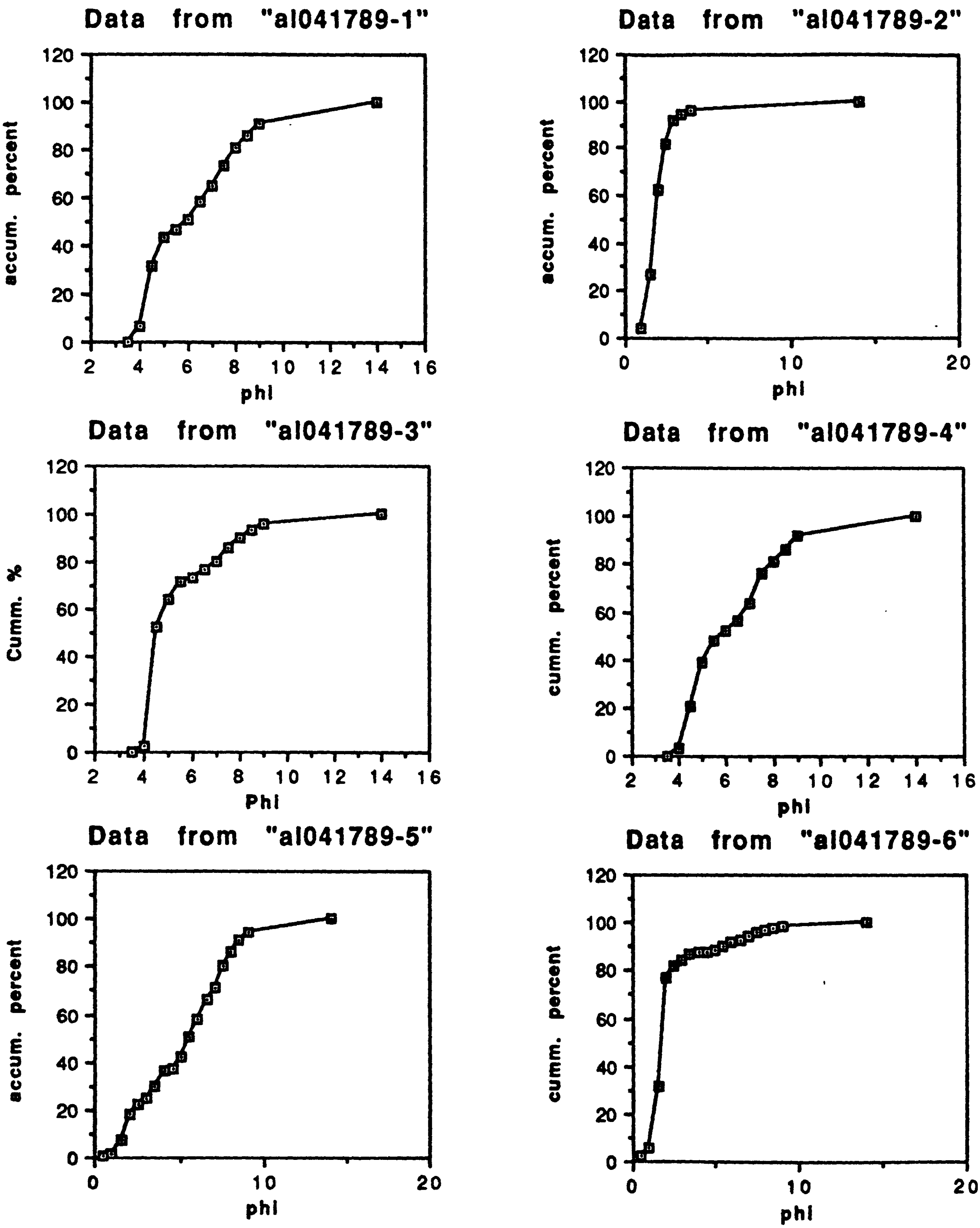
D1a. Graph showing the change in grain size from the entrance of the Drakes Estero to the upper portions of the estero.



D1b. Bar graphs of core samples collected in Drakes Estero samples for grain size analysis.

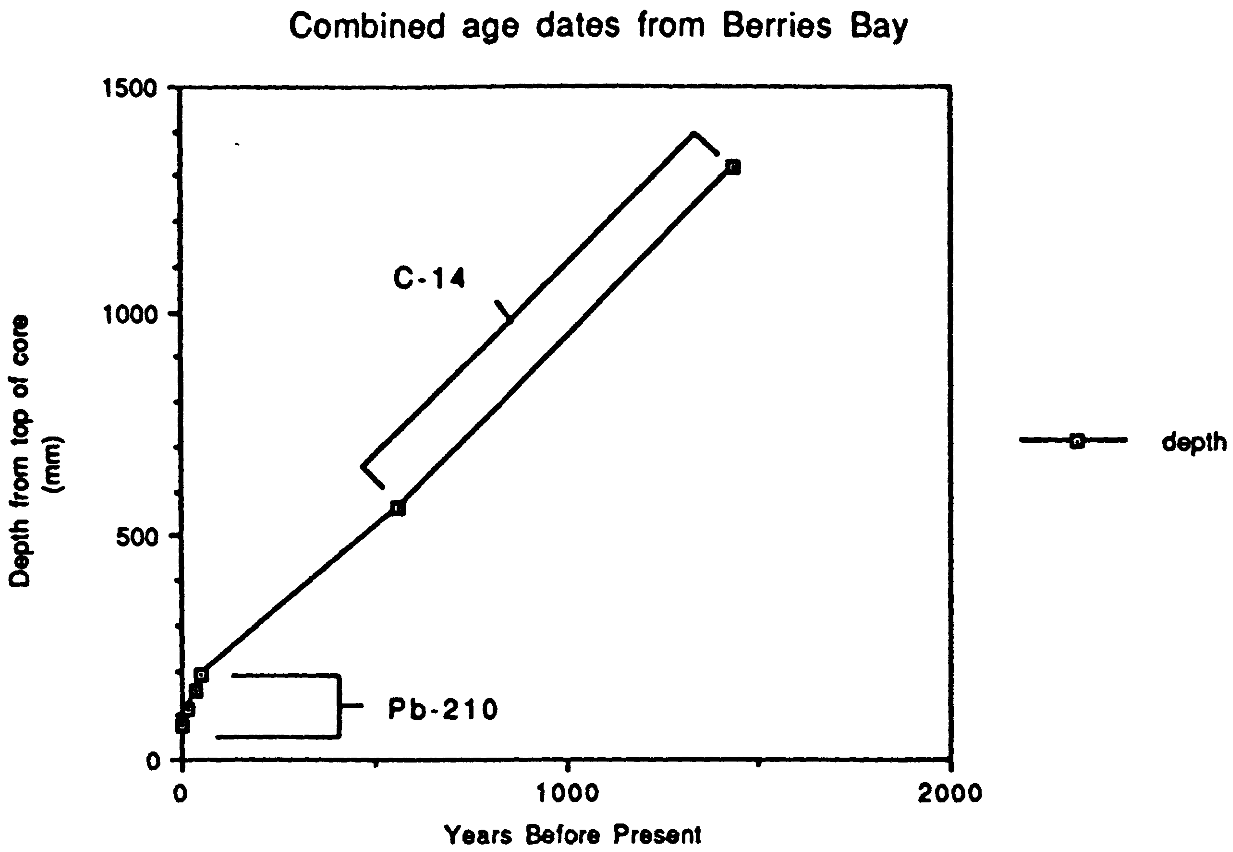


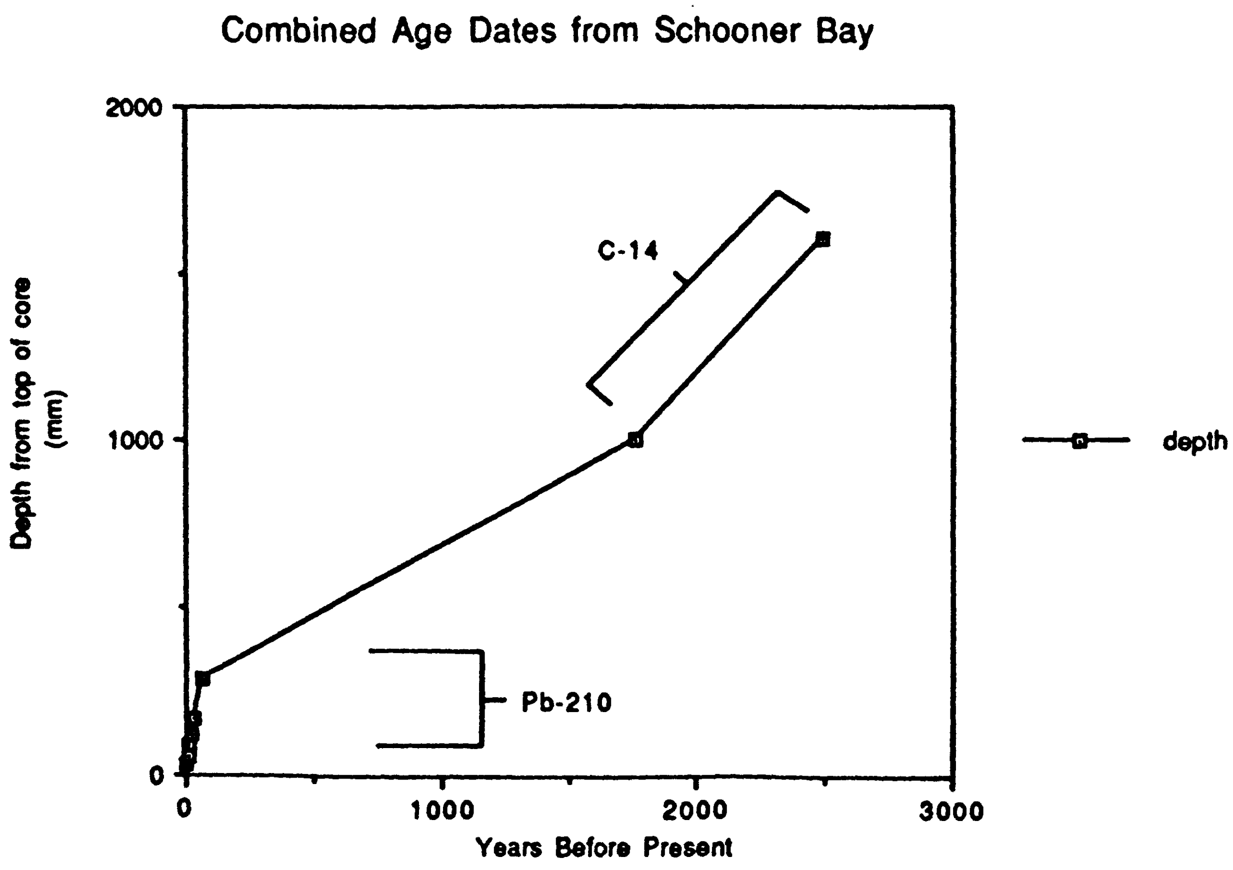
D1c. Bar graphs of core samples collected in Drakes Estero samples for grain size analysis.



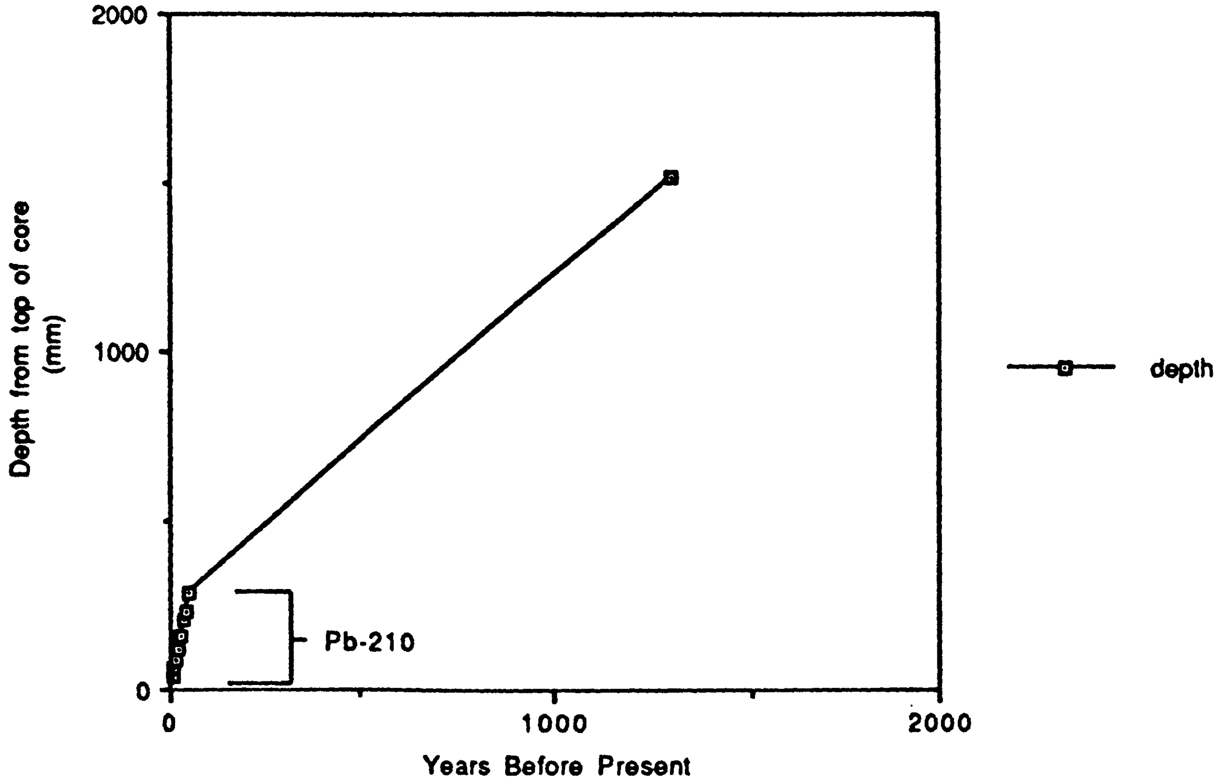
D1d. Cumulative frequency plots of sediment samples collected in Abbotts Lagoon.

Appendix E C^{14}, PB^{210} Comparisons

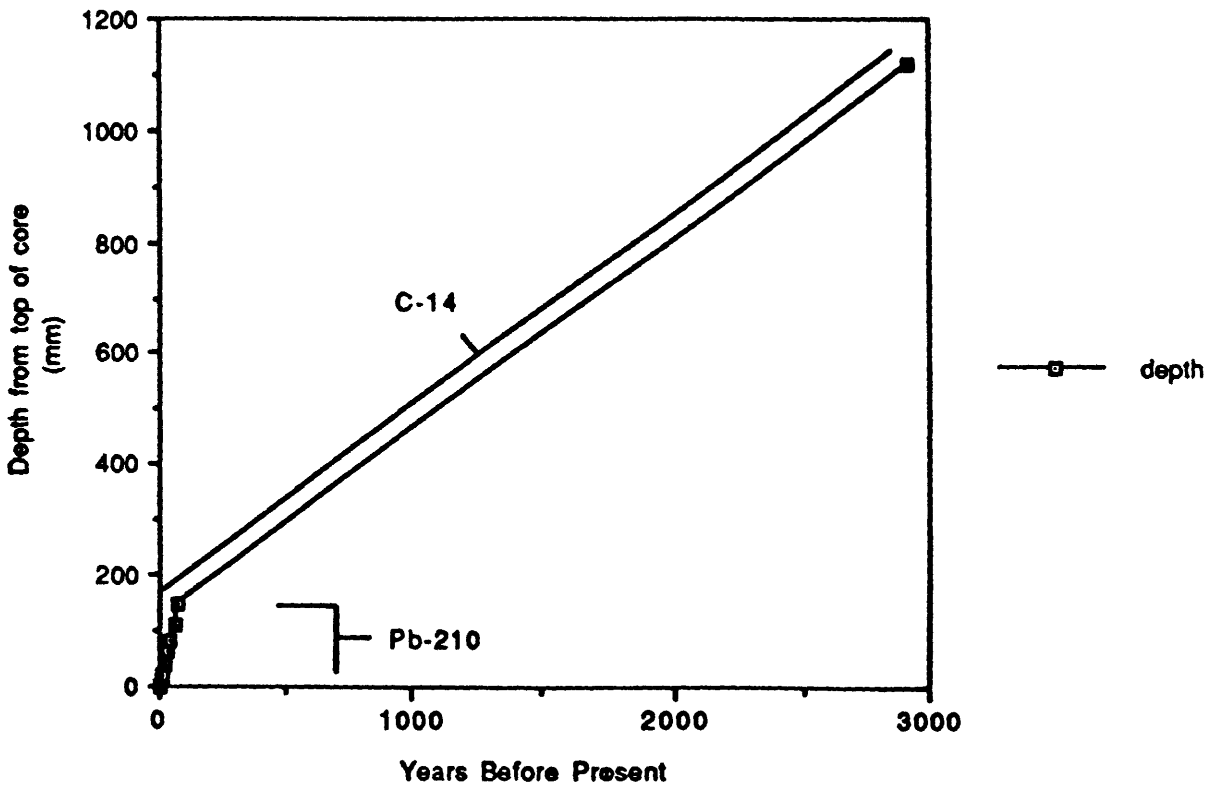




E1a. Graph showing the average combined C14, and Pb210, age dates for Berries and Schooner Bays.



Combined age dates from Abbotts Lagoon



E1b. Graph showing the average combined C14, and Pb210, age dates for Estero de Limantour and Abbotts Lagoon.