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DREDGED SEDIMENT MOVEMENT TRACING IN SAN FRANCISCO BAY UTILIZING NEUTRON ACTIVATION

by

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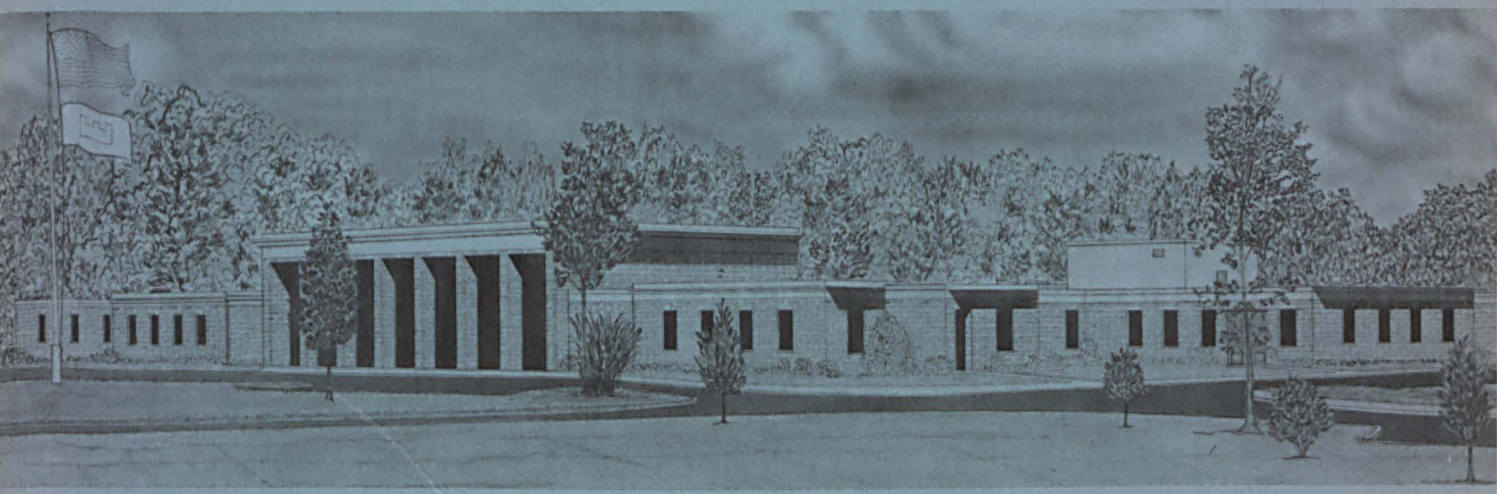

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The U. S. Army Engineer District, San Francisco, in 1973, initiated a study of the environmental impacts of dredging and aquatic disposal operations in San Francisco Bay. One part of this study was a program to determine the movement and recirculation of dredged materials after their aquatic disposal.

The movement and circulation of sediments in San Francisco Bay result from the complex interactions of tidal flows, wind-wave resuspension and

(Continued)

20. ABSTRACT (Continued).

recirculation and variations of freshet conditions with associated sediment loads, stratification, and shifting of nodal point. This complex system is currently beyond the modeling capability of mathematical and physical hydraulic models. Thus, a program was instituted to physically trace the movement of dredged materials with the objective of quantifying the horizontal and vertical recirculation of the dredged sediment. Tracing was accomplished by tagging Bay sediments with the chemical element iridium, neutron-activating sediment samples collected from an extensive test area, and using gamma-ray spectrometry to determine the quantity of iridium and hence the amount of dredged material present.

This report describes the research efforts conducted to (a) identify the chemical elements suitable for use as neutron-activable tracers, (b) tag the San Francisco Bay sediments, (c) introduce the tagged mineral particles into the dredged material, and (d) analyze the collected sediment samples. Interpretation of the sediment samples in terms of sediment circulation and shoaling is the subject of a separate report to be published by the San Francisco District.

A complete listing of all data collected during the March-December 1974 sampling of San Francisco Bay is contained in Appendix A, which is published under separate cover. Copies may be requested from the U. S. Army Engineer Waterways Experiment Station Technical Information Center.

The program was successful and permitted tracing the movement of the dredged material for a period of 10 months after the introduction of traced sediments in February-March 1974 until the completion of sampling in December 1974. The Tracer Program showed that material dredged from Mare Island Strait and released at the Carquinez Strait disposal site is distributed both spatially and with depth in bottom sediments over most of the region sampled. Initial dispersion is fast and resuspension seems to occur continuously. A portion of the dredged material is transported back to the original dredged channel. Upon redredging of the channel in September 1974, the traced sediments from the original tracing operation were detected in the study area. A general conclusion is that the movement of dredged sediments is probably more complex than originally anticipated.

One definite conclusion can be drawn from the overall results of the San Francisco Bay Tracer Program. The technique for tagging material with an inert chemical element, neutron-activating the field samples, and using gamma-ray spectrometry to determine the quantity of tracer material was successfully proven. Although somewhat expensive, iridium was found to be the most cost-effective chemical element for tagging and tracing sediments for the particular set of conditions existing in San Francisco Bay. With the neutron activation process, however, other chemical elements can definitely be used and may be more cost-effective for tracing dredged sediments in other locations.

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PREFACE

The development and use of a neutron-activable chemical element tracer for following the movement of dredged material dumped into the waters of San Francisco Bay was sponsored by the U. S. Army Engineer District, San Francisco. The work was funded under the accounting classification 96 x 3123 O&M General, Civil, Corps of Engineers. This report has been submitted as a part of the San Francisco District's overall study and is incorporated in Dredge Disposal Study, San Francisco Bay and Estuary, "Material Release Study," Appendix E.

The research was conducted by the Explosive Excavation Research Laboratory (EERL) of the U. S. Army Engineer Waterways Experiment Station (WES) with contractual assistance by Stanford Research Institute (SRI) of Menlo Park, California. The San Francisco District conducted the sampling program in the Bay. The Director of EERL was LTC R. R. Mills, Jr. The San Francisco District Engineers were COL J. L. Lammie and COL H. A. Flertzheim, Jr. Messrs. J. F. Sustar and R. M. Ecker of the San Francisco District monitored the research effort and devised and conducted the sampling program. This report was prepared by Messrs. E. J. Leahy, W. B. Lane (formerly with SRI), T. M. Tami, L. B. Inman (SRI), W. R. McLoud, and Major N. J. Adams.

Sincere appreciation to the following individuals for their contributions to this effort is expressed:

1. Drs. Lloyd Mann, Ray Gunnink, and Austin Prindle of the Radio-Chemistry Division, Lawrence Livermore Laboratory, Livermore, California, for their assistance in the preliminary efforts to analyze Bay sediments by gamma-ray spectrometry and for a specific analysis of these sediments for their gold and iridium content.
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3. Messrs. Forrest Allphin and George Perry of the San Francisco District along with the boat crew for the conduct of the sampling program in San Francisco Bay.

4. Mr. Ruben Carter of the U. S. Navy's Mare Island Naval Shipyard for his assistance in obtaining sediment material to be tagged.

5. Captain Martin Jarvis and crew of the Corps of Engineers dredge, the Chester Harding, for the splendid cooperation during all efforts required to install equipment, load traced dredged material, and add traced material to the 706 individual loads dredged from Mare Island Strait.

Members of the EERL deserve special thanks for their efforts in adding the traced sediments to each of the loads of dredged material on an around-the-clock basis, during a total of 35 days of dredging. Those performing this dirty task in all types of weather were: SP5 W. R. McLoud, SP5 J. F. Dishon, SP5 R. J. Gerbino, SP4 M. F. Goodrich, SP4 M. J. Hoeft, SP4 S. C. Kelley, and SP5 A. B. Steen.

Directors of the WES during the conduct of this work were BG E. D. Peixotto, CE, and COL G. H. Hilt, CE. Technical Director was Mr. F. R. Brown.

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CONVERSION FACTORS, METRIC (SI) TO U. S. CUSTOMARY UNITS OF MEASUREMENT

Metric (SI) units of measurement used in this report can be converted to U. S. customary units as follows:

Multiply	By	To Obtain
millimetres	0.03937007	inches
centimetres	0.3937007	inches
metres	3.280839	feet
metres	0.00053	nautical miles
square centimetres	0.1550	square inches
square metres	10.76391	square feet
square metres	2.809×10^{-7}	square nautical miles
square kilometres	0.0002809	square nautical miles
cubic centimetres	0.06102376	cubic inches
cubic metres	1.30795	cubic yards
cubic metres	264.172	gallons (U. S. liquid)
millilitres	0.03381	fluid ounces
litres	33.81	fluid ounces
micrograms	$0.002204622 \times 10^{-6}$	pounds (mass)
grams	0.002204622	pounds (mass)
grams	1.016047×10^{6}	long tons
grams	0.03215	troy ounces
kilograms	2.204622	pounds (mass)
grams per cubic centimetre	0.0361273	pounds (mass) per cubic inch
kilograms per cubic metre	0.06242797	pounds (mass) per cubic foot
centimetres per second	0.3937007	inches per second
centimetres per second squared	0.3937007	inches per second squared
radians	57.29578	degrees (angular)
Celsius degrees or Kelvins	9/5	Fahrenheit degrees*

* To obtain Fahrenheit (F) readings from Celsius (C) readings, use the following formula: $F = 9/5(C) + 32$. To obtain Fahrenheit readings from Kelvins, use: $F = 9/5(K - 273.15) + 32$.

DREDGED SEDIMENT MOVEMENT TRACING IN SAN FRANCISCO BAY UTILIZING NEUTRON ACTIVATION

PART I: INTRODUCTION

Purpose

1. This research was conducted for the U. S. Army Engineer District, San Francisco. Its purpose was to develop a technique which would permit the long-term tracing of the movement of dredged material after aquatic disposal in San Francisco Bay. The research objectives were to identify neutron-activable chemical elements suitable for use as tracers, develop sediment tagging and sample analytical methods, and conduct a large-scale sediment tracing experiment.

2. The first application of the technique involved tagging and tracing the movement of approximately 1,500,000 m^3* (2,000,000 yd^3) of material dredged in the February-March 1974 time frame from the Mare Island Strait. Mare Island Strait is located adjacent to the city of Vallejo, California, and serves as the water access to the U. S. Navy's Mare Island Naval Shipyard.

Scope

3. The report describes the research efforts conducted to (a) identify the chemical elements suitable for use as a neutron-activable tag, (b) place the chemical element on a measured quantity of sediment material from Mare Island Strait, (c) introduce a portion of this tagged sediment material into the dredge hoppers during dredging operations, and (d) analyze collected sediment samples to determine the concentration of released sediments in the 316-km^2 (92 square nautical miles) area in and about Mare Island Strait. Interpretation

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* A table of factors for converting metric (SI) units of measurement to U. S. customary units is presented on page 7.

of the sample data presented in terms of sediment circulation and shoaling will be performed by the San Francisco District and is the subject of a separate report.

4. A complete listing of all data collected during the March-December 1974 sampling of San Francisco Bay is contained in Appendix A, which is published under separate cover. Copies may be requested from the U. S. Army Engineer Waterways Experiment Station Technical Information Center.

Background

5. The San Francisco District is currently conducting a study titled "Dredge Disposal Study: San Francisco Bay and Estuary." The basic objective of the study and its many study elements is to assess the impact of dredging on the Bay and to recommend methods to mitigate identified adverse effects or enhance the marine environment. The Tracer Program of the Material Release Study Element, in which the dredged material was physically traced by tagging dredged material with a neutron-activable chemical element, is directed toward determining the disposition and dispersion patterns of dredged materials released at the Carquinez Strait aquatic disposal site. The results of the Tracer Program will be used to verify a mathematical model of the study area. Once verified, the mathematical model will permit studies to be performed for a variety of hydraulic parameters and dredge disposal conditions.

6. Previous tracing tests[1-3] using a radioactive material, gold-198, have been conducted in the Mare Island Strait. These tests, summarized in Reference 4, provided information on the dispersion of materials entering Mare Island Strait but, because of the short half-life of gold (2.7 days), did not permit following the material movement over a long period of time. To follow the movement of material over a long period of time with radioactive tracers, either the quantity of radioactivity must be increased if a short half-life material is used, or a radionuclide with a longer half-life must be employed. Both

alternatives are objectionable since they pose certain radiological hazards. An alternative approach employing short half-life radioactive material is to follow the material to a point and then introduce additional radioactive tracer, repeating the process as necessary. This approach has not been attempted. It presents the problem of introducing materials periodically in a manner which distributes this material as it would be by the natural processes of the Bay environment. The method used in this study is neutron activation. In this method, no radioactivity is involved until after the samples are collected; therefore, no environmental hazard is presented, provided the trace element employed is either nontoxic, or, if toxic at high concentration, is employed in a very low concentration, or is affixed to the sediment so that it is not available to biological systems. Also, neutron activation provides a very sensitive tracing technique since submicrogram quantities of many tracer elements may be detected with considerable accuracy.

Neutron Activation Technique

7. The technique of using neutron activation and gamma-ray spectrometry is detailed in numerous textbooks. In the subsequent paragraphs, a very brief outline of the technique is presented for readers not familiar with the process.

8. Many chemical elements, when exposed to thermal neutrons in a nuclear reactor or from some other neutron source, become radioactive by capturing neutrons in nuclei of individual atoms of the element. The radioactive atoms (radionuclides) of each element thus formed decay by giving off energy. This is generally in the form of an electron (beta particle) and one or more gamma rays. Each radionuclide in its decay process emits beta particles and any accompanying gamma ray(s) at a distinct rate. The radioactivity of a particular radionuclide is expressed as disintegrations per unit of time, generally disintegrations per second (dis/sec). The period of time required for a particular radionuclide to lose 50 percent of its activity by decay is known as its "half-life." When the disintegration (decay) process is accompanied

by one or more gamma rays, the gamma rays have a distinct energy which is characteristic of the specific atomic mass and chemical species of the decaying radionuclide and serve as identifiers of that radionuclide. The gamma-ray energy emitted by a radioactive material is measured in either thousands of electron volts (keV) or millions of electron volts (MeV).

9. As an example, gold-197 (^{197}Au) when exposed to thermal neutrons forms gold-198 (^{198}Au) which is radioactive. ^{198}Au emits beta particles in its decay process which are accompanied by 0.411-MeV gamma rays. The half-life of ^{198}Au is 2.7 days, i.e., after 2.7 days, one would have only one-half of the original mass of radioactive ^{198}Au as was present at time zero. Iridium-192 (^{192}Ir) is also radioactive and results from capture of thermal neutrons by iridium-191 (^{191}Ir). ^{192}Ir emits beta particles in its decay process accompanied by a number of gamma rays (15 distinct gamma rays). The principal gamma-ray energies are 0.295, 0.308, 0.316, and 0.468 MeV. Iridium-192 has a half-life of 74.37 days.

10. Measuring the gamma-ray energies being emitted by a neutron-activated sample, with a suitable detector and a gamma-ray spectrometer, identifies the neutron-activable chemical elements present. If the gamma-ray emission rate and neutron exposure of the sample are known (flux and time in flux), the quantity of each of those elements can be calculated.

11. In the neutron activation technique of tracing sediment materials, a small amount of a chemical element not naturally present in the sediments (or present in very low concentrations of at least a factor of five less than that being added) is fixed to a quantity of the sediment and subsequently introduced into the environment of interest. After some period of time, samples of the environment are collected, processed, neutron activated, and the gamma-ray spectra determined. From this data, the presence of the tracer can be quantitatively determined. Knowing the tracer concentration placed on the original quantity of sediments and the amount of this material added to each hopper load allows the percentage of the larger quantity of traced and dumped sediments in a sediment sample to be determined.

PART II: TRACER SELECTION

Conditions Affecting Tracer Selection

12. In selecting the neutron-activable chemical element to be used as a tracer for a particular task, four conditions must be met.

a. The chemical element to be used as the tracer must not be naturally present in any significant concentration in the medium being traced and the media with which the traced material may mix. A significant concentration could be defined as a concentration that will not permit addition of a sufficient amount of tracer to produce a quantifiable signal over and above that resulting from the amount naturally present. If the element is naturally present and detectable it must be uniformly distributed, i.e., the natural concentration of the element would remain constant in all samples to be examined.

b. The chemical element must permit homogeneous labeling of the material to be traced and, for sediments in a marine environment, must remain fixed to the particulates of the sediments and not alter their settling characteristics.

c. The mass of tracer to be added must be compatible with the mass of sediment material that may be physically handled during the tagging process.

d. The chemical element employed must not be a toxic substance to the life forms in the environment of the experiment.

13. Other factors must be considered during the tracer selection process but are not controlling. For a rapid and least cost detection technique, one would like to directly examine the neutron-activated samples. To permit direct examination, the trace element must be detectable in the presence of background activities formed by neutron activation of the natural chemical elements in a sample. In many instances, direct examination is not possible. For example, when tracers with a short half-life are used, the radioactive sodium (^{24}Na with a 15-hr half-life) created when most mineral particles are irradiated will prohibit direct examination at early postirradiation times; at later times the short half-life tracer's signal may have decayed. For long half-life tracers when the concentration of the tracer in a sample is low,

direct examination of the sample may be prohibited by a poor signal-to-noise ratio. When direct examination of the sample is not possible, more intricate and time-consuming chemical separations are necessary to recover the trace element for analysis. Thus, in selecting a tracer, the cost of the analytical technique and the cost of the trace element must be considered, and the total cost minimized.

14. The physical facilities available for neutron activation are also a consideration in tracer selection. For a large program involving several thousand samples, it is desirable to irradiate as many samples as possible at one time to minimize irradiation costs. Irradiation of large numbers of samples also requires selection of a tracer with a half-life sufficiently long to permit the analysis of each sample before radioactive decay reduces the tracer element's signal.

Gamma-Ray Spectra of Bay Sediments

15. Figure 1 is a general view of the San Francisco Bay area. Figure 2, an enlargement of a portion of Figure 1, shows the disposal site for traced dredged material from Mare Island Strait and the test areas to be sampled. These consist of the San Pablo Bay, Mare Island Strait, Carquinez Strait, and Suisun Bay areas.

16. To determine the gamma-ray spectra of the sediments to be dredged from Mare Island Strait and the sediments of the test areas with which the dredged material could mix, the San Francisco District provided 21 samples from the locations shown in Figure 2. The sediments were dried, and two 1-g samples from each location were irradiated for 1 hr at a flux of 5×10^{12} neutrons per square centimetre per second ($n/(cm^2 \times sec)$). The gamma-ray spectrum of each sample was examined about every third day between 3 and 40 days postirradiation. No significant spectral differences were noted among the samples, indicating the neutron-activable chemical elements were uniformly distributed in the sediments. To further verify the sediments' gamma-ray spectra and to estimate the quantity of particular elements, the Radio-Chemistry Division, Lawrence Livermore Laboratory (LLL), also analyzed the samples in

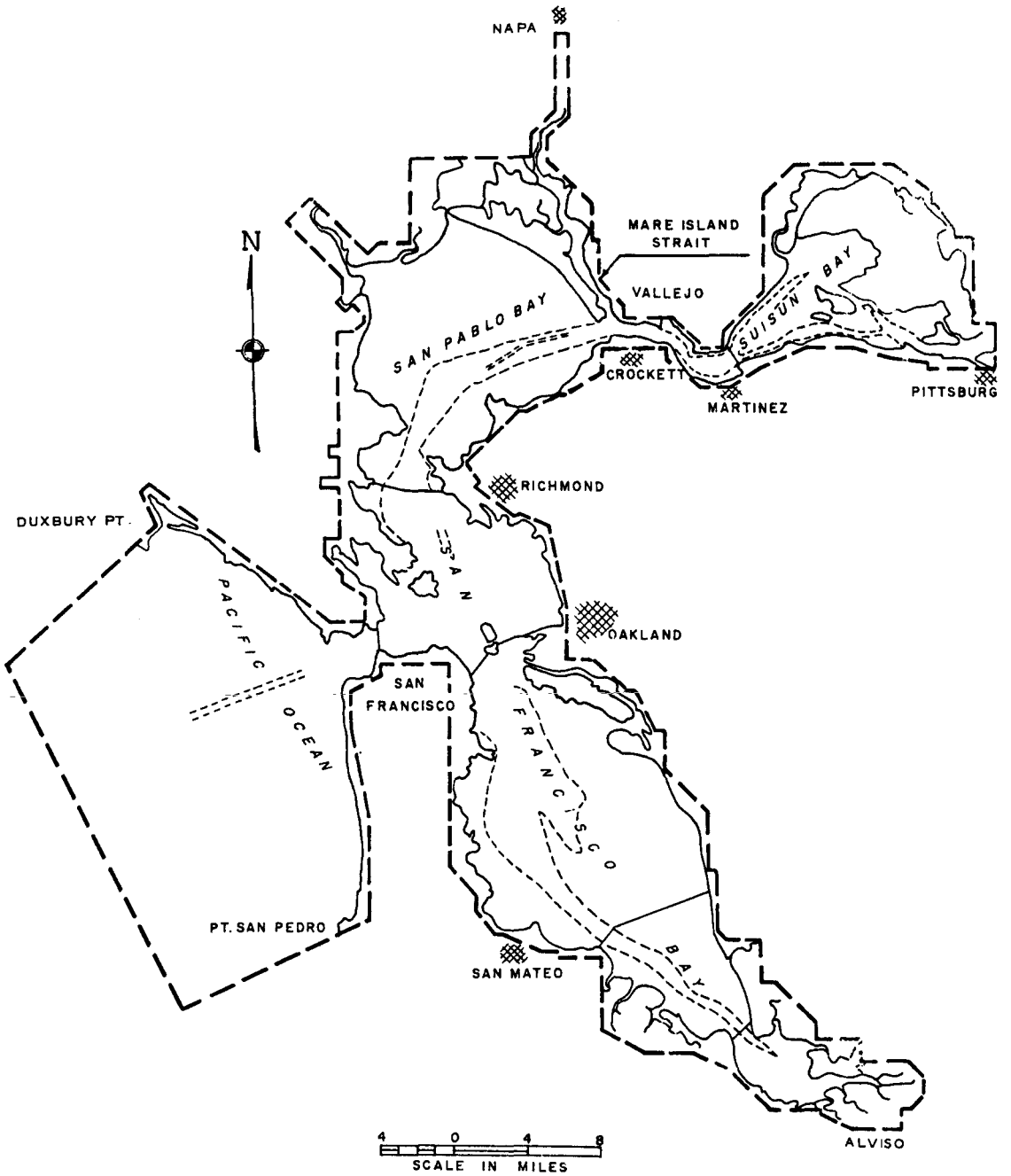

Figure 1. General view of San Francisco Bay area

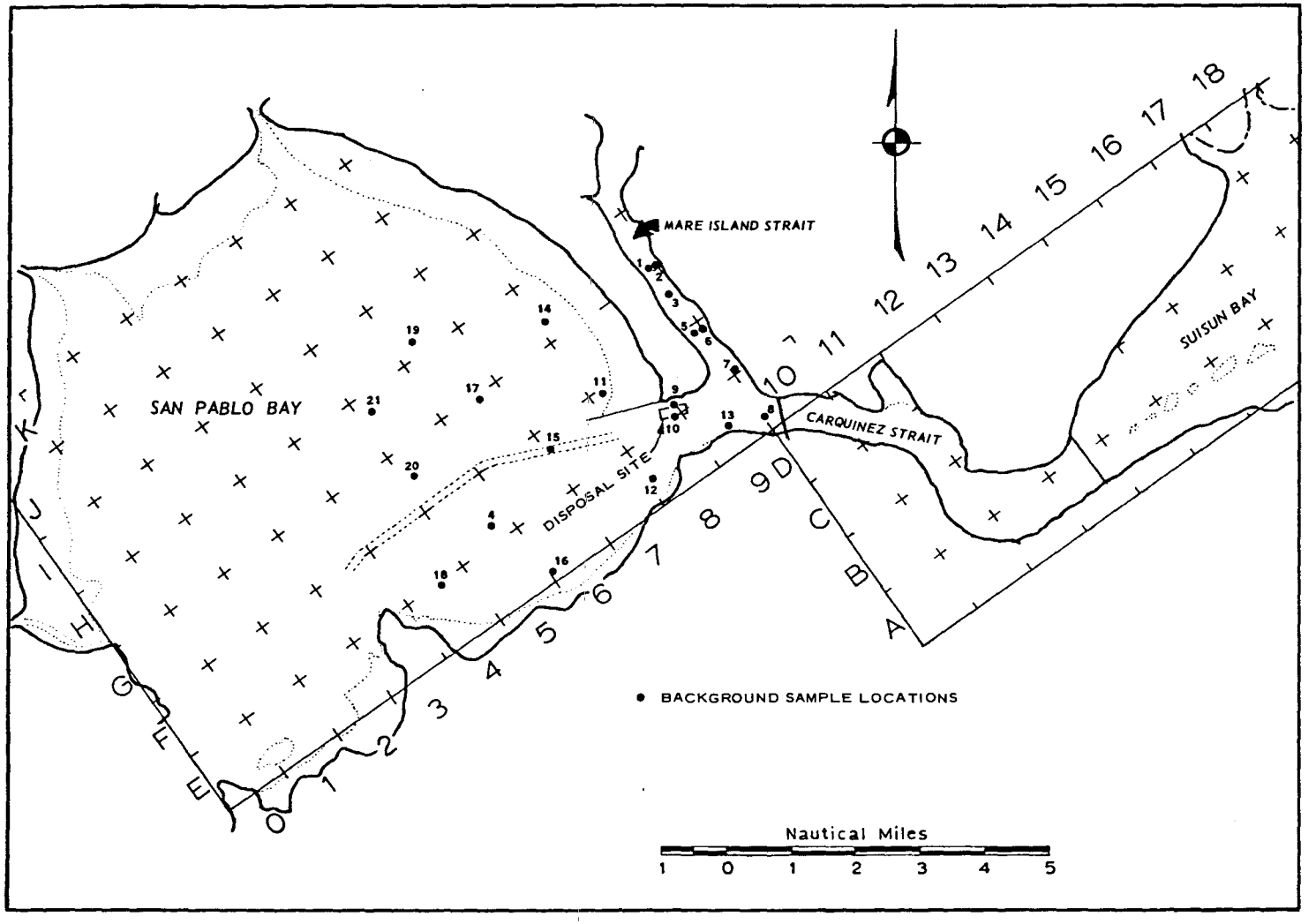

Figure 2. Test area for traced dredged material study

their computerized gamma-ray spectral analysis system, GAMANAL.*[5] This examination was performed at 13 days postirradiation to permit the ^{24}Na in the samples to decay to an insignificant level. Figure 3, produced by the LLL counting system, is a 0-2000 keV plot of the spectrum from a sediment sample. The ordinate is total counts (66-min counting time), and the abscissa is the channel number, which may be converted to gamma-ray energy in keV by dividing by 2. In the figure, each major gamma-ray photon peak is labeled as to its energy in keV.

17. The GAMANAL program also identifies the radionuclides present and assigns a percent of error to the identification. The 30 nuclides identified in the Bay sediments are listed in Table 1. Again, no significant differences were noted in the activation products of any sample. Caution is required in using this listing for other than rough estimates since the GAMANAL Code was designed for analysis of fission product mixtures and not thermal neutron activation products. In addition, the efficiency of the system for the sample geometry was not determined. As a result of the code construction and the assumed geometry, some nuclides are identified which do not result from thermal neutron activation, and the quantities are overestimated.

18. To obtain quantitative concentration information for the thermal neutron-activable chemical elements, similar sediment samples

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* The GAMANAL program is primarily intended for complete computer analysis of high-resolution gamma-ray spectra obtained from mixtures of radioactive species such as fission products. For this purpose, it examines the pulse-height data for "background" and "peak" regions, fits these peaks with the proper shape functions, and corrects for the effects of geometry, attenuation, and detector efficiency in evaluating the photon emission rate and for nonlinearities in the equipment in setting up an energy scale. These intermediate results are listed and plotted; if no further data reduction is requested, the program goes on to the next spectrum. Otherwise, it proceeds to search a "library" of decay scheme information in order to make tentative assignments for each of the peaks. This collection of "candidates" is examined for interactions between the photopeaks of the proposed nuclides and is divided into sets of species which interfere with each other at any point. A least-squares solution of the corresponding set of simultaneous equations is made, and the amounts of various components originally present are calculated and listed, along with their estimated errors.

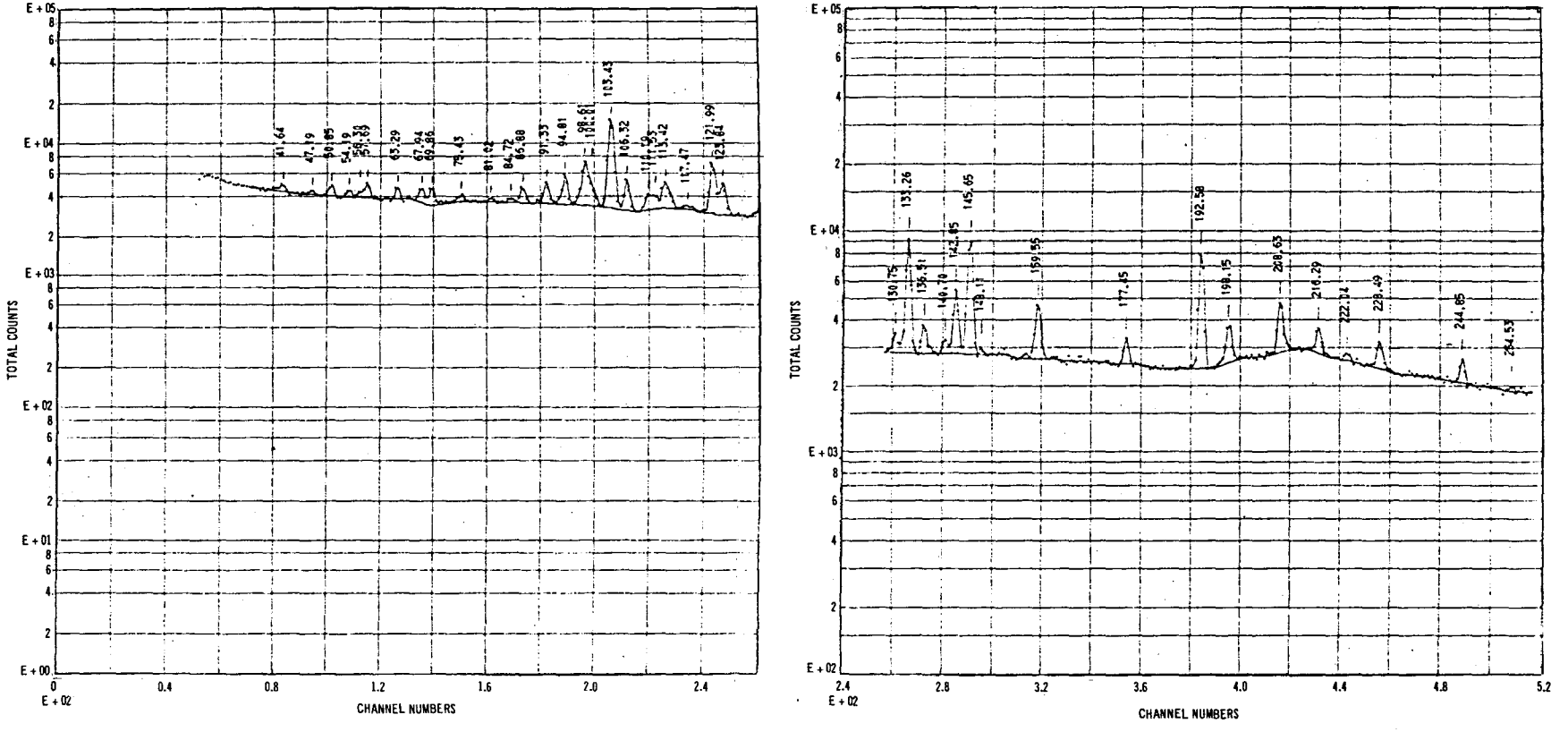


Figure 3. Gamma-ray spectra of San Francisco Bay sediments (sheet 1 of 8)

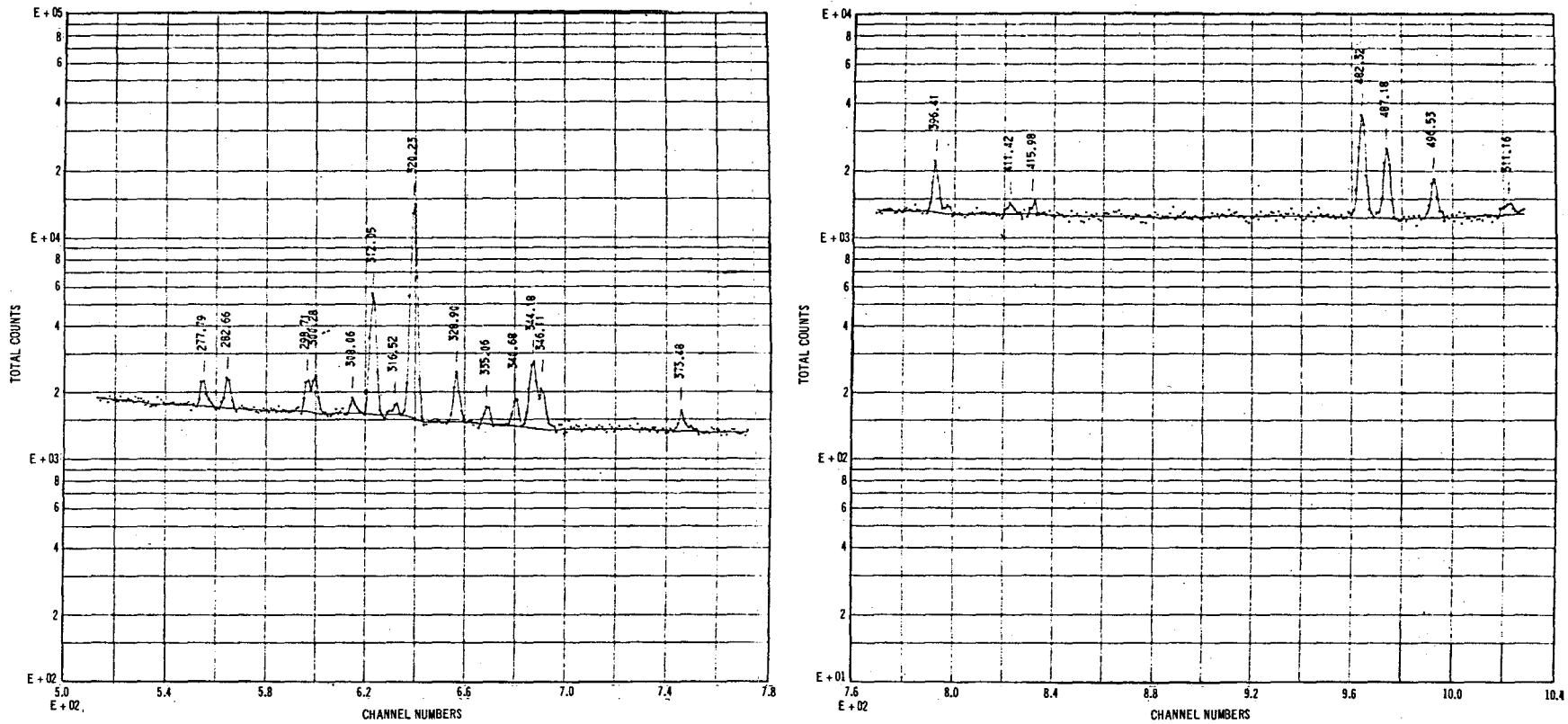
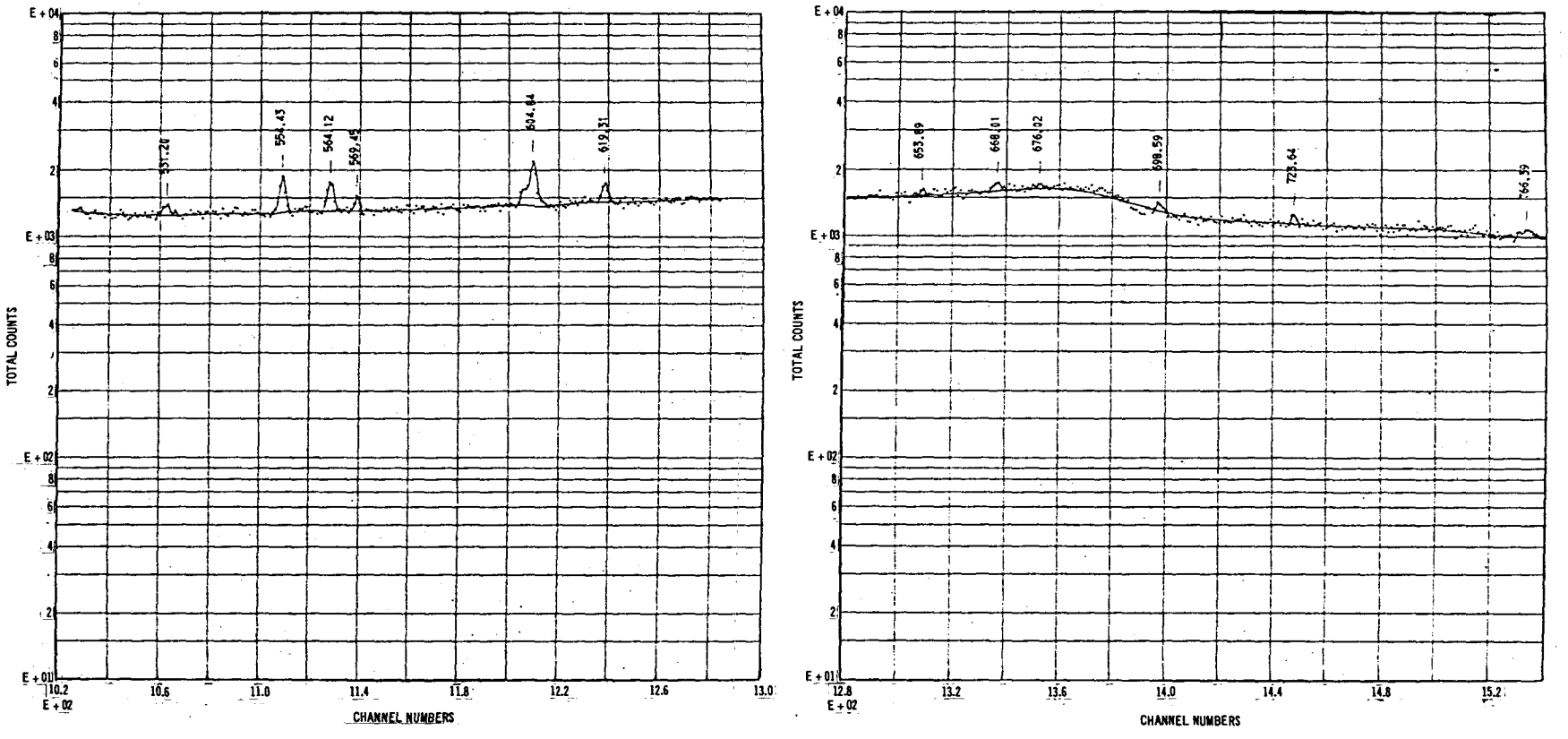


Figure 3 (sheet 2 of 8)



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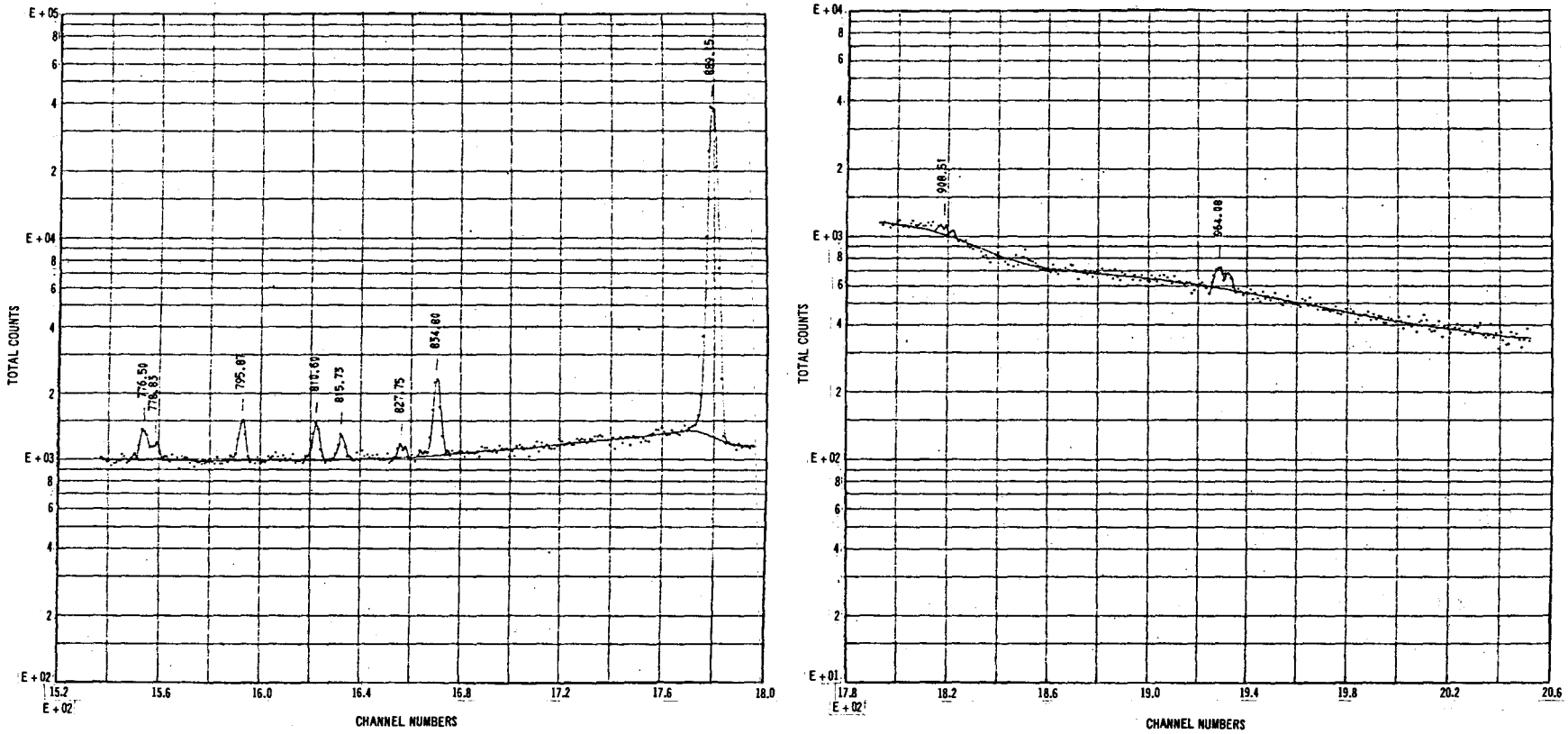

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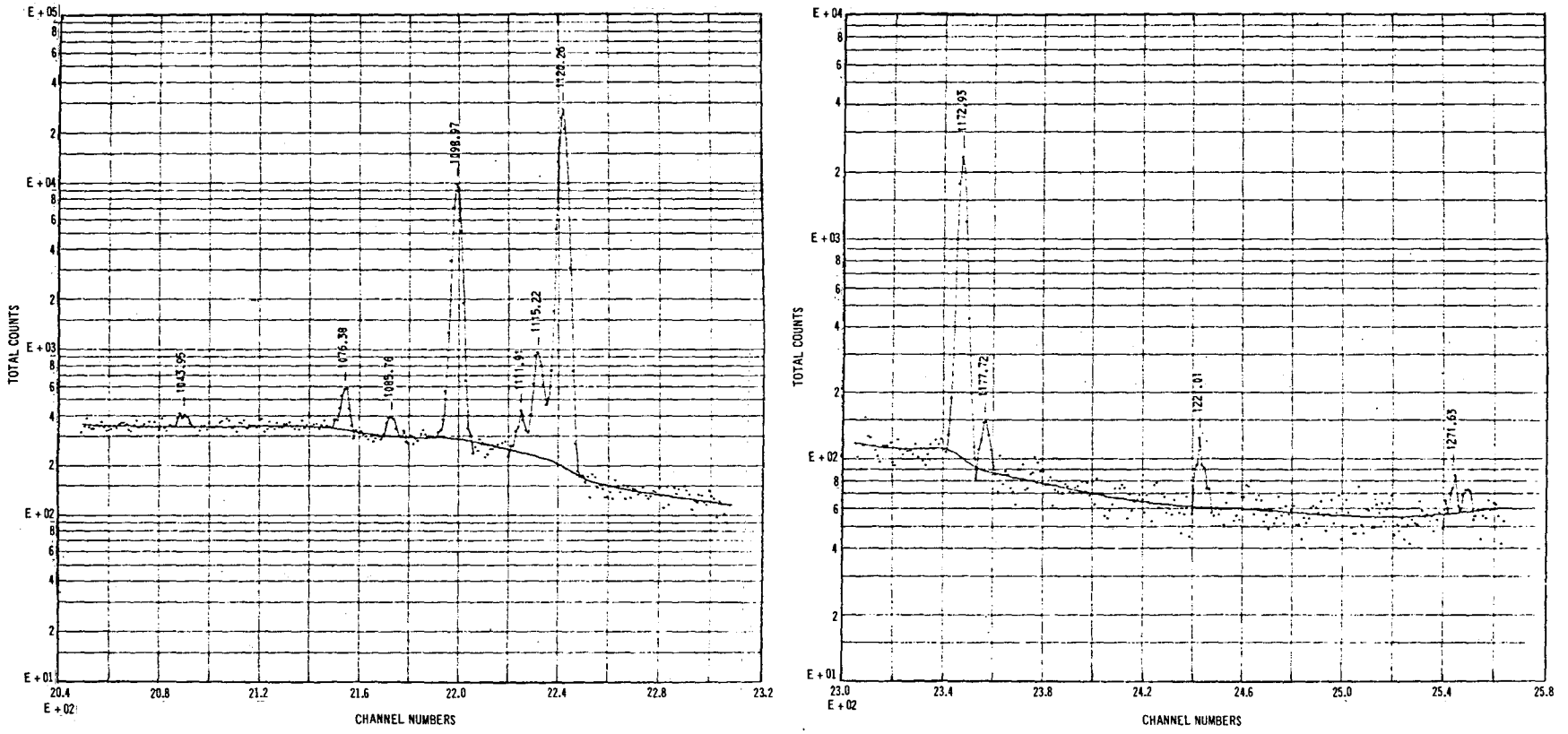

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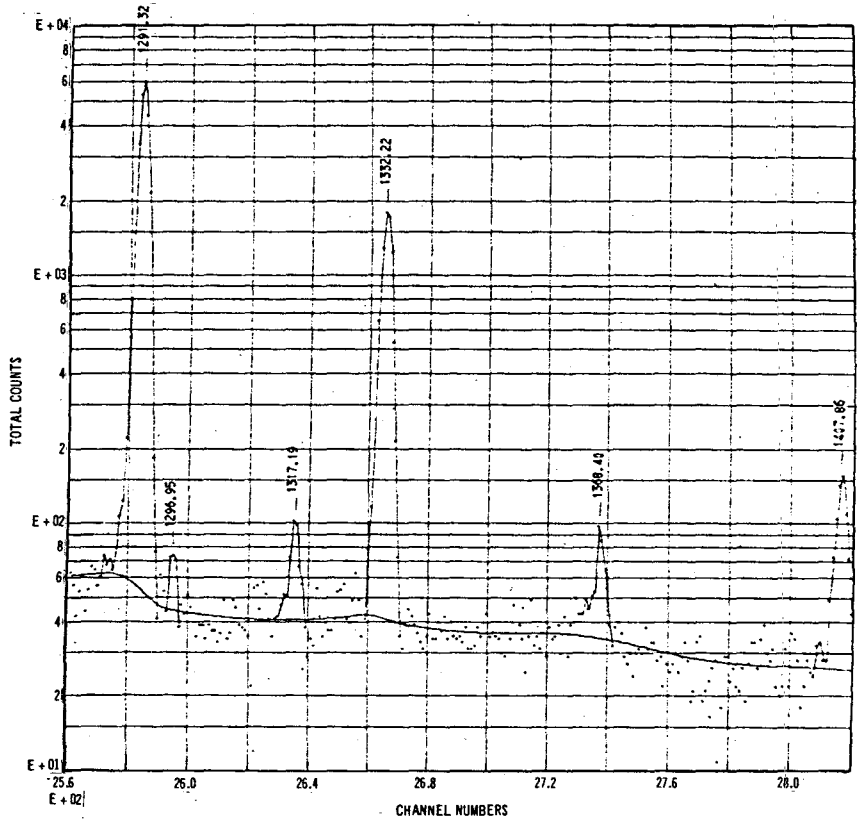

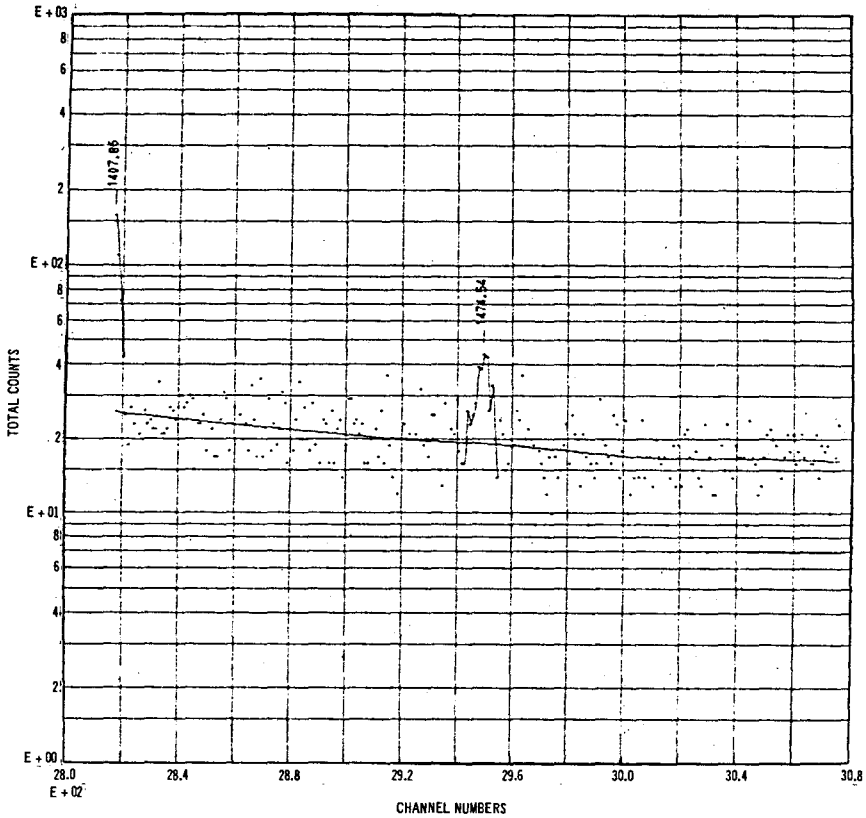

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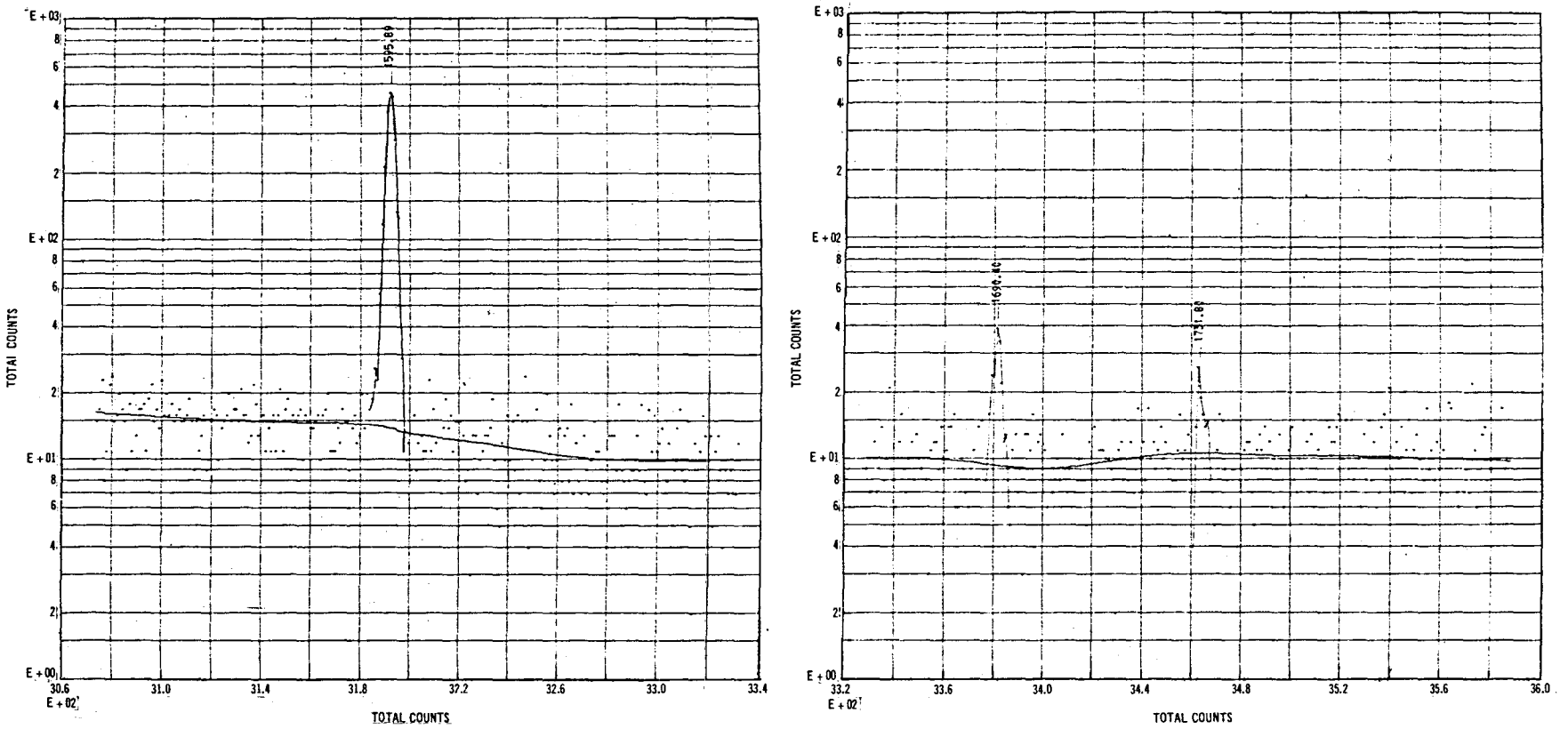

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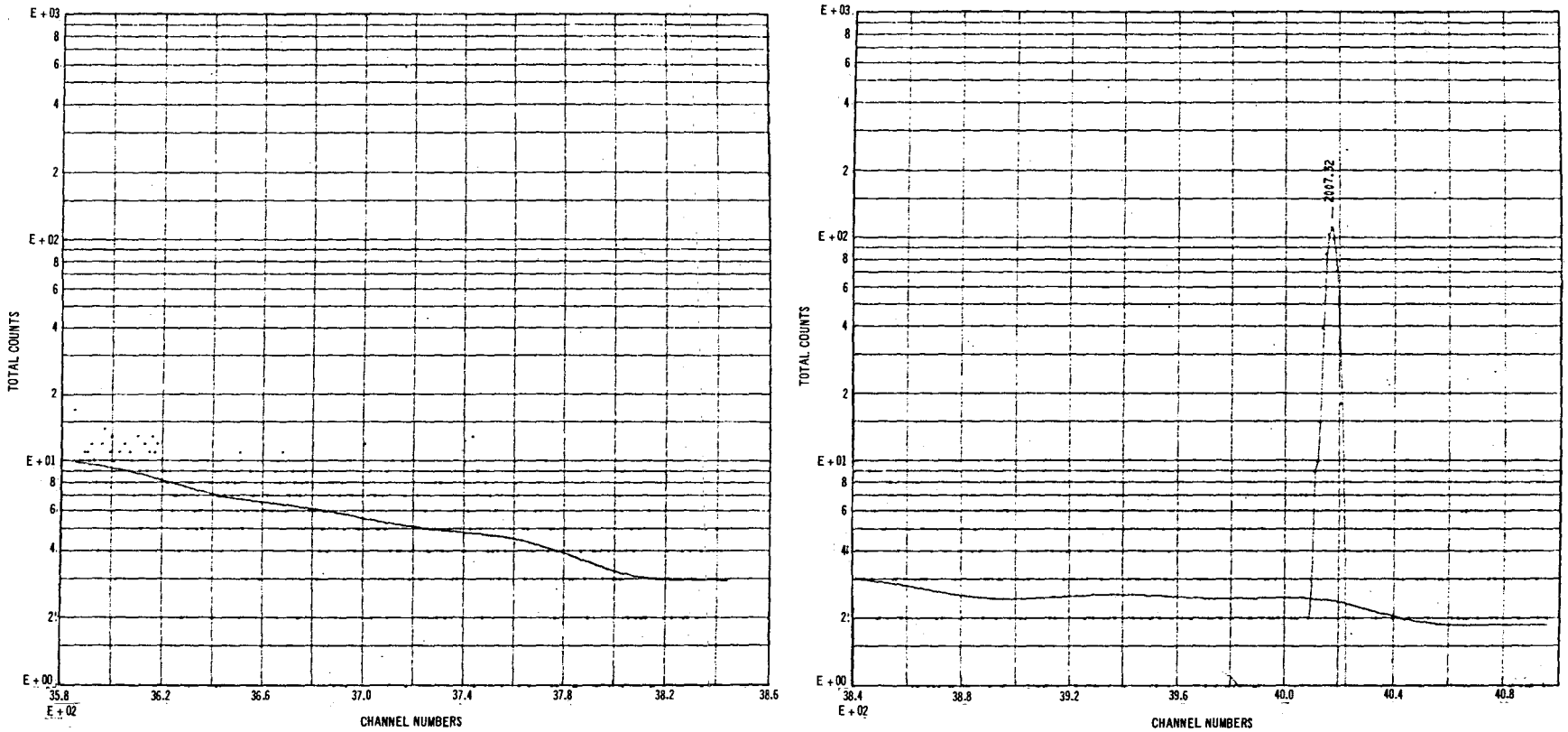

Figure 3 (sheet 8 of 8)

Table 1

Nuclides Identified by the GAMANAL Code

GE Gamma Analysis of 1060 Soil

Experiment No.
Sample Number

Sample Weight = 1.000E+00
Normalization Weight = 1.000E+00
Normalization Factor = 1.000E+00

Geometry is 2.60 CM

Zero Time 129.625

Midtime of Count 142.769

Decay Time is 13.144 Days

Live-Time of Count (Taken from Channel 1) 66.67 Mins.

MLR Least-Squares Results

Nuclide	Dis/min at Count Time	Dis/min at Zero Time	Atoms at Zero Time	Percent Error	Set No.	Qfit*	Identification Confidence Value
SC 46	4.748E+05	5.293E+05	9.224E+10	1.2	1	3.9	0.96
CR 51	3.584E+05	4.976E+05	2.866E+10	2.2	1	3.9	0.77
MN 54	1.424E+04	1.466E+04	9.511E+09	6.1	2	1.0	0.64
FE 59	2.850E+05	3.496E+05	3.239E+10	1.3	1	3.9	1.00
CO 58	4.481E+03	5.092E+03	7.541E+08	25.7	1	3.9	0.81
CO 60	4.003E+04	4.022E+04	1.606E+11	2.3	1	3.9	0.90
ZN 65	2.445E+04	2.538E+04	1.292E+10	8.1	1	3.9	0.72
BR 82	4.721E+03	2.320E+06	7.085E+09	7.7	3	1.0	1.00
RB 86	4.934E+04	8.039E+04	3.116E+09	11.3	4	1.0	0.58
MU 99	4.806E+02	1.317E+04	7.528E+07	20.8	5	1.0	0.36
RU 103	3.514E+03	4.423E+03	3.838E+08	10.9	6	1.0	0.41
SB 122	3.600E+03	9.769E+04	5.600E+08	16.2	7	1.0	0.40
SB 124	1.552E+03	1.806E+03	2.261E+08	18.0	7	1.0	0.15
SB 420	7.578E+02	3.645E+03	4.391E+07	68.9	1	3.9	0.24
TE 132	6.955E+02	1.157E+04	7.788E+07	68.2	1	3.9	0.54
CS 134	5.913E+03	5.985E+03	9.261E+09	9.0	7	1.0	0.97
BA 140	1.218E+04	2.482E+04	6.598E+08	4.8	1	3.9	1.00
CE 141	1.433E+04	1.898E+04	1.277E+09	1.9	8	1.0	0.74
ND 147	4.225E+03	9.643E+03	2.211E+08	43.7	1	3.9	0.77
SM 153	3.812E+04	4.175E+06	1.682E+10	6.3	1	3.9	0.89
EU 152	1.510E+04	1.513E+04	1.608E+11	5.3	1	3.9	1.00
TB 160	5.844E+03	6.631E+03	9.931E+08	16.4	1	3.9	0.68
TM 160	1.662E+03	1.832E+03	3.543E+08	51.0	1	3.9	0.29
LS 177	2.519E+04	9.954E+04	1.371E+09	19.0	1	3.9	0.87
HF 181	1.517E+04	1.881E+04	1.658E+09	3.7	1	3.9	1.00
TA 182	3.674E+03	3.977E+03	9.498E+08	17.8	1	3.9	0.99
AU 199	6.271E+03	1.131E+05	7.399E+08	15.4	1	3.9	0.32
PA 233	2.658E+04	3.725E+04	2.089E+09	4.3	1	3.9	1.00
NP 239	7.722E+03	3.709E+05	1.813E+09	13.3	1	3.9	0.98
AM 241	4.971E+03	4.972E+03	1.634E+12	50.3	1	3.9	0.29

* Measure of reliability.

were analyzed by the University of California, Berkeley, Nuclear Engineering Reactor Laboratory. Table 2* presents the results of this analysis obtained from a series of thermal neutron activation experiments. The quantities of 51 neutron-activable elements in parts per million (ppm) of dried sediments were determined. Additional analyses of iridium and rare earth elements in the Bay sediments were performed by the Department of Nuclear Engineering, North Carolina State University at Raleigh, North Carolina. Their measured concentrations are shown in Table 3.**

19. It will be noted that the iridium concentration reported in Table 2 differs from that in Table 3. This difference is believed to have resulted from iridium contamination in the sample provided to North Carolina State. Additional analyses, to be discussed later, were conducted to resolve this difference.

Identification of Potential Tracer Elements

20. With the gamma-ray spectrum and approximate concentration of the naturally occurring neutron-activable elements in Bay sediments known, identification of candidate chemical element tracers was accomplished by examining the neutron activation products of all stable chemical elements. In turn, these activation products were examined for their detectability by gamma-ray spectrometry and their physical and chemical properties (half-life, gamma-ray energy, and chemical valence).

21. H. P. Yule[6] has experimentally determined the gamma-ray photopeak yields and limits of detection for 118 reactor thermal neutron products of all elements from oxygen through lead, except for Ne, Kr, and Xe. His work was accomplished with a 1-hr irradiation in a flux of 4.3×10^{10} n/(cm^2 × sec) using an instrumental analysis (76.2- × 76.2-mm (3- × 3-in.) solid thallium-activated sodium iodide NaI (Tl)

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* Memo: Messrs. C. Cann and Tek Lim, University of California, to E. Leahy, EERL, dated 19 Feb 1974.

** North Carolina State University, Nuclear Energy Services Activation Analysis, Report No. 50961, dated 7 Feb 1974.

Table 2

Concentrations of Major Constituent and Trace Elements in Mare Island Sediments in Parts Per Million of Dried Sediments*

Major		Trace			
Al	35000 ± 3500	Zn	410 ± 60	Yb	0.6 ± 0.1
Mg	22000 ± 2300	Cu	350 ± 170	Th	0.52 ± 0.06
Na	19500 ± 200	Mn	300 ± 40	Hf	0.50 ± 0.06
K	16000 ± 1600	Br	220 ± 20	Ho	0.23 ± 0.03
Fe	5800 ± 600	Ba	200 ± 50	Lu	0.21 ± 0.03
Ca	4000 ± 500	V	68 ± 7	Mo	<170
Cl	2100 ± 200	Cr	25 ± 3	Pd	<160
Ti	2100 ± 220	Rb	20 ± 3	Ge	<110
		I	15 ± 2	Nb	<30
		As	10.7 ± 1.3	Te	<19
		Ga	10 ± 2	Hg	<7
		Ce	5.8 ± 0.7	Ni	<6
		Co	3.5 ± 0.4	Cd	<5
		Sc	3.2 ± 0.3	Os	<0.6
		La	2.6 ± 0.3	Zr	<0.5
		Sm	1.4 ± 0.4	Pt	<0.2
		Eu	1.2 ± 0.2	Ag	<0.2
		Cs	1.1 ± 0.2	Se	<0.15
		Tm	1.1 ± 0.2	Ta	<0.06
		W	0.7 ± 0.2	In	<0.007
		Sb	0.64 ± 0.11	Au	<0.003
				Ir	<0.0005

* As determined by the Nuclear Engineering Reactor Laboratory, University of California, Berkeley.

Table 3

Rare Earth Sensitivities* and Concentrations**

Isotope	Irradiation Time	Decay Time	Sensitivity	ppm Found in Dry Mud
Ir-192	4 hr	50 days	5 ppb	0.005 ± 0.002
Tb-160	4 hr	40 days	300 ppb	0.04 ± 0.01
Eu-152M	10 min	10 hr	700 ppb	< 0.7
Ho-166	4 hr	6 days	250 ppb	< 0.3
Sm-153	4 hr	6 days	200 ppb	1.57 ± 0.09
Gd-159	4 hr	6 days	1 ppm	< 1.0
Lu-177	4 hr	20 days	250 ppb	< 0.3

* Sensitivities are calculated on the basis of the activity of a standard superimposed on the activity in the mud (i.e., a spiked mud sample) with all experimental parameters identified.

** As determined by Department of Nuclear Engineering, North Carolina State University at Raleigh, North Carolina.

crystal and no interfering elements). This work was selected for screening the neutron-activable elements since it was conducted with a reactor thermal neutron flux which is available at a reasonable cost per reactor hour. The General Atomics TRIGA reactor used by Yule also permits irradiation of large numbers of samples at one time. Other reactor facilities do exist which will permit sample irradiation in a variety of modes, but none were found that allowed processing the number of samples envisioned at the low dollar value possible in the TRIGA type reactor.

22. In reviewing the thermal neutron activation products listed by Yule, the following operational factors were considered in selecting the candidate chemical elements to be considered as tracers:

a. Since several thousand samples were to be irradiated, a TRIGA type reactor would be used because it permits 40 or more samples to be irradiated in a single batch.

b. To prevent contamination of the reactor facility, samples for irradiation would be encapsulated in sealed aluminum containers within a secondary irradiation capsule. For safety consideration, the radioactivity generated in the sample plus that generated in the aluminum container would require a 48-hr cooling time before removal of the samples from the reactor to permit short half-life nuclides to decay. Considering transportation time, approximately 60 hr would elapse before sample examination could commence.

c. The mode and operational cycle of the dredge dictated the quantity and time at which the tracer could be introduced. In its normal operational mode, the dredge filled its hoppers and overflowed an amount of material until a maximum load was acquired. Its cycle time from channel clearance to arrival at the dump site was approximately 20 min. Thus, to prevent inadvertent contamination of the channel, tagged sediments would have to be added after the dredge cleared the channel. The physical facilities for sediment tagging and the logistics and time constraint of adding the tagged material to the dredge's hoppers limited the total tagged sediment that could be employed to approximately 9.1×10^6 g (20,000 lb).

d. The tracer must be detectable after dilution in the Bay by the anticipated load of sediment with which the tagged dredge material might mix. Approximately 1.5×10^6 m^3 (2×10^6 yd^3) or a mass of approximately 6×10^{11} g (1.3×10^9 lb) were to be dredged assuming 448.3-kg/m^3 (28-lb/ft^3) in-place dry density. This mass could be further mixed with approximately 7.6×10^6 m^3 (1×10^7 yd^3) of sediments or 3.4×10^{12} g (7.5×10^9 lb), the estimated yearly influx of sediments to the San Francisco Bay.[4]

e. The gamma-ray energy of the tracer was desired to be as high as possible to maximize the signal-to-noise ratio. The low-energy regions of the gamma-ray spectra are harder to analyze than the high-energy regions.

23. The above operational factors resulted in criteria for selecting candidate tracers as follows:

a. The tracer half-life should be sufficiently long to insure the signal would not be significantly degraded through radioactive decay during the time from neutron activation to sample examination.

b. The quantity of tracer employed must be fixed to approximately 9.1×10^6 g (20,000 lb) of sediment without altering the sediment's settling characteristics. For screening purposes, the authors established that the mass of

tracer to be used could not exceed 1 percent of the mass to be tagged or 0.010 g tracer/g of sediment (g/g).

c. The tracer must be detectable after the mixing of the tagged sediments with the estimated yearly influx of sediments, 3.4×10^{12} g.

24. Using the above criteria, the radionuclides listed in Table 4 were examined, and each radionuclide was rated as to its potential for use as a tracer. The data in Table 4, except for the concentration of elements in the sediments, are from Reference 6. Element concentrations are from Tables 2 and 3.

25. In the minimum detection range of 10^{-5} to 10^{-4} µg, only gold (^{198}Au) was a possible tracer. All other elements were rejected because of their short half-life or high natural abundance in the Bay sediments. As an example, at 60 hr postirradiation time the signal, gamma-ray emission rate, from Europium (^{152m}Eu) with a 9.3-hr half-life would be reduced by radioactive decay to about 1.1 percent of its original value. In addition, to add sufficient Eu to the Bay sediments being dredged to increase the Eu content by a factor of 10 would require 7×10^{7} g (154,000 lb)--more mass than the 9.1×10^{6} g (20,000 lb) to be tagged.

26. In the minimum detection range of 10^{-4} to 10^{-3} µg, only rhenium (^{188}Re) and iridium (^{194}Ir) were possibly suitable, and both were rejected because of their short half-lives which by 60 hr post-irradiation time would reduce their signals to less than 12 percent of their values at the end of neutron activation.

27. In the minimum detection range of 10^{-3} to 10^{-2} µg, rhenium (^{186}Re) and iridium (^{192}Ir) were selected as possible tracers. Their long half-lives (^{186}Re, 90 hr and ^{192}Ir, 74.4 days) would produce suitable signals after 60 hr of decay.

28. The nuclides with detection ranges between 10^{-2} and 10^{-1} µg were also examined, and tantalum (^{182}Ta) and terbium (^{160}Tb) were identified as possible tracers.

29. With the possible candidate tracer elements identified, each element was examined to determine which was the most suitable in terms of technically satisfying the task objectives while minimizing cost. Table 5 lists the elements, radionuclide of interest, certain physical

Table 4

Minimum Detection Range of Reactor Thermal Neutron Products

Minimum Detection Range μg	Nuclide	Half-life	Energy MeV	Concentration ppm of Dried Sediment	Useful Traces*
10^{-5} to 10^{-4}	^{56}Mn	2.58 hr	0.84	300	No - 1
	^{116m}In	54 min	1.27	0.007	No - 1
	^{128}I	25 min	0.455	15	No - 1
	^{198}Au	2.70 days	0.411	0.003	Possible
	^{152m}Eu	9.3 hr	0.961	1.2	No - 1, 3
	^{165}Dy	75 sec	0.108	--	No - 1
	^{165}Dy	2.3 hr	0.94	--	No - 1
10^{-4} to 10^{-3}	^{41}Ar	1.83 hr	1.29	--	No - 1
	^{46m}Sc	20 sec	0.140	3.2	No - 1
	^{52}V	3.76 min	1.44	68	No - 1
	^{82}Br	1.5 days	0.55 + 0.63	220	No - 2, 3
	^{134m}Cs	2.9 hr	0.127	1.1	No - 1
	^{180m}Hf	5.5 hr	0.216	0.5	No - 1
	^{188}Re	16.7 hr	0.155	--**	No - 1
	^{194}Ir	19.0 hr	0.328	< 0.0005	No - 1
	^{153}Sm	1.94 days	0.102	1.4	No - 3
	^{166}Ho	27.3 hr	0.080	0.23	No - 1
	^{171}Er	7.5 hr	0.301	--	No - 1
10^{-3} to 10^{-2}	^{24}Na	15 hr	1.37	19,500	No - 3
	^{28}Al	2.3 min	1.78	35,000	No - 1
	^{60m}Co	10.5 min	0.059	3.5	No - 1

(Continued)

* 1. Half-life too short.
2. Undesirable chemical characteristics.
3. Natural abundance in the Bay sediments.

** Estimated to be about 0.001 ppm.

Table 4 (Continued)

Minimum Detection Range µg	Nuclide	Half-life	Energy MeV	Concentration ppm of Dried Sediment	Useful Traces
10^{-3} to 10^{-2}	^{64}Cu	12.8 hr	0.51	350	No - 3
	^{72}Ga	14.3 hr	0.834	10	No - 3
	^{76}As	1.10 days	0.555	10.7	No - 3
	^{81m}Se	61 min	0.104	0.15	No - 1
	^{87m}Sr	2.8 hr	0.388	--	No - 1
	^{104m}Rh	4.4 min	0.556	--	No - 1
	^{108}Ag	24 sec	0.656	0.2	No - 1
	^{110m}Ag	2.3 min	0.630	0.2	No - 1
	^{111m}Cd	49 min	0.24	< 5	No - 1
	^{122}Sb	2.8 days	0.566	0.64	No - 3
	^{139}Ba	83 min	0.163	200	No - 3
	^{187}W	1.0 days	0.482	0.7	No - 3
	^{140}La	40.2 hr	1.60	2.6	No - 3
	^{149}Nd	1.8 hr	0.211	--	No - 1
	^{159}Gd	18.5 hr	0.364	< 1.0	No - 1
	^{177}Yb	1.9 hr	0.147	0.6	No - 1
	^{177}Lu	6.8 days	0.208	0.21	No - 3
	^{192}Ir	74.4 days	0.316	< 0.0005	Possible
	^{186}Re	90 hr	0.137	-- **	Possible
10^{-2} to 10^{-1}	^{38}Cl	37.3 hr	1.64	2,100	No - 1, 3
	^{42}K	12.5 hr	1.53	16,000	No - 1, 3
	^{115}Cd	54 hr	0.335	< 5	No - 3
	^{123}Sn	41 min	0.153	--	No - 1
	^{124}Sb	60 days	0.603	0.64	No - 3

(Continued)

** Estimated to be about 0.001 ppm.

Table 4 (Concluded)

Minimum Detection Range μg	Nuclide	Half-life	Energy MeV	Concentration ppm of Dried Sediment	Useful Traces
10^{-2} to 10^{-1}	^{51}Ti	5.8 min	0.32	2,100	No - 1, 3
	^{69m}Zn	13.8 hr	0.44	410	No - 1, 3
	^{76}Ge	1.4 hr	0.264	< 110	No - 1, 3
	^{86m}Rb	1.0 min	0.56	20	No - 1, 3
	^{97}Zr	17 hr	0.750	< 0.5	No - 1
	^{101}Mo	14.6 min	0.191	< 170	No - 1
	^{99}Mo	66 hr	0.141	< 170	No - 1
	^{108}Ru	4.5 hr	0.72	--	No - 1
	^{109m}Pd	48 hr	0.19		
	^{109}Pd	13.6 hr	0.088	160	No - 1
	^{131}Te	25 min		19	No - 1
	^{182}Ta	115 days	1.122 + 1.222	0.06	Possible
	^{182m}Ta	16 min	0.147 + 0.172 + 0.184	0.06	No - 1
	^{199}Pt	30 min	0.318	0.2	No - 1
	^{197m}Hg	24 hr	0.133	7	No - 1
	^{143}Ce	1.37 days	0.294	5.8	No - 1
	^{142}Pr	19 hr	1.57	--	No - 1
	^{160}Tb	73 days	0.299	0.04	Possible

Table 5

Candidate Tracer Elements

Element	Nuclide	Half-Life	Limit of Detection g	Abundance in Sediments g/g	Tracer Required* g	Unit Cost $/g	Total Cost**
Gold	^{198}Au	2.7 Days	7.0×10^{-11}	3×10^{-9}	1×10^{5}	3.85	$ 392,700
Rhenium	^{186}Re	90 Hours	2.1×10^{-9}	1×10^{-9}	3.4×10^{4}	1.28-4.00	43,800-136,000
Iridium	^{192}Ir	74.37 Days	1.0×10^{-9}	5×10^{-10}	1.7×10^{4}	8.00	136,000
Tantalum	^{182}Ta	115 Days	4.8×10^{-8}	6×10^{-4}	2×10^{9}	0.08	1,000,000
Terbium	^{160}Tb	73 Days	2.8×10^{-8}	3×10^{-4}	1.0×10^{9}	3.00	1,000,000

* To exceed quantity naturally occurring in 3.4×10^{12} g of sediment.

** Except for iridium and gold, cost data were taken from the Handbook of Chemistry and Physics, 53rd edition, 1972-1973. Iridium had been purchased for $6.95/g and was estimated to inflate to $8.00/g. The market price for gold was $120.00/troy ounce (31.10348 g/troy ounce) and was fluctuating. Rhenium's price was also fluctuating.

characteristics, quantity required, and estimated cost. The amount of element required is the amount necessary to exceed by a factor of 10 the quantity of that chemical element naturally occurring in the 3.4×10^{12} g of sediment assumed as the annual sediment load with which the traced dredged material could mix.

30. From Table 5, it can be seen that gold, rhenium, and iridium were the only suitable chemical element candidates considering cost and the quantity of tracer that could be placed on the 9.1×10^{6} g (20,000 lb) of sediment to be tagged. Each of the chemical elements had no chemical characteristics which would prohibit their use as a chemical element tag.

31. For the three candidate tracer elements, Table 6 indicates the concentration on the sediments to be tagged, the concentration in the dredged material at the time of release, and the possible concentration in samples to be collected assuming dilution occurs by the estimated yearly influx of sediments into the Bay.

32. With the possible concentrations of each tracer element determined for the samples to be collected from the Bay, analysis methods were investigated to determine the candidate element based on minimum overall cost (tracer purchase price plus analysis cost) and maximum tracing sensitivity.

Methods of Sample Analysis

Direct sample examination

33. As previously noted, the detection limits stated by Yule[6] were for an instrumental analysis when no interfering elements were present. To determine the detection limits for a lithium-drifted germanium diode, Ge(Li), system, 1-g samples of sediments were spiked with various concentrations of each candidate element and neutron-activated. The trace element concentrations employed were equal to those shown in Table 6 for the dredged material at the time of release and after dilution by the assumed sediment inflow to the Bay.

34. Examination of these samples at postirradiation times from

Table 6

Concentration of Trace Elements in Tagged Dredged Materials and Bay Samples

Element	Nuclide	Tracer Quantity g	Concentration on Sediments to be Tagged* g/g	Concentration in Sediments at Dump Time** g/g	Possible Concentration in Samples Collected After Dilution† g/g
Gold	^{198}Au	1×10^{5}	1.1×10^{-2}	1.6×10^{-7}	2.9×10^{-8}
Rhenium	^{186}Re	3.4×10^{4}	3.7×10^{-3}	5.6×10^{-8}	1×10^{-8}
Iridium	^{192}Ir	1.7×10^{4}	1.8×10^{-3}	2.8×10^{-8}	5×10^{-9}

* 9.1×10^{6} g (20,000 lb) to be tagged.

** Assuming 1.5×10^{6} m^3 (2×10^{6} yd^3) containing 6×10^{11} g to be dredged.

† Assuming dilution by 7.6×10^{6} m^3 (1×10^{7} yd^3) containing 3.4×10^{12} g of sediment.

60 hr to 30 days indicated that a suitable signal-to-noise ratio could not be obtained. At early postirradiation times, the short-lived nuclides resulting from the naturally present elements in the sediments masked the trace elements' signals. At later times, radioactive decay reduced the gold and rhenium signals. Iridium could be detected, but the signal-to-noise ratio was not satisfactory below 1×10^{-8} g Ir/g of sediment. Thus, examination of the gross spectra was not feasible and chemical separations were indicated since, from Table 6, a detection sensitivity of at least 1×10^{-9} g Ir/g of sediment is required.

Chemical and radiochemical separation techniques

35. To separate the trace elements from the sediments so that an instrumental analysis without the interference of other elements could be performed, chemical separation using dissolution and precipitation methods, radio-chemical separation using dissolution and carrier separation, and fire assay procedures were investigated with the following results:

a. Chemical separation is not possible since the quantity of tracer materials even in a large volume sample is too low to precipitate.

b. Radio-chemical separations are possible using dissolution and carrier separations. However, they were judged to be costly because of the amount of material that had to be irradiated, the safety measures required for handling the radioactivity, the need for time scheduling of operations to minimize the decay of the short half-life nuclides of gold and rhenium, and the difficulty of dissolving the sediments.

c. Fire assay procedures were found to be feasible and less costly. Fire assay is a process routinely used in the assay of ores for noble metals. Briefly, in the fire assay process finely divided ore is mixed with lead oxide, a reducing agent such as starch, and fluxing materials, sodium carbonate and borax. This mixture is heated until it melts. Upon melting, the mixture separates into two liquid phases with the ore staying on top in a slag phase and with the noble metals plus a few other elements contained in the heavy metallic lead phase on the bottom.

36. The fire assay process can be performed on the Bay sediment samples prior to neutron activation and thus permits the use of a large

mass (up to 100 g) of sediment material. It effectively concentrates the elements of interest plus a few unwanted elements from the large sediment mass while eliminating many elements which produce undesirable noise in a sample being counted.

37. Figure 4 presents the gamma-ray spectra of a neutron-activated sediment sample in curve 1 and the spectra after the same sediment was fire-assayed and the iridium collected in a metallic lead pellet in curve 2. Both spectra were measured at the same postirradiation time of 9 days. From the figure, it can also be seen that most of the photon peaks in the sediment sample (curve 1) are absent in the lead pellet (curve 2), that the noise level curve 2 is reduced over its entire energy range, and that the iridium photon peaks (0.316 and 0.468 MeV) are more clearly defined in curve 2.

38. There are methods of separating the noble elements from the lead by cupellation, but these add costs; and our experimental evidence indicated unacceptable losses of the iridium.

Selection of Tracer Element

39. As previously indicated, the candidate tracer elements were gold, rhenium, and iridium. On a cost basis, since each was amenable to the fire assay process, gold was eliminated as a potential tracer due to its high initial purchase cost. From the above evidence, fire assay was judged to be not only satisfactory but also necessary to measure low-iridium concentration sediments.

40. Iridium and rhenium were further investigated to determine which element was the most suited to the task from technical and cost considerations. In Table 5, the cost to accomplish the tracing operation for rhenium is indicated to be from $43,800 to $136,000 depending on the cost information source, and the iridium cost was estimated to be $136,000. Taking the lower value, rhenium's initial cost is one-third that of iridium, but in the fire assay process and spectral resolution rhenium presents certain technical problems due to its low gamma-ray energy of 0.137 MeV and its 90-hr half-life.

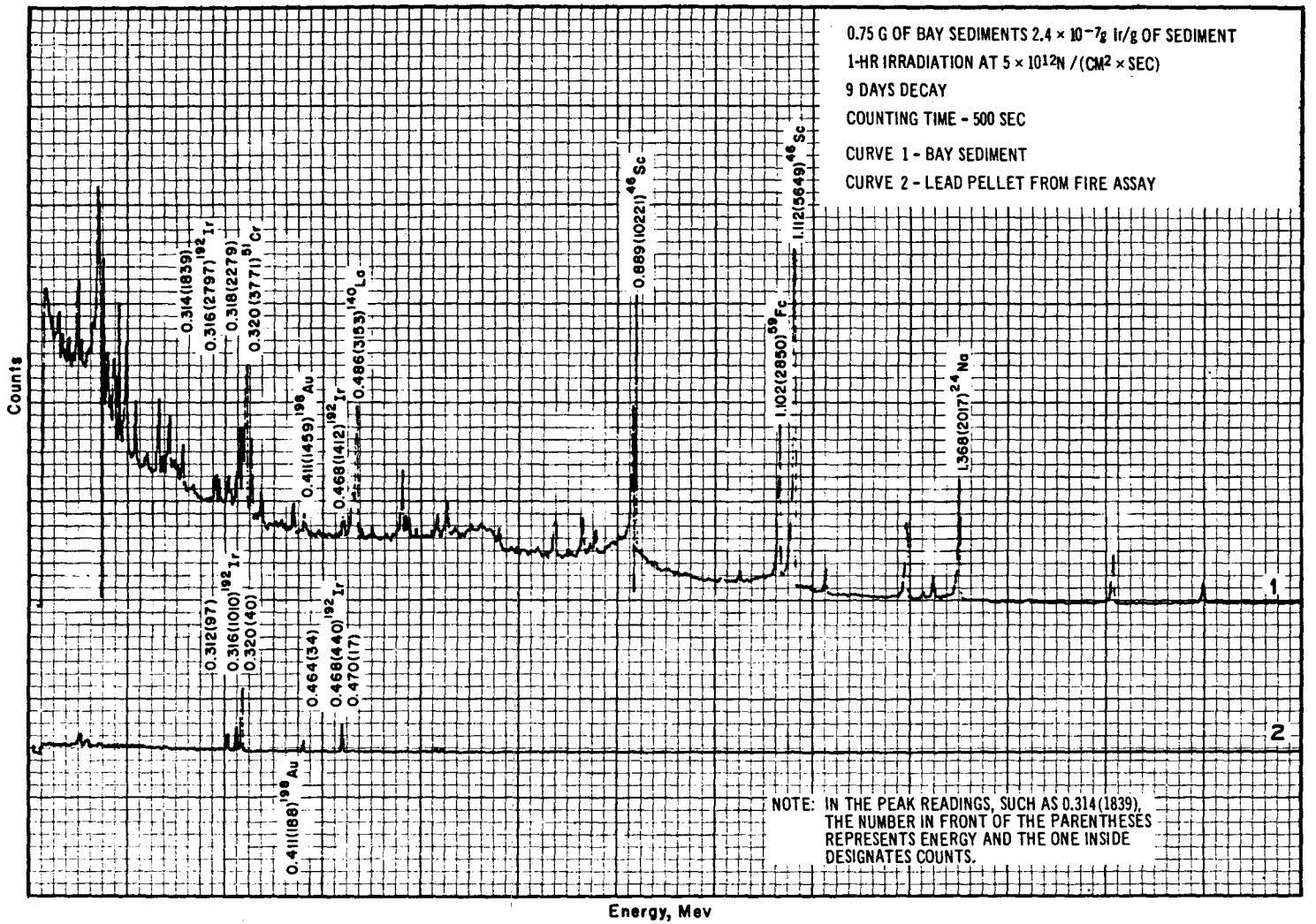

Figure 4. Spectra of iridium-traced San Francisco Bay sediment and fire assay lead pellet from similar sediment

41. The low gamma-ray energy places the rhenium signal in the portion of the spectra which has a high noise level due to the Compton scattered gamma rays from other emitters. While the fire assay process removes most interfering radionuclides, many nuclides from the sediment and from the fire assay chemicals such as silver, lead, and sodium, among others, contribute to Compton scattering and result in noise in the 0.137-MeV region.

42. An additional problem is the gamma-ray emission from selenium (^{75}Se) with a 120-day half-life and a gamma-ray energy of 0.136 MeV. The ^{75}Se comes from both the sediments and the chemicals used in the fire assay process and would interfere with the resolution of the rhenium signal.

43. The signal from rhenium also decays too fast, and at 60-hr postirradiation it would be reduced to 60 percent; at 6 days, to 33 percent; and at 11 days, to 13 percent. To provide an acceptable signal at 6 days and beyond when the interference from ^{24}Na diminishes, the amount of rhenium tracer and thus the cost would have to be increased by at least a factor of 3 or more.

44. By contrast, iridium with a 74.37-day half-life and a principal gamma ray emitted at 0.316 MeV does not exhibit the above-mentioned problems. The higher gamma-ray energy of iridium is in an area of the spectrum little influenced by noise, and its half-life will permit delaying the time of sample counting until the short half-life nuclides in the recovered lead have decayed. No other element directly interferes with the detection of the iridium's 0.316-MeV gamma ray.

45. Thus, it was concluded that iridium was the better choice as a tracer both on the basis of cost and on technical considerations. Iridium's principal attributes as a tracer are summarized below:

a. The amount of iridium required minimizes the mass that must be added to the traced sediment and therefore would least affect particle settling characteristics.

b. The limit of detection for iridium is a factor of 2 lower than that for rhenium.

c. The 74.37-day half-life permits examination of neutron-activated samples at significantly long postirradiation

time without significant reduction in signal due to radioactive decay.

Quantity of Iridium to be Employed

46. The criteria for selecting the tracer element included the assumptions that the natural content of the selected element in the yearly sediment load should be exceeded by a factor of 10 and that 9.1×10^6 g (20,000 lb) of sediment material would be tagged. Prior to purchase of the tracer element these assumptions were reexamined considering the sampling system to be employed. The objective was to determine if the quantity of material to be tagged was sufficient and if the cost* of the tracer could be reduced.

47. San Francisco District personnel during previous sampling efforts had determined the maximum size core sample of the Bay sediments that could be reliably retrieved was 54 mm (2-1/8 in.) in diameter. Using this core diameter and the surface area of the test area, the following calculations were performed to determine if sufficient particulate matter was to be tagged.

48. The test area consisting of San Pablo, Suisun, and Grizzly Bays, plus Mare Island Strait, is approximately 3.16×10^8 m^2 (92 square nautical miles). From examination of sediment samples from this test area, it was determined that the mean particle diameter is between 14 and 20 microns. Assuming all particles (p) are 20 microns in diameter, then the volume (V) of one particle is

$$V = \left(\frac{4}{3}\right)(3.14)(1 \times 10^{-3} \text{ cm})^3 = 4.18 \times 10^{-9} \text{ cm}^3$$

Assuming a specific density of 2.6 g/cm^3 for p , then the weight (W) of one particle is

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* Inflation, devaluation of the dollar, increased industrial demand, and a general withholding from the market by producers outside of the United States eventually increased the price of iridium from $6.95/g to $18.00/g at purchase time.

$$W = \left(2.6 \frac{g}{cm^3}\right)(4.18 \times 10^{-9}\ cm^3) = 1.08 \times 10^{-8}\ g$$

49. In 9.08×10^6 g (20,000 lb), there are

$$\left(\frac{1}{1.08 \times 10^{-8}}\right)\frac{p}{g}(9.08 \times 10^6\ g) = 8.4 \times 10^{14}\ p$$

Assuming uniform particle distribution over the test area of $3.15 \times 10^8\ m^2$, the result is:

$$\frac{8.4 \times 10^{14}\ p}{3.15 \times 10^8\ m^2} = 2.67 \times 10^6 \frac{p}{m^2}$$

Assuming the material from the dredge is uniformly deposited and not mixed in depth a sample with a 25.4-mm (1-in.) radius has an area of $20.3\ cm^2$ ($3.14\ in.^2$). The p/sample is

$$(20.3\ cm^2)\left(2.67 \times 10^6 \frac{p}{m^2}\right) = 5.3 \times 10^3 \frac{p}{sample}$$

With 1.7×10^4 g of iridium on 8.3×10^{14} p, each p would contain

$$\frac{1.7 \times 10^4\ g\ Ir}{8.3 \times 10^{14}\ p} = 2.05 \times 10^{-11}\ g \frac{Ir}{p}$$

in a sample. Then the iridium content from the tagged dredged material could be

$$\left(2.05 \times 10^{-11}\ g \frac{Ir}{p}\right)\left(5.3 \times 10^3 \frac{p}{sample}\right) = 1.09 \times 10^{-7}\ g \frac{Ir}{sample}$$

If the sample is a 50-g size, the iridium content from nature, assuming 5×10^{-10} g Ir/g , would be:

$$\left(50 \frac{g}{\text{sample}}\right)\left(5 \times 10^{-10} \text{ g } \frac{\text{Ir}}{\text{g}}\right) = 2.50 \times 10^{-8} \text{ g } \frac{\text{Ir}}{\text{sample}}$$

Thus the signal would be four times background or 1×10^{-7} g Ir, which is easily seen in the counting system.

50. Using 1×10^{4} g of iridium, the iridium content per sample would be

$$6.3 \times 10^{-8} \text{ g } \frac{\text{Ir}}{\text{sample}}$$

which is 2.5 times the background and also readily seen. Thus, it was concluded that: (a) 9.1×10^{6} g (20,000 lb) were a sufficient amount of material to be tagged; and (b) 1×10^{4} g of iridium would be sufficient signal and would represent a cost savings of 40 percent on the purchase price of the tracer.

PART III: THE TAGGING, TRACING, AND DREDGING OPERATIONS

Physical Properties of the Sediments

51. As previously indicated, the San Francisco District provided samples of the San Francisco Bay sediments from the 21 locations shown in Figure 2 and samples from the Mare Island Strait during dredging. The particle-size distribution of these sediments was determined and is presented in Table 7. The particle-size analysis utilized nondispersed wet-sieving, liquid-sedimentation, and Tyler sieves.

52. Approximately 30 g of as-received sediment were wet-sieved through a 325-mesh screen (43-micron-diam openings) using water from a wash bottle and a spoon to speed the process by breaking agglomerated lumps. The sieve was rinsed with water until only particles greater than 43 microns were retained. The retained material was prepared for additional sieving by drying for several hours in an oven. Sediment particles less than 43 microns which passed through the sieve with the water during the wet sieving were retained for the liquid-sedimentation analysis.

53. The oven-dried particles greater than 43-micron diameter were transferred to a nest of Tyler sieves and Ro-Tapped for 5 min into 991, 350, 180, 125, 43 microns, and pan fractions (less than 43 microns). The dry particle fractions were weighed, and particles less than 43 microns were added to those from the wet-sieving step.

54. The small particles were sized by liquid sedimentation according to Stokes' Law, which describes the rate of fall of a small sphere in a viscous fluid under the action of gravity as

$$V = \frac{2\, g a^2 (d_1 - d_2)}{9\eta}$$

where

V = constant velocity (cm/sec)

g = gravity (cm/sec^2)

Table 7

Sediment Properties

Sample	Location	Solids %	pH*	d** μ	NaCl† %
1	Mare Island Strait, NW upper	37.8	7.6	19	1.5
2	Mare Island Strait, NE upper	38.4	7.6	15	2.0
3	Mare Island Strait, Center Channel	31.6	8.2	19	1.5
4	Pinole Shoal Naval Anchor 315	47.9	7.8	20	1.5
5	Mare Island Strait, SW lower	53.3	8.2	19	1.3
6	Mare Island Strait, SE lower	39.4	8.2	19	5.8
7	Dike 9	42.8	8.1	19	1.3
8	Carquinez Strait, below power cables	63.8	8.4	130	1.2
9	North Side Disposal Dike 12	47.7	8.3	70	0.84
10	South Side Disposal Dike 12	46.8	8.0	15	1.8
11	San Pablo Bay Shoal 1st Target N Dike 12	48.5	8.2	15	5.1
12	SW Davis Point	45.1	8.3	19	1.9
13	Carquinez Strait at Selby Toll	44.7	8.2	17	2.1
14	San Pablo Bay 2nd Target Dike 12	40.4	8.2	16	1.9
15	Pinole Shoal Channel Anchor 318	66.3	8.2	180	0.67
16	South Mud Flat Hercules Wharf	49.7	8.1	14	2.1
17	Shallows of San Pablo Bay	45.9	8.3	19	3.9
18	Mud Flats East of Pinole Point	50.6	7.5	14	1.6
19	Mud Flats Shallows San Pablo Bay	43.5	7.8	15	1.4
20	San Pablo Bay 334 Anchorage	45.2	8.0	16	1.4
21	San Pablo Bay Mud Flats	43.2	7.8	14	1.9
22	Mare Island Strait, sediments from dredge Harding	50.1	7.6	18	1.5

* pH of 50 g of wet sediments mixed with 50-ml distilled water.

** d is diameter of mean particle. One-half the mass is larger than this nondispersed size.

† Includes all insoluble silver salts calculated as NaCl.

a = radius of sphere (cm)

d_1 = density of sphere (g/cm^3)

d_2 = density of medium (g/cm^3)

η = coefficient of viscosity which is temperature dependent ($dyne\text{-}sec/cm^2$)

According to Stokes' Law, a particle of 2.65 density and spherical shape will fall through 10 cm of water of a given temperature in the times listed in Table 8.

55. The liquid-sedimentation apparatus is a vacuum-jacketed glass cylinder of 2-ℓ capacity, with a stopcock controlled sampling spout located exactly 10 cm below the 2000-ml volume mark. The subsieve particle analysis consists of adding the water slurry containing the particles less than 43-micron diameter to the sedimentation column and adjusting the volume to the 2000-ml mark. The particles are uniformly dispersed by shaking the column and repeatedly inverting it, and the settling process is started by standing the column upright on the laboratory bench. At any specified time, an aliquot taken from the sampling spout will have only particles less than the predicted size, since the larger particles will have settled past the 10-cm level. Aliquots taken at increasing times can thus be measured to yield a size distribution for particles less than 43 microns in diameter.

56. As an example, it will be noted in Table 7 that it takes 8 min 5 sec for a 15-micron particle to fall 10 cm in a column of 15°C water. In practice, a 10-ml aliquot is withdrawn first to rinse the spout a few seconds prior to the selected time. At exactly 8 min 5 sec, a 10-ml volumetric flask is filled with the slurry containing particles less than 15 microns in diameter. The 10-ml aliquot is rinsed through an 0.8-micron millipore filter, after which the filter is dried to constant weight and the mass of particles determined. The total weight of particles in the column is determined from a 10-ml aliquot taken at essentially zero time before any settling takes place.

57. Although the numerical values in Table 7 are for particle diameters of spherical shape and uniform density and as such they may be in error, nevertheless, they were obtained by a water-settling

Table 8

Time for Particles of Density 2.65 to Settle

Through 10 cm of Water at Stated Temperature °C

Temperature °C	Particle Size, microns					
	5	10	15	20	30	40
	Settling Time					
10°	1 hr, 16 min	21 min, 30 sec	9 min, 35 sec	5 min, 22 sec	2 min, 29 sec	1 min, 29 sec
15°	1 hr, 6 min	17 min, 30 sec	8 min, 5 sec	4 min, 30 sec	2 min, 12 sec	1 min, 18 sec
20°	57 min, 48 sec	15 min, 18 sec	7 min, 10 sec	4 min, 6 sec	1 min, 54 sec	1 min, 8 sec
25°	51 min, 0 sec	13 min, 36 sec		3 min, 36 sec	1 min, 41 sec	1 min, 0 sec
30°	45 min, 30 sec	12 min, 18 sec		3 min, 14 sec	1 min, 30 sec	53 sec
35°	41 min, 0 sec	10 min, 48 sec		2 min, 54 sec	1 min, 22 sec	49 sec

technique; and since water settling of the particles (from dredging) is a parameter of great interest, the description of this "equivalent" diameter is quite useful.

58. In Table 7 it will be noted that 19 of the 22 samples had mean particle diameters of between 14 and 20 microns. The range of particle-size distributions for these 19 samples is shown in Figure 5. The other three samples, all from channel locations, appeared to be mixtures of mud and sand, such as the particle-size distribution of sample 8 presented in Figure 6.

59. From these data it was concluded that most of the dredge sediment from the Mare Island Strait and most of the sediment from shoaling areas would consist of small particles with a mean particle diameter of about 15 microns and with more than 80 percent of the total mass consisting of particles between 10 and 30 microns in diameter. This then characterized the particle-size distribution of the sediments which would be tagged.

Chemical Properties of the Sediments

60. The now disestablished Naval Radiological Defense Laboratory (NRDL) conducted studies with Bay sediments in 1956. NRDL was assisted in the preparation and analysis of the sediments by the San Francisco District Sausalito Laboratory. A chemical analysis conducted by the Corps at that time is reported in Table 9. It was immediately apparent that high temperatures could not be used in tagging Bay sediment since both the chemical and physical properties of the particle would be altered. This indicates that a surface adsorption mechanism had to be used to tag the sediment particles. Table 9 shows that material less than 44 microns in diameter (some 90 percent) is largely silt and clay. The crystal lattice of clay is known to be able to tightly bond or "fix" cations.[7]

61. Since soluble salts in the sediments provide cations to compete with the tagging element, an analysis was conducted on each of the 22 samples to measure salinity, as noted in the following paragraphs.

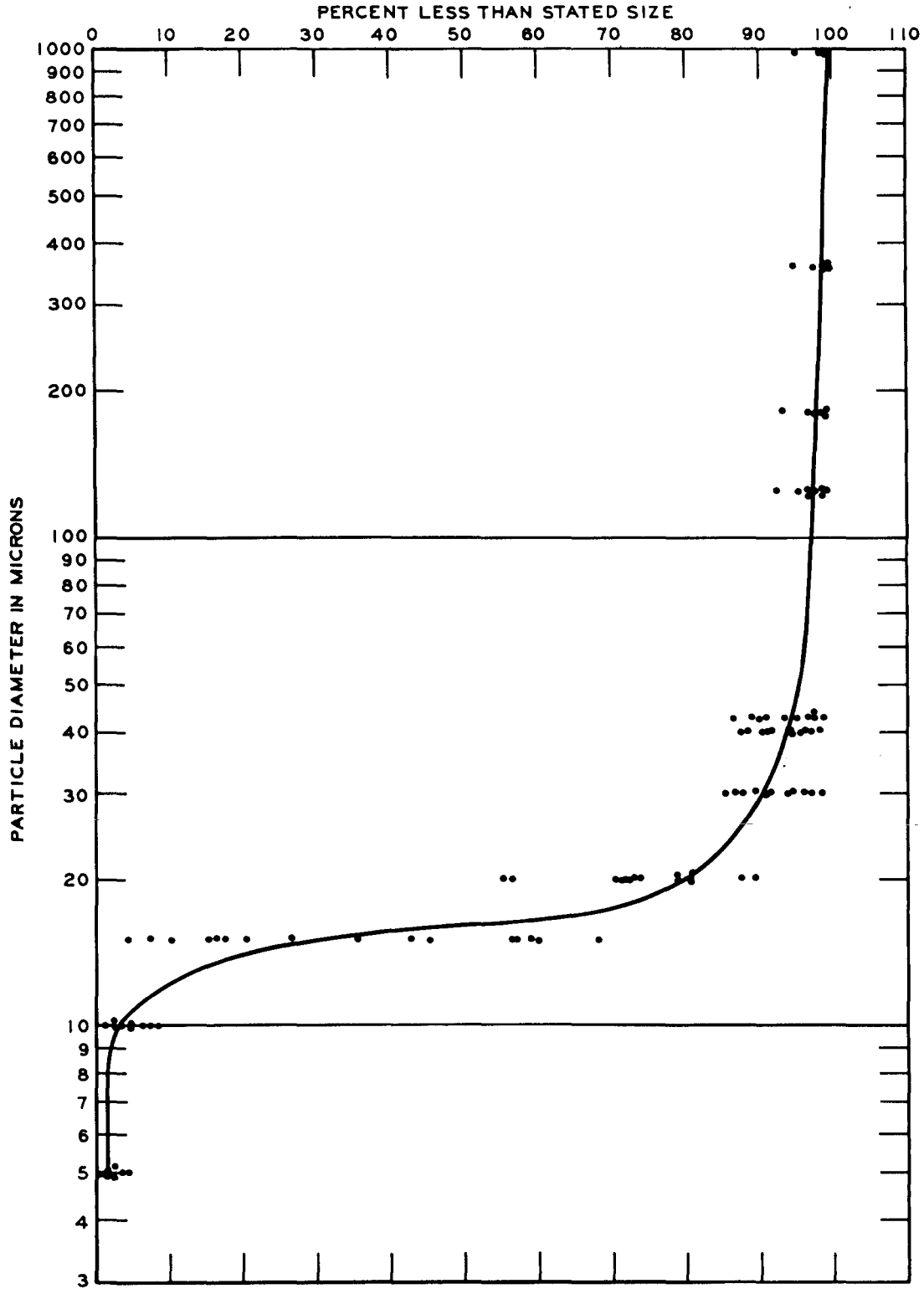

Figure 5. Graph of nondispersed particle mass below stated size for all samples showing single-population distribution

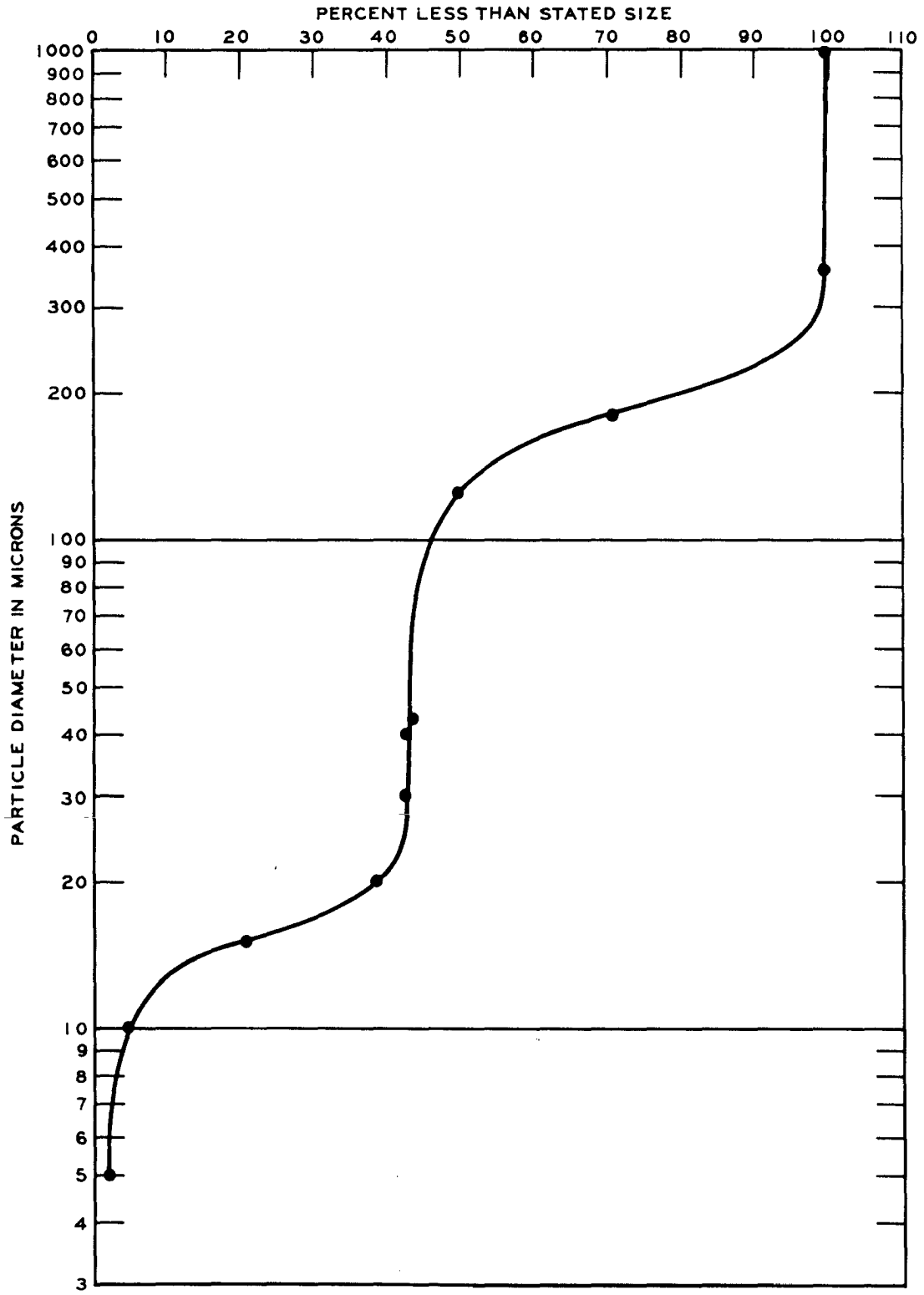

Figure 6. Particle-size distribution of sample 8 from Carquinez Strait

Table 9

Analysis of Sediments from Mare Island Strait

Oxide Analysis	Percent
Loss of Ignition	8.06
Silica (SiO_2)	57.74
Aluminum Oxide (Al_2O_3)	15.18
Ferric Oxide (Fe_2O_3)	6.19
Calcium Oxide (CaO)	2.94
Magnesium Oxide (MgO)	1.68
Sulfur Trioxide (SO_3)	2.56
Sodium Oxide (Na_2O)	2.88
Potassium Oxide (K_2O)	0.86

Material retained on 325-mesh sieve (44 microns):

Organic
- Shell fragments - white and blue shell material
- Vegetative - seaweed, wood fragments

Mineral
- Quartz - fine, rounded-to-angular particles of transparent quartz
- Feldspar - angular particles of weathered feldspar
- Mica - thin, fragile plates of yellow and brown
- Iron Oxides - black particles of magnetite

Material passing 325-mesh sieve:

Largely silt and clay. (Clay probably includes montmorillonite.)

62. Quantitative testing for chloride may be accomplished by precipitation with $AgNO_3$ since AgCl is nearly insoluble in cold water.

$$Ag^+ + Cl^- = AgCl$$

63. Small errors may result from chloride ions originating from species other than NaCl and also from other insoluble silver salts. For our purposes, however, this method yields useful measurements of salt concentration differences in Bay sediments.

64. Aliquots of sediments were taken from each of the 22 samples and dried for two days. The percent solids for each sample is listed in Table 7. Ten grams of dried sediments were weighed into clean dry beakers. Approximately 100 ml of distilled water were added and the slurry was brought to a boil. The water was cooled and the sediment particles settled. The water was decanted off and filtered. Another 50-75 ml of distilled water were added to each beaker and then boiled, cooled, decanted, and filtered. Finally, the sediment samples and beakers were rinsed with distilled water and filtered.

65. The filtrates were combined and adjusted to volume in a 250-ml volumetric flask. A 25-ml aliquot of this solution was then filtered through a millipore filter to determine the weight of sediment particles in 25 ml. Another 25-ml aliquot was transferred to a clean beaker. To this, 10 ml of 0.25 N $AgNO_3$ were added to precipitate the chloride ions. This solution and precipitate were stirred, allowed to settle, and then filtered through a millipore filter.

66. The millipore filters were oven-dried for half an hour and allowed to cool. After weighing, the weight of the sediment particles in 25 ml is subtracted from the weight of AgCl. The percentage of NaCl for each of the 22 samples is listed in Table 7. These values, especially the three high ones, indicated the sediment should be washed to dilute the soluble salts prior to tagging. The pH values in Table 7 show no significant difference among the 22 samples.

Preparation of Soluble Iridium Tagging Solution

67. Iridium was available only in the form of iridium metal powder. Direct purchase of soluble iridium salts involved considerable conversion costs and delivery delays. Therefore, the 10 kg (22.05 lb) of purchased iridium metal were converted to Na_2IrCl_6 in a batch process.

68. Two hundred and fifty grams of powdered metal were thoroughly mixed with 250 g of crystalline NaCl and placed in the center section of a quartz tube which was 1.22 m (4 ft) long and 50.8 mm (2 in.) in diameter. The quartz tube was inserted in a tube furnace at 755.4 K

(900°F), with all the iridium mix in the heated section and with 0.3 m (1 ft) of tube protruding from each end. Chlorine gas from a high-pressure cylinder was bubbled through a water bulb and delivered to the front end of the quartz tube. After passing over and through the iridium charge, the unreacted Cl_2 was discharged from the downstream end of the quartz tube. The tube was rotated through 3.141 radians (180°) several times during the chlorination to fluff the charge and insure exposure to the Cl_2.

69. The reaction was essentially complete after 24 hr, and the quartz tube and contents were removed from the furnace and cooled. The iridium charge was then released into a 1.89×10^{-2}-m^3 (5-gal) polyethylene container. When five batches (1250 g) of iridium had accumulated, distilled water was added to make 1.89×10^{-2} m^3 (5 gal) of solution. The solution was agitated several times a day for one week and then filtered into a second container. The filter was dried and ignited to recover the unreacted metallic iridium. The recovered iridium was weighed and recycled to the chlorination process. The weight of the recovered iridium was subtracted from 1250 g to get the concentration of iridium in the freshly prepared solution. A total of 9900 g of iridium was placed in solution. The solution was stored for use during the tagging operation.

Fixing Iridium to Dredge Sediments

70. Numerous preliminary tests showed that iridium was strongly bonded to the dredge sediments although the exact mechanism is obscure. No doubt the following factors are involved. The dredge sediments have a cation exchange capacity of about 30 milliequivalents per 100 g, which is much more than adequate for the small concentration of iridium involved (0.1 percent by weight). The small sizes and platy shapes of the particles give very large surface areas for adsorption. According to Coulomb's Law, large attractive forces exist between the negative oxygen ions in the crystal lattice and the adsorbed cation, which is iridium in this case. Other mechanisms such as organic complexes or

chelates no doubt contribute to fixation of iridium to the dredge sediments. To measure the stability of the iridium-tagged sediments over a long period of time and leaching by saline water, the following tests were conducted.

71. Iridium "fixing" tests were conducted using sediments from Mare Island Strait (sample 22, Table 7). One litre of wet sediments was placed in a beaker, and 1 litre of distilled water was added with vigorous stirring. The slurry was allowed to settle for 2 hr, and the water was removed by decanting. This washing was repeated three times to dilute soluble salts and reduce the number of very small particles.

72. Leaching tests were conducted as follows:

A volume of washed sediments containing 4 g of solids was placed in each of three centrifuge tubes. One millilitre of a solution containing 4 mg of iridium was added to each tube followed by an aliquot of solution containing about 20,000 counts per minute (c/m) of Ir-192. This then simulated the iridium concentration which was planned for the tagged sediments. The contents of the tubes were stirred and then mechanically agitated to insure mixing. One tube was placed in a drying oven at 393.2 K (120°C), the second tube was allowed to air-dry, and 20 ml of tap water were added to the third tube. When the first two tubes were thoroughly dry (6 days later), 25 ml of tap water were added to each.

The leaching solutions were thoroughly mixed with the tagged sediments and set aside for several days. Periodically, the leaching solutions were removed from all three tests by decanting into clean test tubes and replaced by equal volumes of fresh tap water. The tube containing oven-dry sediment was leached twice with tap water, and the third and subsequent leaches were water from Mare Island Strait. Table 10 shows the dates and leaching times that apply to the three tests.

On 17 September 1973, 1-ml aliquots were carefully removed from each of the test tubes containing leach solutions and from the three tubes containing tagged sediments and the 5th leach. The 5th leach solution was then decanted into a clean tube, and the 6th leach solution was added. The tagged sediments and the 1-ml aliquots were then counted, and the data are presented in Table 11. It can be seen that when the leach aliquots' activity has been corrected by subtracting background, no significant Ir-192 was removed from the tagged sediments by leaching. The 6th leach was similarly measured on 25 September 1974, and again no Ir-192 was found

Table 10

Schedule of Leaching Tagged Sediments

Date	Procedure	Leach Interval Δt (days)	Leach Time Total Σt (days)
15 Jun 73	Prepared sediments		
20 Jun 73	Dried sediments		
21 Jun 73	Added 25 ml water		
19 Jul 73	Removed 1st leach	28	28
30 Jul 73	Removed 2nd leach	11	39
6 Aug 73	Removed 3rd leach	7	46
4 Sep 73	Removed 4th leach	29	75
17 Sep 73	Removed 5th leach	13	88
25 Sep 74	Removed 6th leach	373	461

in the aliquot although by this time the tagged sediments' activity had decayed to less than 800 c/m.

73. Thus, the leaching data show that iridium is "fixed" to dredge sediments by application to the wet sediments, and that no advantage is inherent in drying or heating the tagged sediments.

Preparation and Assay of a Batch of Tagged Sediments

74. Prior to tagging the sediment material to be added during the dredging operation, a batch of sediments was tagged using essentially the same procedures and equipment to be employed in the large-scale tagging operation. The objective was to proof-test the preparation and analytical procedures.

75. A 0.5-g sample of iridium-tagged sediments (10^{-3} g Ir/g sediments) was neutron-activated in the TRIGA reactor for 1 hr. Since a concentration of 10^{-8} g Ir/g sediments was anticipated for the released dredge material, a dilution of 10^{5} was required. Accordingly,

Table 11

Iridium "Fixing" to Dredge Sediments

	Leach Test 1* c/m	Leach Test 2** c/m	Leach Test 3† c/m
Bkg††	306	305	305
Sediments	12,189	9,277	8,343
1st	328	307	322
2nd	311	308	310
3rd	299	312	319
4th	305	315	313
5th	318	314	315
Bkg	311	306	312

* Iridium-tagged wet sediments - 4-g sediments, 20-ml tap water.
** Iridium-tagged air-dry sediments - 4-g sediments, 20-ml tap water.
† Iridium-tagged oven-dry sediments - 4-g sediments, 20-ml tap water for leaches 1 and 2, then Mare Island Strait water for leaches 3, 4, 5, and 6.
†† Bkg is normal response of counter with no sample present.

0.155 m^3 (41 gal) of processed sediments from the Mare Island Strait were prepared in a plaster mixer at a density of 1.16 g/cm^3. The neutron-activated sediments were added to 0.155 m^3 (41 gal) and then mixed for 15 min to insure uniform blending.

76. Three samples of the simulated tagged dredged material were taken from the plaster mixer, dried, and 50 g of each sample were fire assayed. The gamma spectra of the resulting lead were very uniform, and the Ir-192 peak from a 300-sec count was sufficiently large to permit a good measurement after an additional 10-fold dilution and a reasonable signal-to-noise response after a 100-fold dilution. The 100-fold dilution (10^{-10} g Ir/g sediment) was expected to be contained in the natural sediment material and fire assay chemicals and, as such,

would be a background value to be subtracted from the field samples.

77. After the particles settled in the plaster mixer, 3.8×10^{-3} m^3 (1 gal) of water was removed from the top; after filtering, it was evaporated to dryness. The residue was collected in a 40-ml test tube and examined in the spectrometer. No Ir-192 was found.

Tagging Operation

78. For the tagging operation, a net weight of 9.1×10^6 g (20,000 lb) of Mare Island Strait sediment materials was required. The most desirable source of material would have been from the hopper of a dredge, but, since no dredging was possible prior to the conduct of the tracing operation, the material was obtained from a landfill, dredged material disposal site in the northwestern area of the Mare Island Naval Shipyard. The material in this site had been dredged from the Mare Island Strait over a period of years.

79. Prior to accepting this material for tagging, samples were obtained from five test holes (four corners and the center of a 15.2-m (50-ft) square) 1.5 m (5 ft) deep. The sediments from this test area were found to have the same physical and chemical properties as those from the Mare Island Strait (Table 1).

80. A total of 1.8×10^7 g (40,000 lb) of wet marine sediments was removed from the disposal site and delivered to the Stanford Research Institute's (SRI) facilities at Camp Parks near Dublin, California. Here the material was converted from large agglomerated masses to particulate material having the same characteristics and size distribution as that determined to be in the dredge's hoppers during the previous dredging of Mare Island Strait. Figures 5 and 7 show the size distribution of the materials from Mare Island Strait and those resulting from the marine sediments.

81. The agglomerated lumps were converted to particulate materials by first breaking the material into 50.1-mm-(2-in.-) diam pieces using a soil shredder. The pieces were then placed into a 0.21-m^3 (55-gal) drum of water which was slowly agitated using an air-driven

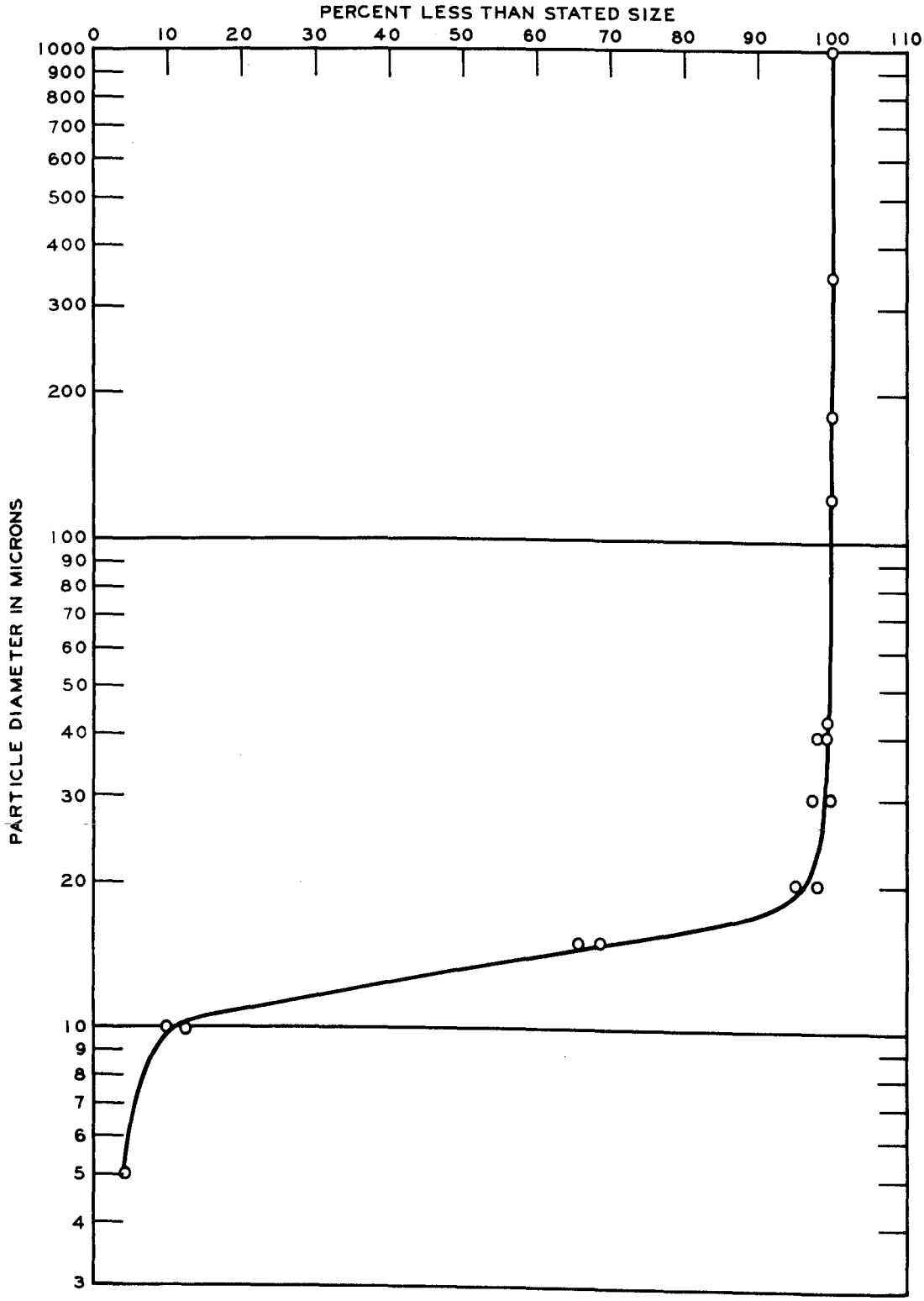

Figure 7. Nondispersed particle-size distribution of sediment material to be tagged

mixer until a slurry was produced. The slurry was transferred to another agitated 0.21-m^3 (55-gal) drum where the solid-liquid content was adjusted to produce a uniform mixture. This mixture was then transferred to storage drums which were sampled to determine the particle-size distribution. While in the drums, fresh water was added, the mixture was agitated and then allowed to settle, and the water was decanted. This process was repeated three times to dilute the soluble salts and remove very fine particles prior to tagging.

82. With sufficient slurry prepared, about 0.23 m^3 (60 gal) of the slurry were pumped into a plaster mixer of the type commonly used by building contractors. After thorough mixing, the slurry's density was adjusted to 1.16 g/ml. The resulting volume was then measured, and a calculated iridium addition was slowly sprayed into the mixing slurry to produce an iridium concentration of 1.212 g of iridium per 3.8×10^{-3} m^3 (1 gal).

83. The tagged sediment was transferred to 1.89×10^{-2}-m^3 (5-gal) paint cans and 0.21-m^3 (55-gal) drums and palletized for shipment to the dredge. A total of 30.9 m^3 (8169 gal) of slurry containing 9.86×10^6 g (21,729 lb) of solids and 9900 g (22 lb) of iridium, or 1.01×10^{-3} g Ir/g of sediment, was prepared.

Dredging and Tracer Addition Operations

84. Figure 8 shows the Mare Island Strait area, the channel area dredged, and the disposal area. Dredging was commenced on 19 February 1974 and continued until 30 March 1974. Dredging operations were conducted for 24 hr a day for 12 consecutive days followed by a 2-day rest period. Thirty-five dredging days were completed, making a total of 706 trips between the channel and the release site.

85. Dredging was accomplished by the U. S. Army Corps of Engineers dredge, Chester Harding. The Harding is a dual-suction dredge having port and starboard variable depth trailing suction arms, each powered by a 1000-horsepower diesel-driven pump. During dredging of the Mare Island Strait, the Harding proceeded ahead slowly with one or both

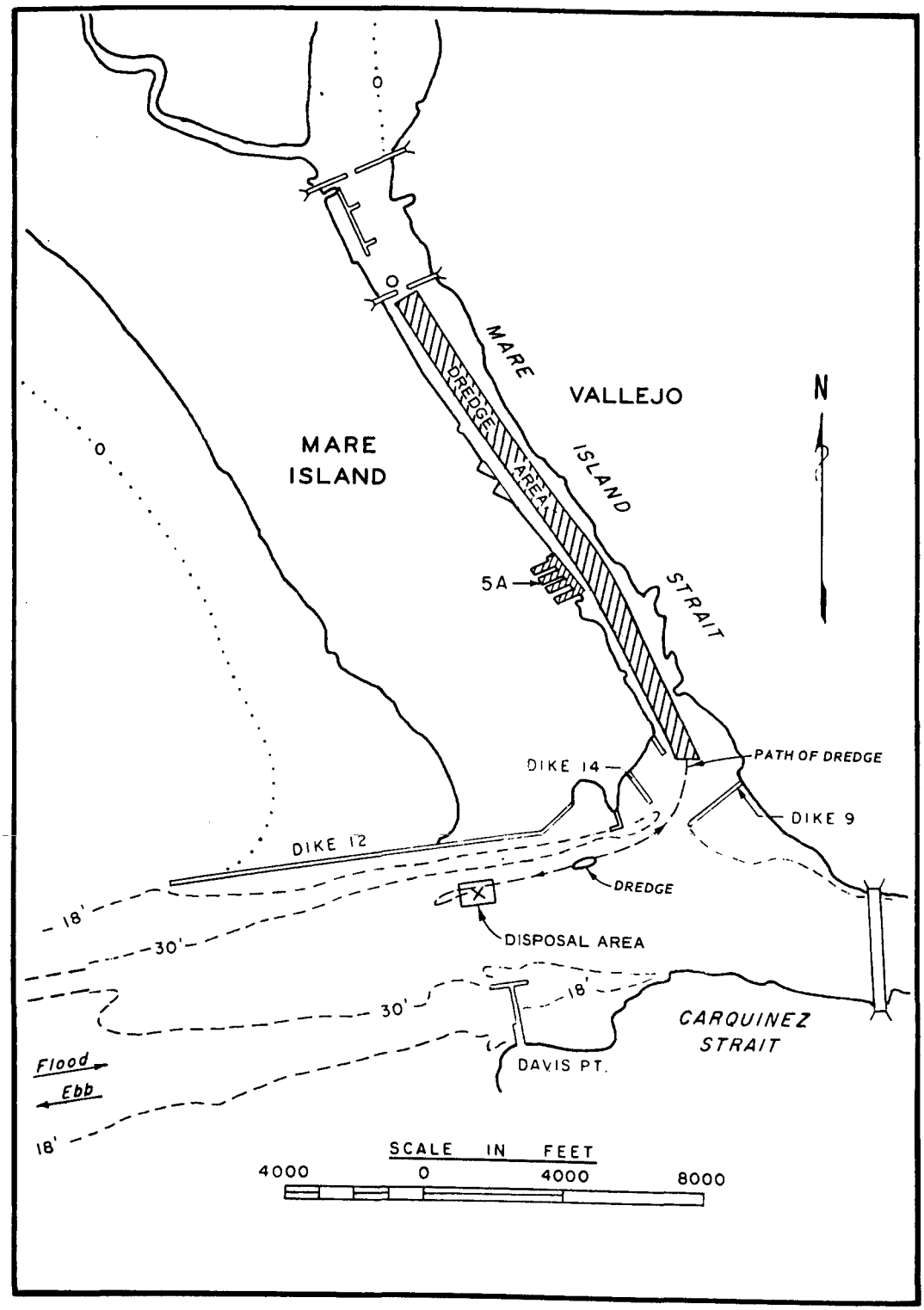

Figure 8. Area dredged in Mare Island Strait

suction arms trailing alongside at a depth that permitted pumping a water-sediment slurry into the dredge's hoppers. The Harding has two bottom-dumping hoppers located forward and aft of the midship superstructure. Dredged materials are fed from both trailing arms into both hoppers. Each hopper is filled to capacity, and to maximize payload, pumping may be continued with excess water and some sediment overflowing back into the channel. Figure 9 is a cross section of a hopper showing its general configuration.

86. San Francisco District personnel* determined the capacity of the dredge hopper on three separate occasions during the dredging cycle and calculated the volume to be 1758 m^3 (2300 yd^3) per trip. For the dredging cycle of 706 loads, the total sediments removed were 5.12×10^{11} g (504,000 long tons). With 9900 g of iridium added, the concentration of iridium was 1.95×10^{-8} g Ir/g of sediments dredged.

87. The traced sediments were added to the two hoppers via standpipes located in the center of each hopper with their outlets extending approximately 1.8 m (6 ft) below the top of the dredged material (Figure 9). Approximately 2.27×10^{-2} m^3 (6 gal) of traced sediments were added to each hopper by pouring the traced sediments into the standpipe, sealing the top of the pipe, and pressurizing and flushing the pipe with the ship's water supply (Figure 10). To preclude contamination of the channel by overflow, the addition of the traced sediments was always accomplished after the dredge had departed from the channel and prior to its arrival at the release site.

88. The release site location, shown in Figure 8, is in the Carquinez Strait where the water depth is approximately 18.3 m (60 ft). Once at the release site, the dredge pumps were activated pouring water on top of the loaded hoppers while simultaneously opening the hoppers' dump doors. The above actions produced a very turbulent condition in the dredged material being discharged. This turbulence, plus that encountered in water following hopper discharge, served to further mix the traced sediments with the dredged sediments.

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* Memo: Mr. John Sustar, SFD, to Mr. E. Leahy, EERL, of 17 May 1974.

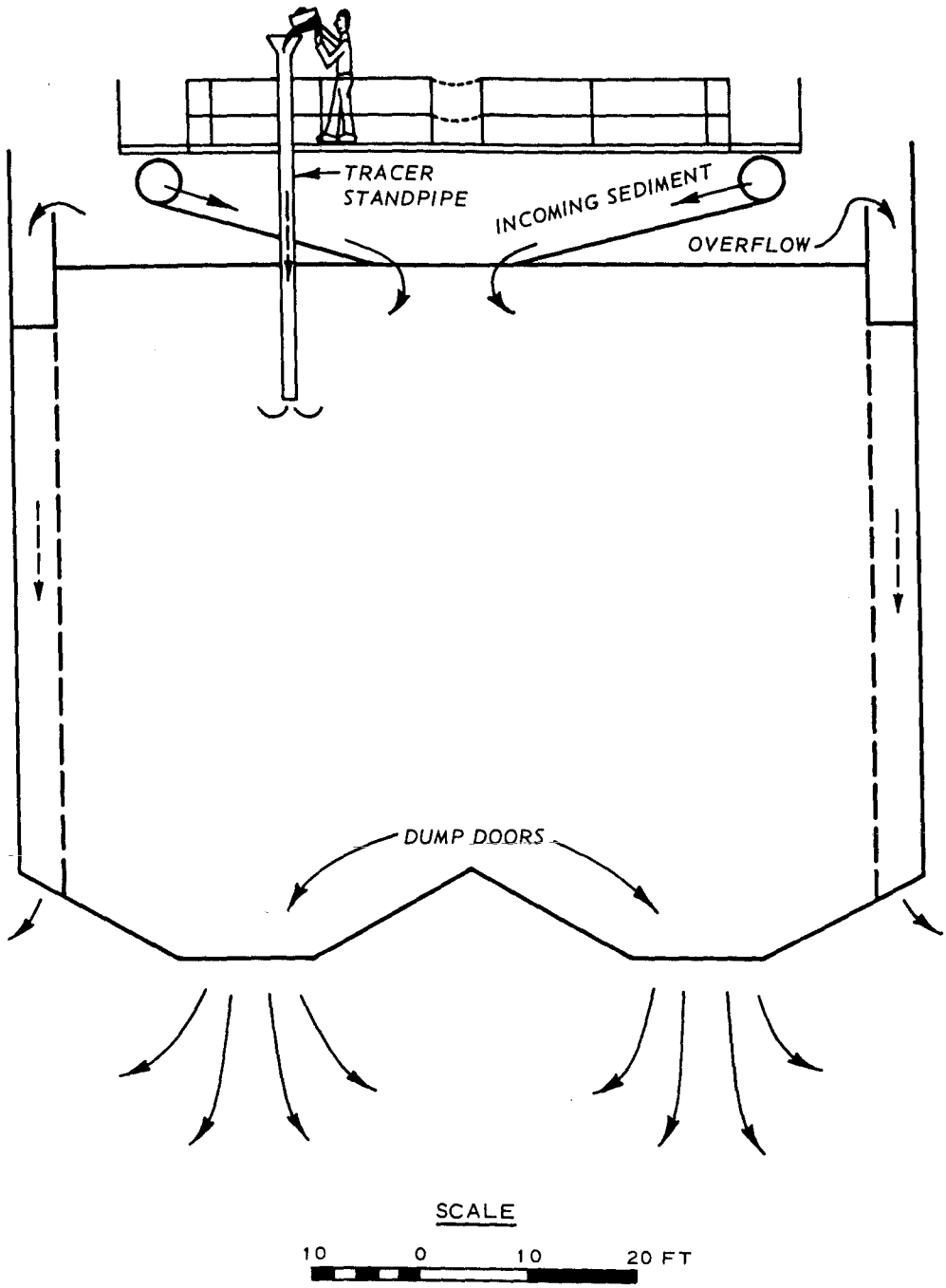
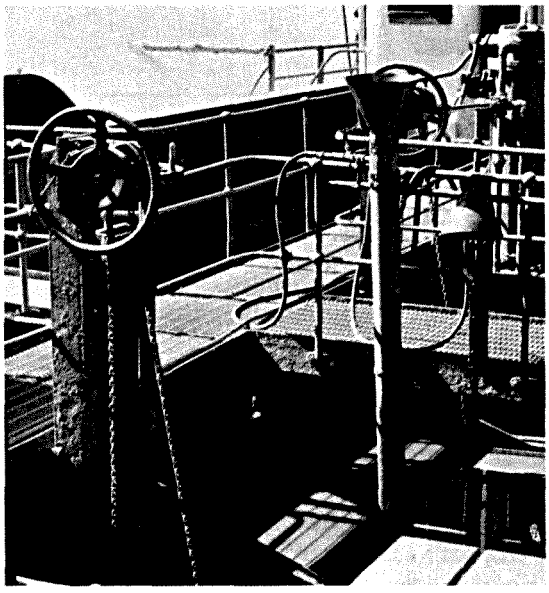
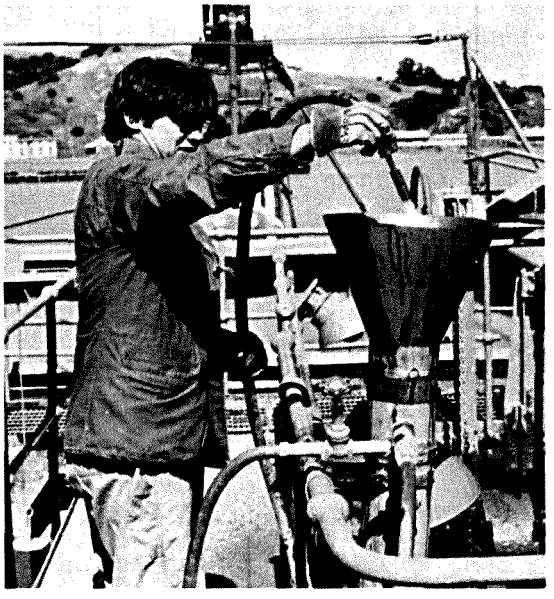


Figure 9. Schematic cross section of Harding's hoppers

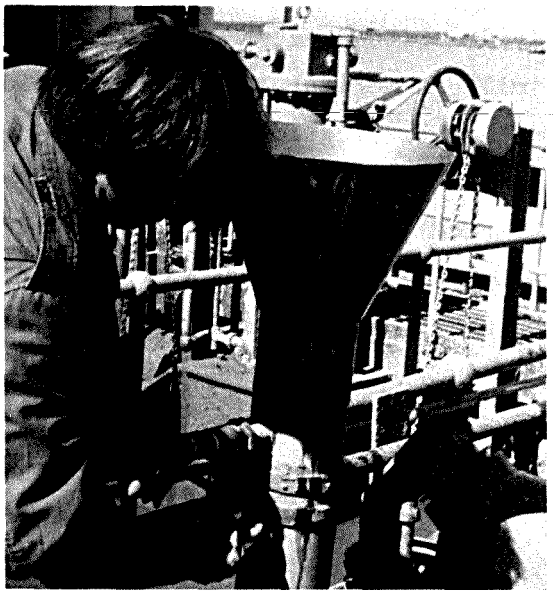


a. Loaded hopper prior to adding traced sediments

b. Adding traced sediments



c. Rinsing funnel and sealing



d. Pressurizing standpipe

Figure 10. Addition of traced sediments to loaded hopper

PART IV: SAMPLING OPERATIONS AND ANALYSIS

Test Area and Grid System

89. Figure 2 shows the area sampled for the tracer program. The area included San Pablo and Suisun Bays, and Carquinez Strait which connects the two bays with the Mare Island Strait. Figure 11 shows the tracer program sample grid overlaid on Figure 2. For sample location identification, each sample point was given a numerical designation as shown in the figure. The numerical designators, referred to as hole numbers, were assigned when the sampling boat first reached a location. The order of points sampled in any particular time period depended on the current direction at the time. A total of 111 locations were so designated.

90. To assist in locating the hole numbers in the test area, each hole number was further described by a major and minor grid system. The major grid consisted of squares with 2037.2-m (1.1-nautical mile) sides having a numerical designation in the X direction and a letter designation in the Y direction. Each individual grid was further subdivided into squares with 203.7-m (0.11-nautical mile) sides and a similar numerical-letter designation system. The convention adopted for identifying samples was to list the hole number followed by the major and minor alphabetical designators and then the major and minor numerical designators. For example, in Figure 11, hole number 72, also designated with coordinates H, h-4, 3, is located in the major grid defined by H and 4 and the minor grid by h and 3.

Sampling Operations

91. Sampling operations were conducted using a modified World War II type landing-craft medium (LCM). The LCM, which was on loan to the San Francisco District from the National Oceanographic and Atmospheric Administration, was equipped with a navigation bridge containing radar, depth indicator, and conventional small-craft navigational instruments.

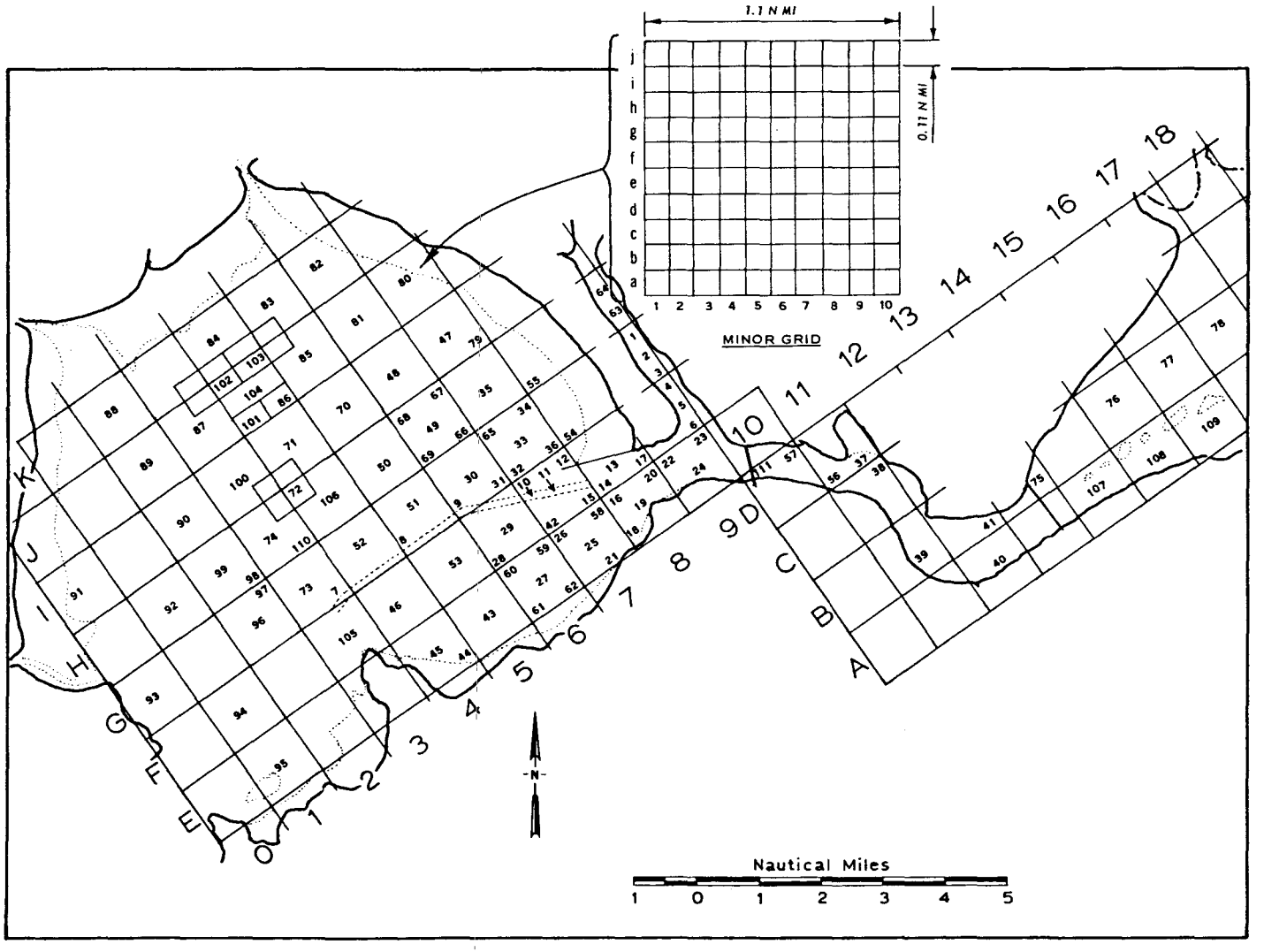


Figure 11. Tracer program grid

92. For sampling operations, the cargo deck of the LCM had been modified to contain a well. A double "A" frame was positioned above the well. The "A" frame and a motor-driven block and tackle were used to handle a wash-bore, push-type, verticle-tube core sampler. The core sampler contains a 762- by 54-mm-ID (30- by 2-1/8-in.-ID) clear acrylic liner and a vacuum seal system to retain the sampled material in the core liner.

93. In a typical sampling operation, the sample boat was brought into position, using sextant and radar navigation, and anchored. At some locations where the water was shallow the sample locations were marked with a stake. The depth of the top of the sediments was referenced to mean lower low water (mllw) and was determined by the depth indicator and the reference to a tide gage reading and the tide tables. Lengths of pipe were fixed to the core sampler head, and the unit was lowered through the well in the cargo deck via the "A" frame and its block and tackle to a depth just above the bottom. The sampler was then pushed into the bottom for a distance of about 762 mm (30 in.). While in place, a sealing ball was inserted into the top of the handling pipe followed by a steel bar to seat the sealing ball. The sampler was retrieved, and the liner containing the cored sediment material was carefully removed, capped on both ends, labeled, and logged. Five cores were taken at each sampling location. Figure 12 shows several groups of

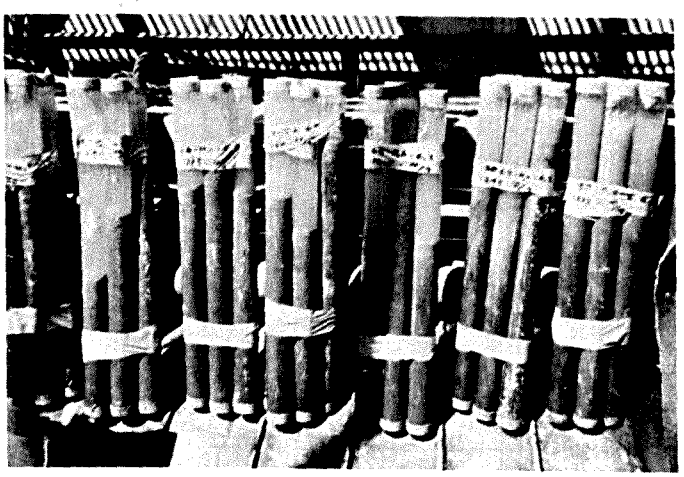


Figure 12. Sediment cores collected from a number of sample locations

five core samples prior to being boxed for shipment.

94. Figure 13 is a typical log sheet completed for each sampling location. The first horizontal line indicates the hole number, major and minor grid coordinates, date, time, gage readings, measured water depth, and wind, wave, and current direction data. The data for each core are listed above the tube sketch showing the tube number, the depth pushed into the sediment, the measured amount of solid material in the tube, and the elevation of the top of the sediment referenced to mllw. Each tube was diagrammed on the log showing the measured depth of various materials in the tube. The nomenclature used is shown in the figure. The designation of "Fluff" was used to describe the very fine mineral particles suspended in the top layer of the sample. "Active" was used to describe the most recently deposited sediments which are believed to be easily resuspended by wave and/or current action. "Inactive" described the sediments that are believed to move rarely, if ever. The distinction among the various layers is made by visual examination of each tube.

Sample Processing

Core processing

95. The daily collection of samples was removed from the boat and stored ashore. Weekly, the collected samples were transported from storage to the processing area of SRI at Camp Parks located near Dublin, California.

96. SRI personnel took the five tubes from a particular location, carefully removed the top 25.4 mm (1 in.) of material from each tube, and then dried and recorded the weight of solid sediment material. The top 25.4 mm (1 in.) were selected in an effort to obtain sufficient sediment materials from the very fluffy-like sediments that were in the process of transport and settling in a particular location.

97. Once the top 25.4 mm (1 in.) were removed, one of the five tubes was selected and its sediments were carefully removed in 101.6-mm (4-in.) increments. Each increment was dried, weighed, and recorded.

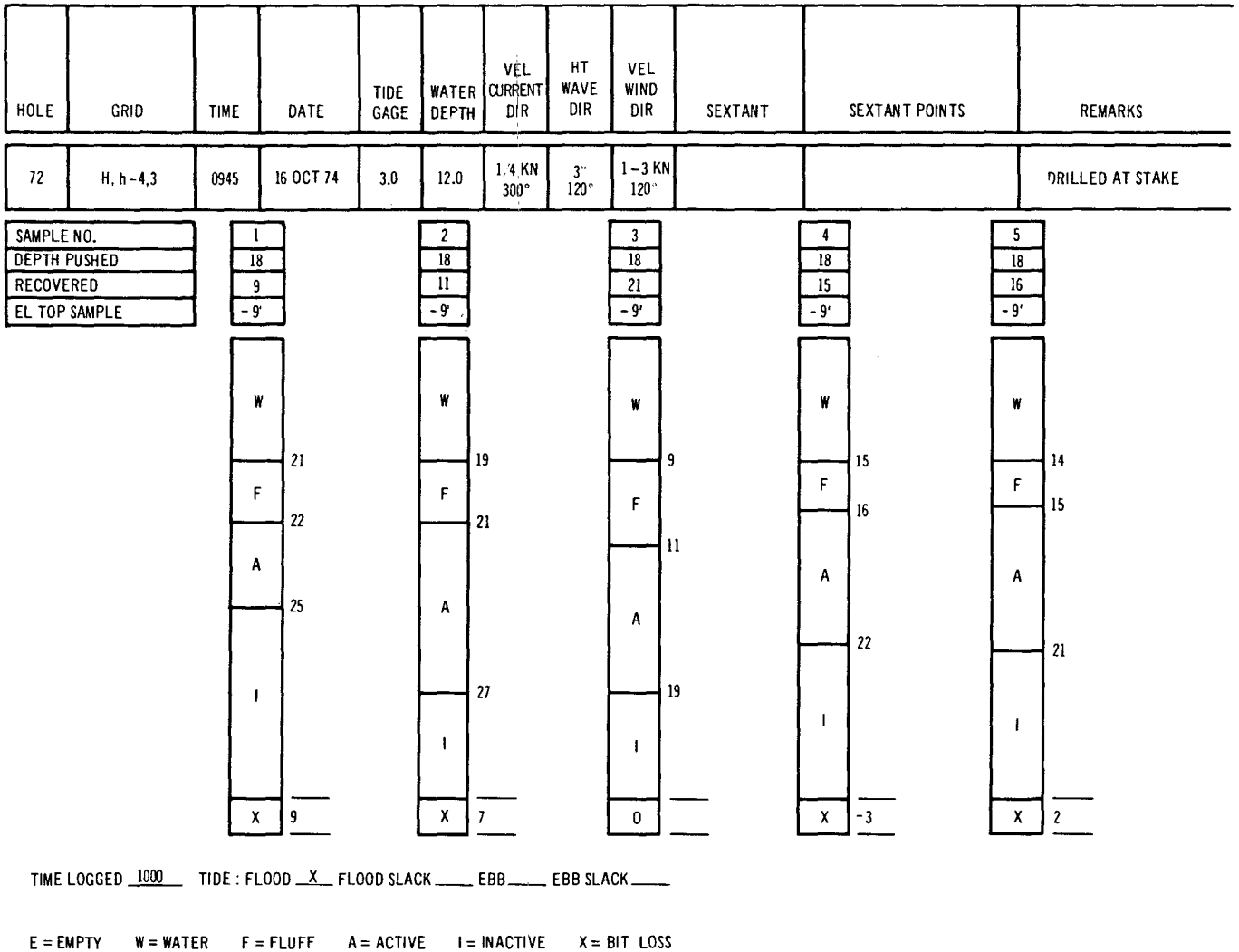


Figure 13. Typical core log for a sample location

The remainder of the tubes were stored for possible future use.

98. Each dried sample was then ground in a Wiley Mill and passed through a 20-mesh sieve. To prevent cross contamination in the grinding operations, the Wiley Mill and sieve were cleaned after each sample grinding, and the first 50-80 g of the next sample were passed through the mill and discarded. The remainder of the sample was then ground and stored until sufficient samples were prepared for the fire assay process.

Fire assay process

99. In the fire assay process, 50 g of the dry ground sediments are mixed with 60 g of litharge (PbO), 20 g of sodium carbonate (Na_2CO_3), 18 g of sodium borate ($Na_2B_4O_7$), and 2-5 g of starch. The amount of starch used for lead reduction varies with the type of mineral particles and organic material in the sample.

100. After thorough mixing, the material is placed in a refractory crucible and heated to 1338.7 K (1950°F) and held for 1 hr. The molten mass is then poured into a steel mold where the slag forms on top and the lead settles to the bottom. When cool, the slag and lead are separated, and the slag is discarded. The weight of the metallic lead recovered is 30-50 g depending on the PbO reduction by the combined action of sediments and starch. The lead mass is weighed, formed into a right cylinder, and sealed in a 12.7-mm-(1/2-in.-) OD × 63.5-mm-(2-1/2-in.-) long numbered aluminum tube. Each tube is then leak-tested and placed in a 139- by 25.8-mm (5.5- by 1-1/8-in.) polyethylene irradiation container.

Neutron activation

101. All irradiations were performed in the Lazy Susan Facility of the General Atomic TRIGA Mark III Reactor operated by the Nuclear Engineering Department of the University of California, Berkeley. The Lazy Susan is a specimen rack contained within a dry chamber surrounding the reactor core. The specimen rack has 41 sample locations evenly spaced around the circumference. Of the 41 locations, 38 were available for use.

102. With the reactor operating at a 1-megawatt (MW) power level

(thermal), the nominal neutron flux at midline of the specimen chamber is $5 \times 10^{12} n/(cm^2 \times sec)$. All irradiations were conducted for 1 hr at a 1-MW power level.

103. The samples remained in the Lazy Susan for at least 48 hr after irradiation to allow decay of the short-lived radionuclides induced in the aluminum and sediment components. For this storage period, the Lazy Susan was placed in an up-position which is essentially out of the thermal neutron flux and permits reactor operation for other purposes.

104. The neutron flux experienced by the samples was determined by placing a flux monitor in every fourth irradiation container. Flux monitors were known amounts of iridium, 4.12×10^{-5} g Ir. After approximately 20 days of decay, the flux monitors were measured in the SRI 4-pi ion chamber,[8,9] and the flux was calculated. The flux calculated for a particular location was considered to apply to the irradiation cans adjacent to the can monitored.

Sample counting

105. After at least 48 hr of cooling time in the reactor, the samples were removed, packaged in shielded containers, and transported to SRI's Camp Parks Facility. At SRI the samples were stored for approximately 20 days to permit further radioactive decay.

106. When the decay period had passed, the lead slug was removed from the aluminum tubing and placed in a 50.8-mm-(2-in.-) diam aluminum foil weighing dish. The dish and lead slug were heated until the lead melted and formed a smooth disc on the bottom of the dish. After cooling, the sides of the dish were folded in, and the sample was ready for counting.

107. Counting was performed using an ORTEC lithium-drifted germanium diode and preamplifier connected to a Canberra 1024 channel analyzer. The Canberra analyzer was connected to both a teletype printer-paper tape unit and an X-Y plotter. The teletype printer-paper tape unit was used to enter sample identification data and to record output from the Canberra analyzer. The X-Y plotter gave a visual presentation of the sample spectra as shown in Figure 14. The punched

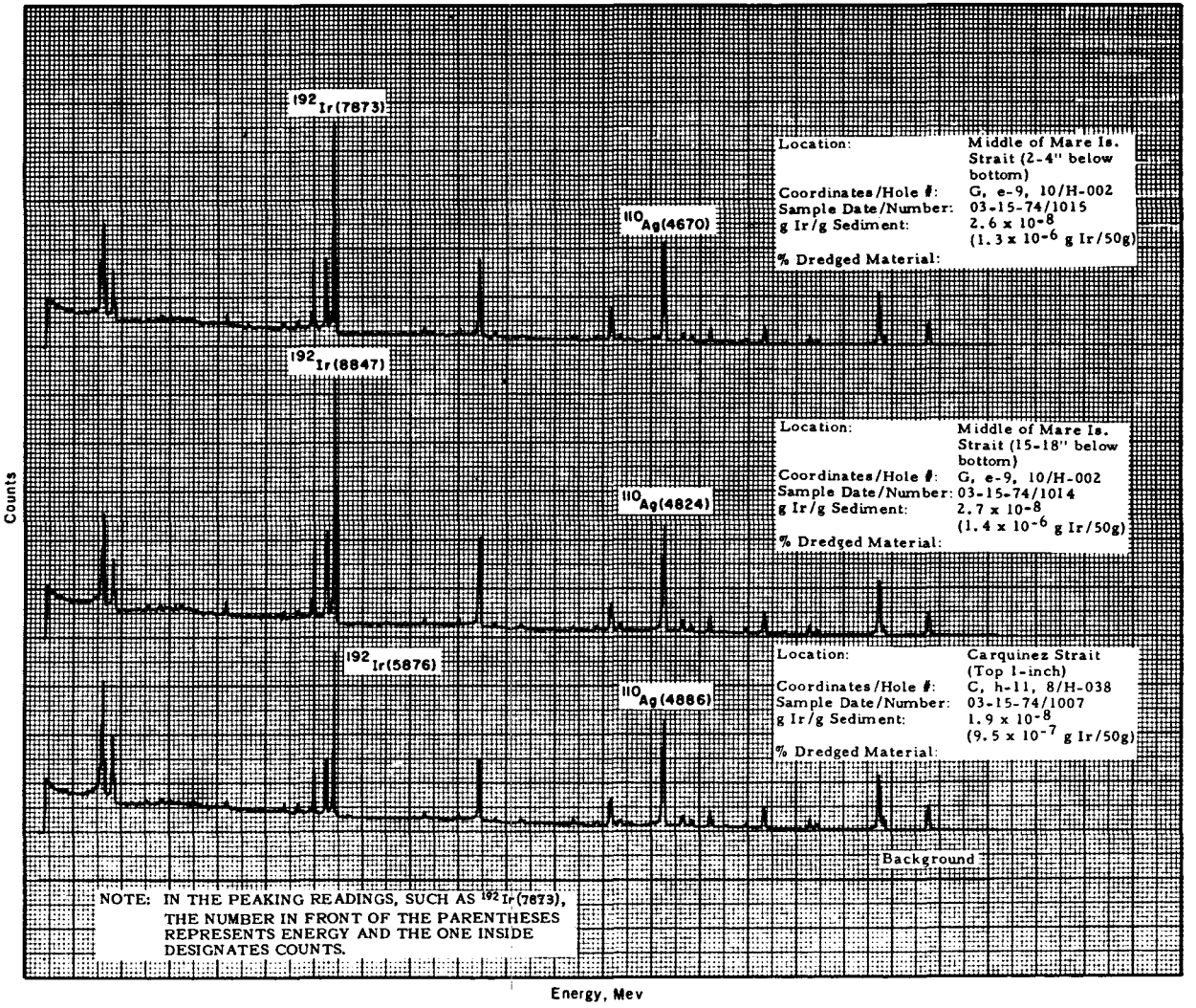


Figure 14. Typical spectra of fire-assayed 50-g sediment sample

paper tape was used to input the sample identification and spectra data into computer codes which calculated the amount of iridium in a sample and the mass of dry sediment per unit volume of wet sample. The percentage of dredged material represented by the iridium was then calculated.

108. The amount of iridium in a sample was calculated by integrating the area under the 316-keV photon peak. Each sample was counted for a total of 300 sec. The following calculations were performed to determine the amount of iridium in a sample.

109. Total counts (C_T) in the 316-keV photon peak were determined by considering the counts in channels (ch) 313 and 318 or 319 as being background noise and subtracting this noise value from the total counts

$$C_T = \sum \text{counts (ch 313 to 319)} - [3(\text{ch 313}) + 4(\text{ch 319})]$$

if ch 319 > ch 318

$$= \sum \text{counts (ch 313 to 318)} - [3(\text{ch 313}) + 3(\text{ch 318})]$$

The C_T were then corrected for decay to determine counts at the end of irradiation

$$C_{T_o} = \frac{C_T}{e^{-0.693t/T_{1/2}}}$$

where

C_{T_o} = counts at the end of irradiation

C_T = counts at counting time

t = time after irradiation (days)

$T_{1/2}$ = half-life of ^{192}Ir (74.37 days)

C_T at irradiation time were then converted to dis/sec

$$I_o = \frac{C_{T_o}}{(B)(E)(RG)}$$

where

I_o = dis/sec at end of irradiation

B = counting time (300 sec)

E = counting efficiency, 0.0234 counts per disintegration

RG = fire assay recovery and counting geometry factor, 0.514

110. Counting efficiency was determined by measuring a radioactive iridium solution in the SRI 4-pi ion chamber and then taking aliquots of that solution, drying the solution to a point source, and determining the count rate observed in the 316-keV photon peak as previously described. Point-source counting efficiency (E) was

$$E = \frac{\frac{C}{S_{316}}}{A_o}$$

where

C/S_{316} = counts per sec measured under the 316-keV photon peak

A_o = activity of the point source (dis/sec)

The recovery-geometry factor (RG) was determined by measuring the activity of radioactive iridium solutions in the SRI 4-pi ion chamber and then tagging San Francisco Bay mineral particles with various concentrations of the solution. The tagged minerals were fire-assayed using the same procedures as previously described and the recovered lead was melted into a disc and counted. The RG was expressed as

$$RG = \frac{\frac{C}{S_{316}}}{A_o \times E}$$

The weight of iridium (W_{Ir}) in a sample was written as

$$W_{Ir} = \frac{I_o A}{\sigma N_c m \phi \left(1 - e^{-0.693 t_i / T_{1/2}}\right)}$$

where

W_{Ir} = weight of iridium (g)

I_o = activity of sample at T_o (dis/sec)

A = atomic weight of I_r, 192.2 g

σ = neutron cross section of $^{191}Ir\ (n,\gamma)\ ^{192}Ir$ reaction, 7.50×10^{-22} cm^2

N_c = Avagadro number, 6.02×10^{23} molecules/mole

m = percentage of isotopic abundance (37.3%)

ϕ = neutron flux ($n/(cm^2/sec)$)

t_i = length of irradiation (1 hr)

$T_{1/2}$ = half-life of ^{192}Ir (hr)

With the weight of iridium in a sample known, the grams of iridium per gram of dry sediments and the percentage of dredged material in a sample were calculated as follows:

$$SIr = \frac{(W_{Ir})(Pb_y)}{(Sw)(Pb_a)}$$

where

SIr = grams of iridium per gram of dry sediments (g Ir/g)

Pb_y = weight of lead from fire assay process (g)

Sw = weight of sediments fire-assayed (g)

Pb_a = weight of lead irradiated

$$\text{Percentage of dredged material} = \frac{SIr - Bkg}{D_c} \times 100$$

where

Bkg = naturally occurring iridium in San Francisco Bay sediments plus iridium in fire assay chemicals = 3.16×10^{-10} g Ir/g

D_c = concentration of iridium in dredged materials, 9900 g on 5.12×10^{11} g of sediments dredged = 1.95×10^{-8} g Ir/g

Background for the San Francisco Bay mineral particles was determined by the previously described irradiations conducted at University of California and noted in Table 2, by irradiation and chemical separations techniques conducted by the Lawrence Livermore Laboratory, and from a large number of fire-assayed samples of sediments collected during the sampling of San Francisco Bay.

111. The Lawrence Livermore Laboratory determined* a limiting value only for iridium using radiochemistry techniques. The limit

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* Memo: Mr. Austin Prindle (LLL) to Mr. E. Leahy, EERL, of 1 March 1974.

determined was $\geq 1 \times 10^{-10}$ g Ir/g of sediment.

112. To define the iridium background for the sediments and for the fire assay chemicals, a total of 366 fire-assayed samples were averaged and accepted as representing the background of iridium in the Bay. The samples were those showing "no iridium" from the early post-dredging collection periods. The arithmetic average was determined to be 3.16×10^{-10} g Ir/g of sediment with a standard deviation of 1.49×10^{-10}. This value was considered as the best representation of the iridium background of the sediments including the iridium contributed by the fire assay chemicals.

113. Using 3.16×10^{-10} g Ir/g of sediment as background, in a 50-g fire assay sample, the total iridium from background and chemicals is 1.58×10^{-8} g Ir per counting sample. The level of tracer on the dredged sediments is 1.95×10^{-8} g Ir/g of dredged materials. Thus, in a sample with 1 g of dredged material and 49 g of natural sediments, the total signal is 3.49×10^{-8} g Ir per sample. This amount of iridium is easily detectable and permits detection of dredged material concentrations of 2 percent and less in a sample.

114. Figure 15 shows a typical printout from the calculational codes for one sample hole. The data for the 111 holes are presented in Part I of Appendix A, which is published under separate cover. In the figure, the first two lines give the coordinates of the sample, the hole designation, and the name of the general area in which the sample is located. The third line lists the date the sample was collected. The next four lines show the distance to the top of the sediment below mllw in feet and the thickness in inches of the fluff, active, and inactive layers as recorded on the sample log sheets at sample collection time.

115. The remainder of the data lines pertain to a particular sample and repeat for each sample. Sample A represents the first 25.4 mm (1 in.) of material taken from all five cores and combined into one sample. The number opposite sample A is the capsule number assigned by SRI personnel and used throughout the processing steps. The numerical values are not in order since they are assigned when a sediment sample

COORDINATES	HOLE NO.	LOCATION
G A 3 10	7	SAN PABLO STRAIT

SAMPLING DATES	11MAR74	20MAR74	24APR74	15MAY74	19JUN74	22JUL74	20AUG74	28SEP74	70CT74	15NOV74	4DEC74
DEPTH OF SEDIMENT BELOW MLLW (FT)	42.0	41.0	41.0	39.0	40.5	40.0	40.0	40.0	40.0	41.0	40.0
THICKNESS OF LAYERS (IN)											
FLUFF	1.5	0.2	1.5	1.5	0.0	0.5	0.0	0.0	6.0	1.0	0.0
ACTIVE	15.0	4.5	12.0	11.0	13.0	5.0	4.0	7.0	12.0	5.0	3.0
INACTIVE	3.0	14.0	11.0	15.0	14.0	14.0	9.0	20.0	11.0	21.0	22.0
SAMPLE A	1001	3787	1234	1492	1846	2005	2428	2725	2845	3352	3481
G.DRY/CC.WET MUD	0.703	0.450	0.517	0.914	1.307	0.840	0.708	1.095	0.846	0.684	0.746
G.IR/G.DRY MUD	2.00E-08	5.87E-11	8.14E-10	2.98E-10	2.05E-10	5.80E-10	3.19E-10	3.64E-10	4.01E-11	2.11E-10	1.09E-10
% DREDGE MATERIAL	101.150	0.000	2.555	0.000	0.000	1.354	0.016	0.246	0.000	0.000	0.000
SAMPLE B	1002	3788	1235	1493	1847	2006	2429	2726	2846	3353	3482
G.DRY/CC.WET MUD	1.148	0.924	1.358	0.514	1.520	0.900	0.575	1.014	1.041	0.562	0.372
G.IR/G.DRY MUD	1.26E-08	-BDL-	1.01E-09	3.85E-10	3.30E-10	1.79E-10	1.87E-10	2.56E-10	-BDL-	-BDL-	3.29E-10
% DREDGE MATERIAL	63.036	0.000	3.585	0.355	0.070	0.000	0.000	0.000	0.000	0.000	0.066
SAMPLE C	1003	3789	1236	1494	1848	2007	2430	2727	2847	3354	3483
G.DRY/CC.WET MUD	1.004	0.660	0.982	0.567	1.433	0.860	0.774	0.740	1.098	0.682	0.975
G.IR/G.DRY MUD	3.43E-09	-BDL-	1.92E-09	4.36E-10	3.47E-10	4.41E-10	4.33E-11	3.75E-10	4.01E-10	1.95E-10	4.85E-10
% DREDGE MATERIAL	15.988	0.000	8.229	0.613	0.158	0.641	0.000	0.304	0.436	0.000	0.866
SAMPLE D	4891		4151	4153				4155	4157		
G.DRY/CC.WET MUD	0.789		0.552	0.564				0.626	0.763		
G.IR/G.DRY MUD	5.61E-10		3.45E-10	2.34E-10				3.70E-10	3.34E-10		
% DREDGE MATERIAL	1.258		0.146	0.000				0.279	0.091		
SAMPLE E	1005							4156			
G.DRY/CC.WET MUD	1.230							0.762			
G.IR/G.DRY MUD	2.23E-08							4.71E-10			
% DREDGE MATERIAL	112.616							0.795			
SAMPLE F	1006		4152	4154					4158		
G.DRY/CC.WET MUD	0.921		0.723	0.671					1.251		
G.IR/G.DRY MUD	6.97E-09		2.30E-10	-BDL-					4.48E-10		
% DREDGE MATERIAL	34.133		0.000	0.000					0.678		
SAMPLE G	4892										
G.DRY/CC.WET MUD	0.777										
G.IR/G.DRY MUD	-BDL-										
% DREDGE MATERIAL	0.000										
SAMPLE H											
G.DRY/CC.WET MUD											
G.IR/G.DRY MUD											
% DREDGE MATERIAL											

Figure 15. Sample data output

is processed. The density of the layer is listed in terms of grams of dry material per cubic centimetre of wet mud. The amount of Ir/g of dry material is determined from the fire assay of 50 g of dry sediments. The percentage of dredged material is determined as previously presented. Additional samples taken from a single core at a location are labeled B, C, D, etc. Each alphabetic designator consists of 101.6 mm (4 in.) of material. Thus, B represents the material residing between 25.4 and 127 mm (1 and 5 in.) below the surface; C, between 127 to 228.6 mm (5 to 9 in.) below the surface.

Special Samples

116. In addition to the samples collected in the test areas, samples of sediments were also collected: (a) from the hoppers of the dredge during the February-March 1974 dredging; (b) from selected shoaling areas of the Central and South Bays between the cities of Richmond and San Mateo (Figures 1 and 16); and (c) from 10 cross-section profiles of the Mare Island Strait (Figure 17). The data collected from these samples are discussed in Part V; the reason for their collection is given below.

Hopper samples

117. Samples of the materials being dredged from Mare Island Strait in February-March 1974 were collected from the hoppers of the Harding on every tenth dredging pass. The purpose of the samples was to attempt to determine if the dredge was rehandling previously dredged material. The dredged material was collected by dipping a new plastic container directly into the sediments in the hopper and immediately resealing the container. A complete set of results of this sampling effort is presented in Part II of Appendix A.

Central and South Bay samples (outside test area)

118. Samples of the shoaling materials were collected, using the same coring technique as in the test area, at 20 locations in the Central and South Bays during September-December 1974. The purpose

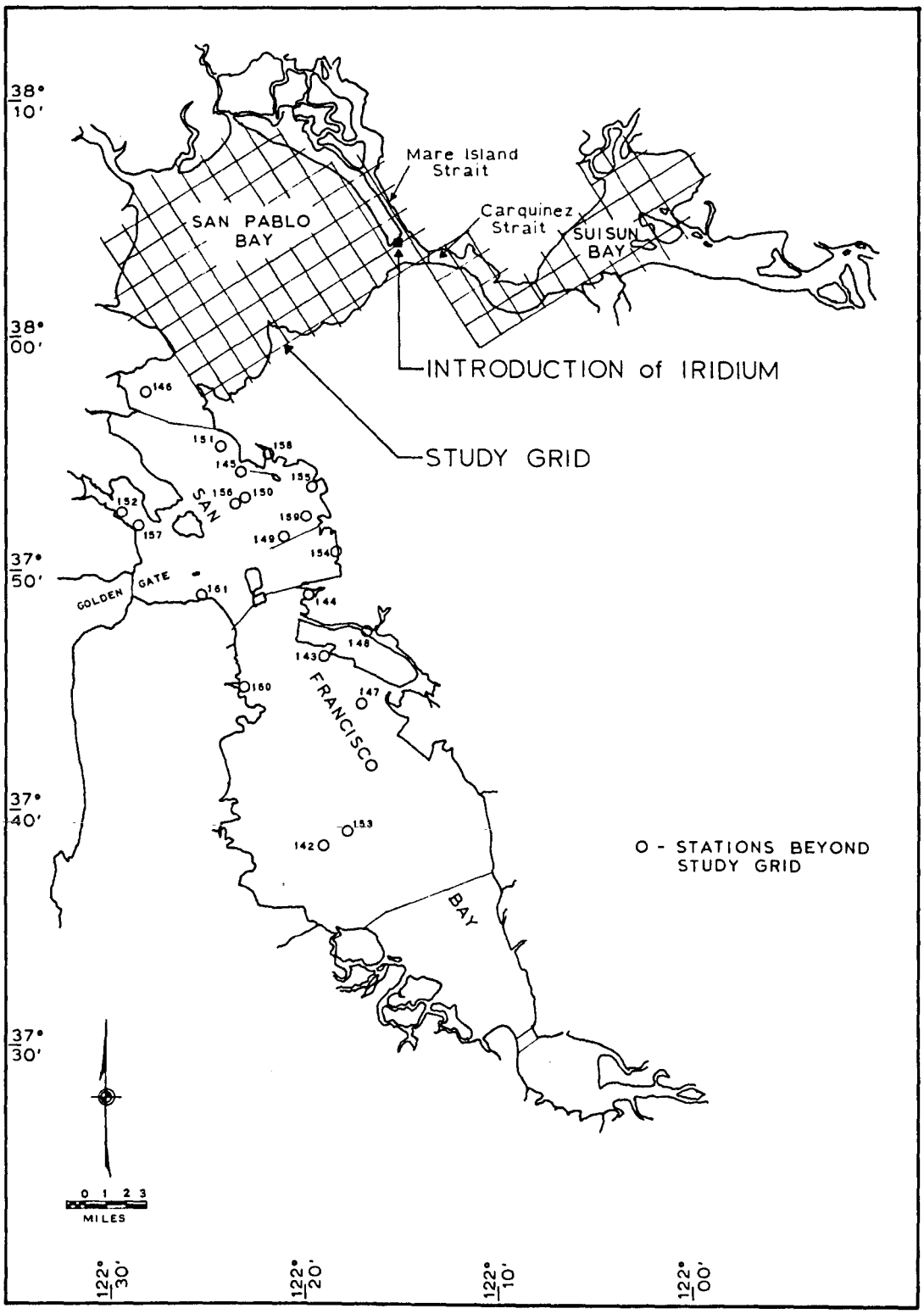

Figure 16. Tracer program location map of stations sampled in Bay areas beyond study grid

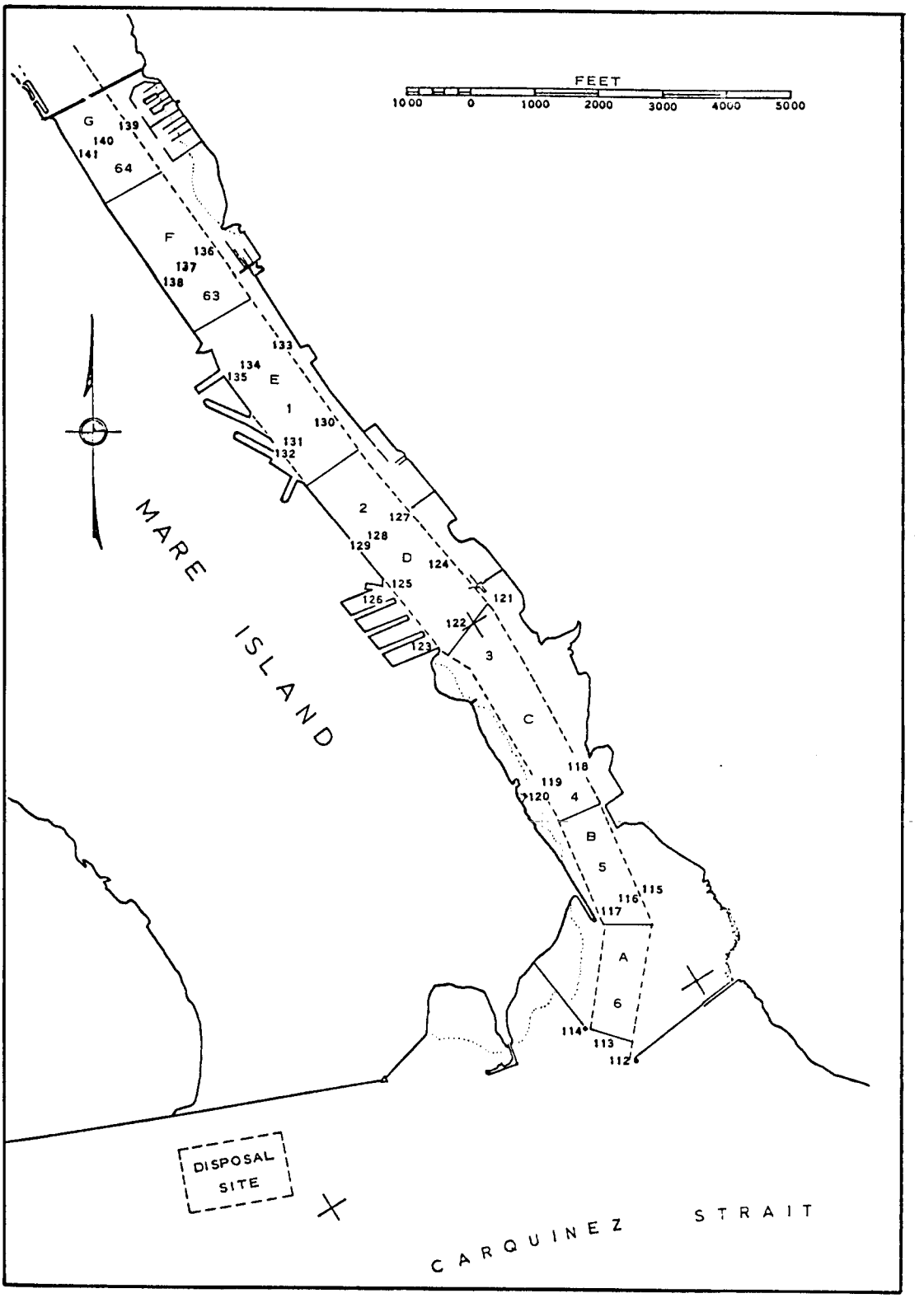

Figure 17. Mare Island Strait cross-section stations and channel sections

of these samples was to determine if dredged material from Mare Island Strait which was released in Carquinez Strait was a significant contributor to the shoaling in the selected areas. These samples were processed in the same manner as the other Bay samples. The complete set of results of these samplings is given in Part III of Appendix A.

Mare Island Strait
cross-section profiles

119. In September 1974, dredging was again scheduled to remove the accumulated sediments in the Mare Island Strait. Prior to this dredging, in late August 1974, 30 cores were collected at 10 cross-section profiles of the Mare Island Strait. These samples were split into two equal sections per sample tube. Each section was homogenized, and an aliquot of 50 g of dry sediment was taken for analysis. The complete set of results of this analysis is presented in Part IV of Appendix A.

PART V: RESULTS AND CONCLUSIONS

General

120. The detailed analysis and interpretation of sample data in terms of sediment transport and shoaling will be performed by the San Francisco District. This report presents only sufficient data to demonstrate the effectiveness of the tracer for labeling and following the movement of dredged material. In the San Francisco District's report,[10] the results of the tracer program will be combined with data from other programs to produce an in-depth analysis of the sediment transport and shoaling process. This report will also contain a complete listing of all data collected during the March-December 1974 sampling of San Francisco Bay. The same listing is also included in Appendix A.

Samples

121. During the March-December 1974 period, the following samples were collected:

a. A total of 56 samples from the dredge's hoppers just after loading and prior to starting toward the disposal site. (Since the Harding made 706 round trips, a sample represents an average of 12 trips.)

b. Approximately 110 samples each month for 10 months from the test area grid (Figure 11).

c. A total of 30 profile samples from the Mare Island Strait in August 1974 just prior to redredging the channel in September and October 1974 (Figure 17).

d. A total of 20 samples from areas of the Bay outside the test area (Figure 16).

122. From the above field sampling operations, a total of 3990 laboratory samples and several hundred control and background samples were processed and analyzed for iridium. Portions of the results from each of the above sampling operations are presented to demonstrate the tracing capability achieved.

Hopper samples

123. Table 12 lists the date, time, approximate dredging location, and percentage of dredged material in the dredge's hoppers during the February-March dredging operation. The dredging locations refer to specific areas of Mare Island Strait (Figure 17). As can be seen in the table, the hopper samples indicate concentrations of tagged dredged material of as much as 50 percent, with a considerable number of samples showing concentrations of 10-25 percent. These concentrations of tagged dredged material suggest that a certain amount of material was rehandled during the dredging operation and indicate that tagging does permit tracing the dredged sediments.

124. Interpretation of the iridium data from the hopper samples in terms of quantities of material being rehandled may require assuming a uniform distribution of iridium throughout the hopper. Although the sampling technique itself (i.e., immersing a plastic container into hopper sediment) does not permit a measure of accuracy of this assumption, the physical configuration of the loading system ensures good mixing and distribution to both hoppers. As a result, the distribution should be uniform in the lateral and longitudinal directions, but may not be uniform as a function of depth in the hopper.

125. Accidental contamination of the Mare Island Strait or of the hopper samples with iridium-tagged sediments is considered unlikely for the following reasons:

a. Iridium-tagged sediments were never added to the hoppers until after the dredge had cleared the channel and was approaching the disposal site.

b. Cleaning the decks was not permitted in the Strait.

c. No liquid discharge from laundering or other operations was permitted in the channel.

d. Each sample was collected in a new plastic container removed from its individual wrapper just prior to filling.

e. After filling, by immersing the container in the hopper sediment, the container was sealed and its outer surface washed with fresh water.

f. The sediments were spooned out of the container in a

Table 12

Samples from Hoppers of Dredge Harding During the February-March 1974 Dredging Operations

Date	Time	Location by Channel Section*	Percentage of Dredged Material
2/23	AM	Not recorded	0.98
2/23	PM	Not recorded	4.06
2/24	PM	Not recorded	2.38
2/24	AM	A	3.47
2/25	PM	A	6.74
2/26	AM	A	4.91
2/26	PM	A	1.90
2/27	PM	A	7.51
2/28	AM	A	2.58
2/28	PM	A	29.68
3/1	AM	A	0.0
3/2	AM	A	5.06
3/5	AM	F	10.12
3/5	PM	F	0.0
3/6	AM	F	49.91
3/6	PM	F	27.12
3/7	AM	F	2.64
3/7	PM	F	41.74
3/8	AM	E	0.0
3/8	PM	D	0.44
3/9	AM	D	0.0
3/9	PM	E	27.07
3/10	AM	D	5.13
3/10	PM	D	5.66
3/11	AM	D	1.55
3/11	PM	D	13.38
3/12	AM	E	2.05
3/12	PM	D	0.0
3/13	AM	C&D**	37.14
3/13	PM	D	5.34
3/14	AM	D	0.0
3/14	PM	A	8.34
3/15	AM	B	2.42
3/15	PM	A	6.04
3/16	AM	B	3.50
3/18	AM	F	9.91
3/19	AM	E	11.39
3/19	PM	F	25.88
3/20	AM	F	0.0
3/20	PM	E	4.05
3/21	AM	F	26.05
3/21	PM	F	9.07
3/22	AM	F	7.55
3/22	PM	F	3.05
3/23	AM	E	3.32
3/24	AM	E	9.25
3/24	PM	D	3.57
3/25	PM	D	24.74
3/26	AM	D	2.61
3/26	PM	D	5.84
3/27	AM	C	26.96
3/27	PM	C	0.42
3/28	AM	C	14.74
3/28	PM	C	24.36
3/29	AM	B	4.33
3/29	PM	A	23.29

* Figure 17 shows the channel sections.

** Interface of sections C and D.

COORDINATES	HOLE NO.	LOCATION
C H 11 8	38	CARQUINEZ STRAIT

SAMPLING DATES	15MAR74	29MAR74	23APR74	9MAY74	17JUN74	29JUL74	28AUG74	13SEP74	150CT74	13NOV74	12DEC74
DEPTH OF SEDIMENT BELOW MLLW (FT)	45.0	44.0	44.0	44.0	43.0	43.0	43.0	43.0	43.0	43.5	43.0
THICKNESS OF LAYERS (IN)											
FLUFF	0.3	-NA-	1.0	1.0	1.0	0.0	0.0	0.0	1.0	0.0	1.0
ACTIVE	16.0	-NA-	5.0	5.0	9.0	5.0	5.0	5.0	8.0	6.0	2.0
INACTIVE	0.0	-NA-	16.0	12.0	6.0	4.0	12.0	16.0	15.0	20.0	26.0
SAMPLE A	1007	3907		1411	1825	2182	2461	2647	3007	3208	3400
G.DRY/CC.WET MUD	0.379	0.773	LOST	0.764	0.989	0.658	0.780	1.015	0.519	0.622	0.742
G.IR/G.DRY MUD	2.26E-08	2.01E-10	SAMPLE	6.05E-10	2.35E-10	-BDL-	1.31E-10	9.03E-11	9.25E-10	-BDL-	1.94E-09
% DREDGE MATERIAL	114.230	0.000		1.481	0.000	0.000	0.000	0.000	3.124	0.000	8.344
SAMPLE B	4660	3908	4854	1412	1826	2183	2462	2648	3008	3209	3401
G.DRY/CC.WET MUD	0.767	0.586	0.478	0.716	0.825	0.762	0.688	0.901	0.554	0.814	0.601
G.IR/G.DRY MUD	2.91E-10	3.86E-11	6.64E-10	5.55E-10	2.67E-10	1.89E-10	-BDL-	-BDL-	9.92E-10	6.59E-11	3.86E-10
% DREDGE MATERIAL	0.000	0.000	1.784	1.224	0.000	0.000	0.000	0.000	3.465	0.000	0.357
SAMPLE C	4661	3909	4855	1413	1827	2184	2463	2649	3009	3210	3402
G.DRY/CC.WET MUD	0.802	0.629	0.543	0.749	0.801	0.892	0.748	0.788	0.652	0.775	0.634
G.IR/G.DRY MUD	1.29E-10	8.58E-12	5.88E-10	1.43E-09	4.13E-10	5.41E-10	5.14E-10	3.01E-11	-BDL-	3.85E-11	3.09E-10
% DREDGE MATERIAL	0.000	0.000	1.393	5.694	0.498	1.153	1.015	0.000	0.000	0.000	0.000
SAMPLE D	4662	4869	4851	4272	4274	4276	4278				
G.DRY/CC.WET MUD	0.810	0.526	0.732	0.737	0.640	0.724	0.699				
G.IR/G.DRY MUD	-BDL-	-BDL-	1.99E-10	5.99E-10	6.61E-10	9.73E-10	1.36E-09				
% DREDGE MATERIAL	0.000	0.000	0.000	1.449	1.768	3.371	5.344				
SAMPLE E	4663	4870	4852	4273	4275		4279				
G.DRY/CC.WET MUD	0.789	0.538	0.527	0.747	0.730		0.623				
G.IR/G.DRY MUD	-BDL-	1.28E-10	5.47E-11	2.28E-09	5.15E-10		7.83E-10				
% DREDGE MATERIAL	0.000	0.000	0.000	10.082	1.023		2.395				
SAMPLE F	4664	4871	4853			4277					
G.DRY/CC.WET MUD	0.679	0.538	0.543			0.685					
G.IR/G.DRY MUD	-BDL-	3.41E-10	1.13E-10			7.56E-10					
% DREDGE MATERIAL	0.000	0.129	0.000			2.259					
SAMPLE G	4665	4872									
G.DRY/CC.WET MUD	0.681	0.535									
G.IR/G.DRY MUD	1.60E-10	4.03E-10									
% DREDGE MATERIAL	0.000	0.447									
SAMPLE H	4666										
G.DRY/CC.WET MUD	0.864										
G.IR/G.DRY MUD	3.57E-12										
% DREDGE MATERIAL	0.000										

COORDINATES	HOLE NO.	LOCATION
A F 12 6	40	CARQUINEZ STRAIT

SAMPLING DATES	15MAR74	28MAR74	16APR74	16MAY74	11JUN74	30JUL74	13AUG74	11SEP74	100CT74	14NOV74	11DEC74
DEPTH OF SEDIMENT BELOW MLLW (FT)	0.0	1.0	1.0	1.0	1.5	1.0	1.5	2.0	1.5	8.0	8.0
THICKNESS OF LAYERS (IN)											
FLUFF	0.2	0.4	2.5	1.5	1.0	1.0	1.0	1.0	1.5	0.0	0.0
ACTIVE	17.0	9.0	8.0	9.0	15.0	14.0	14.0	7.0	8.0	11.0	5.0
INACTIVE	0.0	8.0	8.0	10.0	3.0	6.0	6.0	6.0	9.0	16.0	16.0
SAMPLE A	1021	3904	1129	1426	1717	2122	2329	2572	2902	3226	3430
G.DRY/CC.WET MUD	0.584	0.730	0.444	0.638	0.588	0.576	0.755	0.682	0.691	0.289	0.432
G.IR/G.DRY MUD	7.45E-09	4.14E-10	1.08E-09	3.57E-10	3.59E-10	1.93E-10	2.25E-10	9.83E-11	6.68E-10	2.10E-11	8.87E-10
% DREDGE MATERIAL	36.569	0.503	3.905	0.213	0.219	0.000	0.000	0.000	1.806	0.000	2.930
SAMPLE B	1022	3905	1130	1427	1718	2123	2330	2573	2903	3227	3431
G.DRY/CC.WET MUD	0.630	0.565	0.566	0.604	0.573	0.586	0.612	0.629	0.708	0.490	0.347
G.IR/G.DRY MUD	6.50E-09	-BDL-	2.22E-09	7.06E-10	3.07E-10	2.46E-10	3.43E-10	3.53E-10	3.43E-09	2.51E-10	1.75E-09
% DREDGE MATERIAL	31.740	0.000	9.753	2.001	0.000	0.000	0.139	0.190	15.983	0.000	7.359
SAMPLE C	1023	3906	1131	1428	1719	2124	2331	2574	2904	3228	3432
G.DRY/CC.WET MUD	0.642	0.654	0.558	0.551	0.593	0.545	0.632	0.635	0.723	0.578	0.418
G.IR/G.DRY MUD	1.30E-08	2.23E-10	1.21E-09	7.27E-10	5.93E-10	1.37E-10	4.38E-10	5.32E-10	1.03E-09	-BDL-	2.05E-10
% DREDGE MATERIAL	64.840	0.000	4.585	2.110	1.423	0.000	0.625	1.108	3.670	0.000	0.000
SAMPLE D	4356		4529	4286	4288	4290	4292	4294	4295	4756	4758
G.DRY/CC.WET MUD	0.616		0.552	0.539	0.641	0.583	0.601	0.641	0.541	0.506	0.434
G.IR/G.DRY MUD	3.76E-11		-BDL-	4.82E-10	7.04E-11	6.18E-10	5.91E-10	2.22E-10	2.97E-10	3.48E-10	2.72E-10
% DREDGE MATERIAL	0.000		0.000	0.852	0.000	1.551	1.410	0.000	0.000	0.164	0.000
SAMPLE E	4357				4289	4291					4759
G.DRY/CC.WET MUD	0.577				0.603	0.629					0.520
G.IR/G.DRY MUD	3.64E-10				9.63E-11	2.22E-10					1.71E-10
% DREDGE MATERIAL	0.245				0.000	0.000					0.000
SAMPLE F			4530	4287			4293		4296	4757	
G.DRY/CC.WET MUD			0.615	0.572			0.709		0.642	0.525	
G.IR/G.DRY MUD			3.51E-10	2.56E-10			2.33E-10		4.47E-10	4.37E-10	
% DREDGE MATERIAL			0.178	0.000			0.000		0.670	0.622	
SAMPLE G											
G.DRY/CC.WET MUD											
G.IR/G.DRY MUD											
% DREDGE MATERIAL											
SAMPLE H											
G.DRY/CC.WET MUD											
G.IR/G.DRY MUD											
% DREDGE MATERIAL											

Figure 18. Data sheets for holes 38 and 40, Carquinez Strait

COORDINATES	HOLE NO.	LOCATION
F E 5 5	53	PINOLE SHOAL

SAMPLING DATES	22MAR74	3APR74	13MAY74	3JUN74	31JUL74	23AUG74	4SEP74	90CT74	6NOV74	4DEC74
DEPTH OF SEDIMENT BELOW MLLW (FT)	18.5	19.0	18.5	21.5	21.0	21.5	21.5	21.0	21.5	22.0
THICKNESS OF LAYERS (IN)										
FLUFF	0.2	0.5	1.5	2.0	0.0	0.0	1.0	1.5	0.0	0.0
ACTIVE	11.0	10.0	9.0	7.0	14.0	3.0	6.0	5.0	6.0	2.0
INACTIVE	8.0	12.0	15.0	8.0	0.0	18.0	13.0	8.0	23.0	20.0
SAMPLE A	3853	3928	1441	1591	2149	2452	2524	2866	3193	3529
G.DRY/CC.WET MUD	0.522	0.673	0.812	0.682	0.716	1.178	0.887	0.774	0.461	0.650
G.IR/G.DRY MUD	4.25E-09	-BDL-	3.77E-10	2.91E-10	3.64E-10	-BDL-	4.55E-10	1.52E-11	5.02E-10	3.77E-10
% DREDGE MATERIAL	20.177	0.000	0.313	0.000	0.247	0.000	0.711	0.000	0.954	0.311
SAMPLE B	3854	3929	1442	1592	2150	2453	2525	2867	3194	3530
G.DRY/CC.WET MUD	0.492	0.470	0.623	0.874	0.615	0.866	0.721	0.656	0.676	0.620
G.IR/G.DRY MUD	6.76E-10	2.83E-10	3.51E-10	5.97E-10	4.54E-10	3.45E-10	9.84E-11	-BDL-	4.85E-11	-BDL-
% DREDGE MATERIAL	1.845	0.000	0.178	1.441	0.708	0.151	0.000	0.000	0.000	0.000
SAMPLE C	3855	3930	1443	1593	2151	2454	2526	2868	3195	3531
G.DRY/CC.WET MUD	0.944	0.724	0.527	1.004	0.668	0.758	0.702	0.922	0.703	0.660
G.IR/G.DRY MUD	1.13E-09	-BDL-	6.74E-10	2.06E-09	7.00E-10	1.45E-10	-BDL-	1.71E-10	4.85E-11	6.70E-11
% DREDGE MATERIAL	4.191	0.000	1.838	8.949	1.970	0.000	0.000	0.000	0.000	0.000
SAMPLE D			4386	0513	4388					
G.DRY/CC.WET MUD			0.689	0.823	0.671					
G.IR/G.DRY MUD			1.85E-10	5.75E-10	1.28E-10					
% DREDGE MATERIAL			0.000	1.330	0.000					
SAMPLE E										
G.DRY/CC.WET MUD										
G.IR/G.DRY MUD										
% DREDGE MATERIAL										
SAMPLE F				0514	4389					
G.DRY/CC.WET MUD				0.724	0.727					
G.IR/G.DRY MUD				7.43E-10	3.54E-11					
% DREDGE MATERIAL				2.188	0.000					
SAMPLE G			4387							
G.DRY/CC.WET MUD			0.812							
G.IR/G.DRY MUD			-BDL-							
% DREDGE MATERIAL			0.000							
SAMPLE H										
G.DRY/CC.WET MUD										
G.IR/G.DRY MUD										
% DREDGE MATERIAL										

COORDINATES	HOLE NO.	LOCATION
A F 14 6	107	SUISUN BAY

SAMPLING DATES	23APR74	16MAY74	17JUN74	29JUL74	13AUG74	11SEP74	100CT74	13NOV74	11DEC74
DEPTH OF SEDIMENT BELOW MLLW (FT)	35.0	33.0	24.5	27.0	27.0	27.0	28.0	27.5	28.0
THICKNESS OF LAYERS (IN)									
FLUFF	-NA-	0.0	1.5	2.0	0.5	0.0	2.0	0.0	0.0
ACTIVE	-NA-	18.0	6.0	3.0	6.0	1.0	9.0	7.0	2.0
INACTIVE	-NA-	0.0	6.0	5.0	6.0	12.0	8.0	7.0	14.0
SAMPLE A		1438	1822	2176	2380	2659	2974	3214	3436
G.DRY/CC.WET MUD	NO	0.798	0.894	0.579	1.004	0.525	0.645	0.592	0.590
G.IR/G.DRY MUD	SAMPLE	7.78E-10	1.67E-10	3.02E-10	1.85E-10	2.60E-10	1.11E-09	1.86E-10	6.88E-10
% DREDGE MATERIAL		2.367	0.000	0.000	0.000	0.000	4.072	0.000	1.908
SAMPLE B		1439	1823	2177	2381	2660	2975	3215	3437
G.DRY/CC.WET MUD	NO	0.608	1.513	0.672	0.503	0.671	0.594	0.799	0.217
G.IR/G.DRY MUD	SAMPLE	7.91E-10	1.67E-10	2.05E-10	3.74E-10	4.93E-10	1.77E-09	5.65E-11	1.03E-10
% DREDGE MATERIAL		2.437	0.000	0.000	0.298	0.908	7.444	0.000	0.000
SAMPLE C		1440	1824	2178	2382	2661	2976	3216	3438
G.DRY/CC.WET MUD	NO	0.575	1.337	0.709	0.260	0.749	0.592	0.875	0.350
G.IR/G.DRY MUD	SAMPLE	1.34E-09	1.13E-10	3.77E-10	1.02E-10	4.35E-10	1.40E-09	-BDL-	6.15E-10
% DREDGE MATERIAL		5.256	0.000	0.313	0.000	0.608	5.537	0.000	1.533
SAMPLE D		4612					4614	4886	
G.DRY/CC.WET MUD		0.834					0.603	0.650	
G.IR/G.DRY MUD		5.78E-10					-BDL-	8.71E-10	
% DREDGE MATERIAL		1.342					0.000	2.848	
SAMPLE E		4613							
G.DRY/CC.WET MUD		0.928							
G.IR/G.DRY MUD		3.39E-10							
% DREDGE MATERIAL		0.117							
SAMPLE F									
G.DRY/CC.WET MUD									
G.IR/G.DRY MUD									
% DREDGE MATERIAL									
SAMPLE G							4615		
G.DRY/CC.WET MUD							0.609		
G.IR/G.DRY MUD							5.08E-10		
% DREDGE MATERIAL							0.985		
SAMPLE H									
G.DRY/CC.WET MUD									
G.IR/G.DRY MUD									
% DREDGE MATERIAL									

Figure 19. Data sheets for hole 53, Pinole Shoal, and for hole 107, Suisun Bay

COORDINATES	HOLE NO.	LOCATION
E H 6 8	59	SAN PABLO BAY FLATS (STAKED)

SAMPLING DATES	2APR74	2MAY74	4JUN74	9JUL74	2AUG74	3SEP74	17OCT74	5NOV74	13DEC74
DEPTH OF SEDIMENT BELOW MLLW (FT)	10.0	8.5	8.5	8.0	9.0	7.5	8.5	9.0	8.5
THICKNESS OF LAYERS (IN)									
FLUFF	0.4	1.5	1.5	2.0	3.0	0.0	2.0	0.0	2.0
ACTIVE	20.0	8.0	6.0	5.0	6.0	5.0	7.0	5.0	6.0
INACTIVE	0.0	6.0	12.0	11.0	15.0	9.0	14.0	12.0	17.0
SAMPLE A	3922	1297	1603	1894	2203	2476	3022	3103	3364
G.DRY/CC.WET MUD	0.674	0.697	0.746	0.687	0.696	0.836	0.659	0.549	0.494
G.IR/G.DRY MUD	5.31E-11	1.61E-10	2.39E-10	3.96E-10	1.53E-10	2.68E-10	5.49E-10	2.00E-10	2.80E-10
% DREDGE MATERIAL	0.000	0.000	0.000	0.412	0.000	0.000	1.193	0.000	0.000
SAMPLE B	3923	1298	1604	1895	2204	2477	3023	3104	3365
G.DRY/CC.WET MUD	0.382	0.666	0.500	0.524	0.630	0.692	0.564	0.790	0.493
G.IR/G.DRY MUD	-BDL-	2.95E-10	2.67E-10	4.95E-10	2.92E-11	1.09E-10	1.08E-08	2.71E-10	3.03E-10
% DREDGE MATERIAL	0.000	0.000	0.000	0.919	0.000	0.000	53.623	0.000	0.000
SAMPLE C	3924	1299	1605	1896	2205	2478	3024	3105	3366
G.DRY/CC.WET MUD	0.474	0.529	0.516	0.628	0.513	0.670	0.553	0.784	0.590
G.IR/G.DRY MUD	4.83E-10	4.48E-10	9.21E-10	4.72E-10	3.74E-10	1.59E-10	8.50E-10	1.87E-10	1.92E-09
% DREDGE MATERIAL	0.854	0.677	3.103	0.803	0.298	0.000	2.739	0.000	8.224
SAMPLE D		4404	4642	4406					4783
G.DRY/CC.WET MUD		0.584	0.711	0.569					0.647
G.IR/G.DRY MUD		-BDL-	2.54E-10	1.24E-10					1.32E-10
% DREDGE MATERIAL		0.000	0.000	0.000					0.000
SAMPLE E		4405	4643	4407					
G.DRY/CC.WET MUD		0.495	0.617	0.706					
G.IR/G.DRY MUD		2.28E-10	4.99E-10	4.28E-10					
% DREDGE MATERIAL		0.000	0.941	0.576					
SAMPLE F									4784
G.DRY/CC.WET MUD									0.634
G.IR/G.DRY MUD									4.40E-10
% DREDGE MATERIAL									0.639
SAMPLE G									
G.DRY/CC.WET MUD									
G.IR/G.DRY MUD									
% DREDGE MATERIAL									
SAMPLE H									
G.DRY/CC.WET MUD									
G.IR/G.DRY MUD									
% DREDGE MATERIAL									

COORDINATES	HOLE NO.	LOCATION
I E 4 5	71	SAN PABLO BAY FLATS (STAKED)

SAMPLING DATES	12APR74	10MAY74	7JUN74	22JUL74	6AUG74	5SEP74	16OCT74	23NOV74	17DEC74
DEPTH OF SEDIMENT BELOW MLLW (FT)	7.5	6.0	6.5	6.5	7.0	6.5	6.5	7.0	7.0
THICKNESS OF LAYERS (IN)									
FLUFF	1.0	1.0	2.0	0.0	0.5	0.0	2.0	0.0	1.0
ACTIVE	10.0	8.0	16.0	3.0	14.0	8.0	6.0	2.0	4.0
INACTIVE	11.0	12.0	5.0	9.0	3.0	3.0	9.0	20.0	12.0
SAMPLE A	1147	1417	1663	2020	2230	2560	2986	3262	3613
G.DRY/CC.WET MUD	0.391	0.635	0.629	0.560	0.580	0.805	0.530	0.507	0.613
G.IR/G.DRY MUD	7.25E-10	5.14E-10	2.38E-10	3.10E-10	2.74E-10	3.77E-10	6.13E-10	4.63E-11	9.94E-10
% DREDGE MATERIAL	2.097	1.013	0.000	0.000	0.000	0.310	1.525	0.000	3.476
SAMPLE B	1148	1418	1664	2021	2231	2561	2987	3263	3614
G.DRY/CC.WET MUD	0.587	0.567	0.583	0.537	0.658	0.678	0.562	0.600	0.626
G.IR/G.DRY MUD	7.69E-10	1.05E-09	2.15E-10	2.42E-10	1.05E-10	8.24E-10	5.67E-10	1.35E-10	2.36E-10
% DREDGE MATERIAL	2.321	3.785	0.000	0.000	0.000	2.604	1.287	0.000	0.000
SAMPLE C	1149	1419	1665	2022	2232	2562	2988	3264	3615
G.DRY/CC.WET MUD	0.527	0.643	0.524	0.609	0.657	0.720	0.660	0.702	0.636
G.IR/G.DRY MUD	5.15E-10	5.90E-10	8.69E-10	1.50E-10	-BDL-	3.33E-10	-BDL-	3.77E-10	4.70E-10
% DREDGE MATERIAL	1.021	1.406	2.836	0.000	0.000	0.088	0.000	0.313	0.788
SAMPLE D			4454		4455	4457	4458	4837	4839
G.DRY/CC.WET MUD			0.679		0.824	0.875	0.689	0.602	0.568
G.IR/G.DRY MUD			5.45E-10		6.01E-10	-BDL-	-BDL-	0.00E+00	1.67E-10
% DREDGE MATERIAL			1.175		1.461	0.000	0.000	0.000	0.000
SAMPLE E					4456		4459		4840
G.DRY/CC.WET MUD					0.811		0.718		0.589
G.IR/G.DRY MUD					4.10E-10		-BDL-		3.63E-10
% DREDGE MATERIAL					0.482		0.000		0.242
SAMPLE F								4838	
G.DRY/CC.WET MUD								0.573	
G.IR/G.DRY MUD								-BDL-	
% DREDGE MATERIAL								0.000	
SAMPLE G									
G.DRY/CC.WET MUD									
G.IR/G.DRY MUD									
% DREDGE MATERIAL									
SAMPLE H									
G.DRY/CC.WET MUD									
G.IR/G.DRY MUD									
% DREDGE MATERIAL									

Figure 20. Data sheets for holes 59, 71, 89, and 101, San Pablo Bay Flats (sheet 1 of 2)

COORDINATES	HOLE NO.	LOCATION
J E 2 5	89	SAN PABLO BAY FLATS (STAKED)

SAMPLING DATES	18APR74	21MAY74	18JUN74	18JUL74	14AUG74	12SEP74	30OCT74	12NOV74	9DEC74
DEPTH OF SEDIMENT BELOW MLLW (FT)	4.5	5.0	5.0	5.5	5.5	5.5	5.5	5.0	5.0
THICKNESS OF LAYERS (IN)									
FLUFF	0.0	1.0	0.0	0.0	0.0	1.0	0.0	1.0	1.0
ACTIVE	9.0	7.0	7.0	1.0	9.0	8.0	6.0	8.0	7.0
INACTIVE	10.0	7.0	7.0	12.0	5.0	12.0	12.0	16.0	19.0
SAMPLE A	1186	1480	1840	1951	2344	2599	2788	3205	3418
G.DRY/CC.WET MUD	0.626	0.595	0.851	0.715	0.855	0.790	0.741	0.619	0.710
G.IR/G.DRY MUD	6.83E-10	4.06E-10	2.37E-10	9.41E-10	-BDL-	2.54E-10	6.87E-11	1.14E-09	3.75E-10
% DREDGE MATERIAL	1.882	0.463	0.000	3.206	0.000	0.000	0.000	4.246	0.301
SAMPLE B	1187	1481	1841	1952	2345	2600	2789	3206	3419
G.DRY/CC.WET MUD	0.635	0.641	0.722	0.740	0.851	0.663	0.593	0.637	0.888
G.IR/G.DRY MUD	7.21E-10	2.60E-10	5.69E-10	8.84E-10	1.92E-10	2.04E-10	1.91E-11	4.74E-10	2.44E-09
% DREDGE MATERIAL	2.078	0.000	1.298	2.912	0.000	0.000	0.000	0.811	10.909
SAMPLE C	1188	1482	1842	1953	2346	2601	2790	3207	3420
G.DRY/CC.WET MUD	0.651	0.594	0.604	0.604	0.687	0.703	0.686	0.682	0.724
G.IR/G.DRY MUD	3.75E-10	6.59E-10	1.07E-10	7.07E-10	1.47E-10	5.55E-10	-BDL-	5.25E-10	8.53E-10
% DREDGE MATERIAL	0.303	1.759	0.000	2.006	0.000	1.223	0.000	1.074	2.752
SAMPLE D		4513	4543	4545		4546		4766	4764
G.DRY/CC.WET MUD		0.576	0.584	0.554		0.617		0.624	0.717
G.IR/G.DRY MUD		2.95E-10	-BDL-	7.69E-11		-BDL-		1.21E-10	1.39E-10
% DREDGE MATERIAL		0.000	0.000	0.000		0.000		0.000	0.000
SAMPLE E			4544						
G.DRY/CC.WET MUD			0.711						
G.IR/G.DRY MUD			1.22E-10						
% DREDGE MATERIAL			0.000						
SAMPLE F						4547		4767	4765
G.DRY/CC.WET MUD						0.610		0.554	0.630
G.IR/G.DRY MUD						4.07E-10		3.65E-10	3.79E-10
% DREDGE MATERIAL						0.466		0.253	0.324
SAMPLE G									
G.DRY/CC.WET MUD									
G.IR/G.DRY MUD									
% DREDGE MATERIAL									
SAMPLE H									
G.DRY/CC.WET MUD									
G.IR/G.DRY MUD									
% DREDGE MATERIAL									

COORDINATES	HOLE NO.	LOCATION
J C 4 3	101	SAN PABLO BAY FLATS (STAKED)

SAMPLING DATES	25APR74	22MAY74	13JUN74	22JUL74	14AUG74	9SEP74	40CT74	23NOV74	9DEC74
DEPTH OF SEDIMENT BELOW MLLW (FT)	5.0	5.0	5.0	5.5	6.0	5.5	5.0	5.5	5.5
THICKNESS OF LAYERS (IN)									
FLUFF	1.0	3.0	1.0	0.0	0.0	1.0	1.0	0.0	0.0
ACTIVE	5.0	8.0	6.0	7.0	8.0	10.0	7.0	17.0	2.0
INACTIVE	9.0	6.0	12.0	9.0	4.0	11.0	8.0	3.0	16.0
SAMPLE A	1222	1534	1753	1987	2347	2569	2944	3271	3409
G.DRY/CC.WET MUD	0.520	0.453	0.724	0.756	0.680	0.737	0.655	0.471	0.660
G.IR/G.DRY MUD	9.03E-10	3.38E-10	3.72E-10	5.78E-10	1.29E-10	1.75E-10	1.97E-09	4.17E-10	3.40E-10
% DREDGE MATERIAL	3.011	0.113	0.288	1.342	0.000	0.000	8.479	0.518	0.123
SAMPLE B	1223	1535	1754	1988	2348	2570	2945	3272	3410
G.DRY/CC.WET MUD	0.657	0.703	0.664	0.661	0.648	0.641	0.665	0.584	0.619
G.IR/G.DRY MUD	2.80E-09	3.68E-10	4.30E-10	5.33E-10	-BDL-	-BDL-	2.54E-09	3.01E-10	2.62E-10
% DREDGE MATERIAL	12.751	0.268	0.585	1.111	0.000	0.000	11.392	0.000	0.000
SAMPLE C	1224	1536	1755	1989	2349	2571	2946	3273	3411
G.DRY/CC.WET MUD	0.675	0.767	0.718	0.705	0.676	0.761	0.759	0.799	0.687
G.IR/G.DRY MUD	3.66E-09	4.78E-10	5.92E-10	3.93E-10	4.76E-10	4.13E-10	7.40E-10	8.23E-11	-BDL-
% DREDGE MATERIAL	17.156	0.830	1.417	0.393	0.921	0.500	2.173	0.000	0.000
SAMPLE D	4588	4862	4590				4592		
G.DRY/CC.WET MUD	0.668	0.593	0.743				0.695		
G.IR/G.DRY MUD	3.07E-10	2.61E-10	8.92E-10				1.50E-09		
% DREDGE MATERIAL	0.000	0.000	2.953				6.057		
SAMPLE E	4589	4863	4591				4593		
G.DRY/CC.WET MUD	0.694	0.615	0.740				0.776		
G.IR/G.DRY MUD	-BDL-	-BDL-	2.16E-10				-BDL-		
% DREDGE MATERIAL	0.000	0.000	0.000				0.000		
SAMPLE F									
G.DRY/CC.WET MUD									
G.IR/G.DRY MUD									
% DREDGE MATERIAL									
SAMPLE G									
G.DRY/CC.WET MUD									
G.IR/G.DRY MUD									
% DREDGE MATERIAL									
SAMPLE H									
G.DRY/CC.WET MUD									
G.IR/G.DRY MUD									
% DREDGE MATERIAL									

Figure 20 (sheet 2 of 2)

manner that ensured that the analytical sample would not be accidentally contaminated by any iridium that might have been deposited on the outside of the plastic container.

Test area samples

126. Data sheets for sampling locations (holes) in various parts of the test area are shown in Figures 18-20. Examination of the data reveals that the depth of sediment measurement often conflicts with the thickness measurements of fluff, active, and inactive layers as previously defined. That is, from month to month the measured changes in depth of sediment cannot be correlated with corresponding changes in the measured sediment layers. Reference 10 discusses this conflict.

127. With regard to the other entries on the data sheets, because iridium concentration was determined on a dry-weight basis, it was necessary to measure an in-place or bulk density in units of grams of dry sediment per cubic centimetre of wet sediment. The reported density measurements have a wide range of values. Some of this variation may result from the difficulty of physically removing a specified volume from the core sample as received; that is, marking 25.4 mm (1 in.) of sediment on a 762-mm (30-in.) column, removing the water above the sediment, and then spooning out the sediment to a 25.4-mm (1-in.) depth.

128. The numerical values for the iridium concentration (g Ir/g of dry sediment) probably contain a small experimental error when compared with the uncertainties involved in some of the other steps of the tracer program. Several sets of data were obtained from replicate fire-assayed tests of sediments with known iridium concentrations. Statistical analysis of these data always resulted in a coefficient of variation of less than 10 percent. The overall experimental error for the sampling and laboratory operations was not determined and probably could not be measured because so many steps in the operations could not be controlled. However, many of these errors are compensating, and the large number of samples, almost 4000, increases the credibility of the final results.

129. The value for the percentage of dredge material discussed previously was determined by dividing the measured iridium concentration

by the theoretical iridium concentration applied to the tagged sediments, assuming that all the iridium was uniformly fixed to the tagged dredged sediments which were uniformly mixed in each hopper released. A few values greater than 100 percent were obtained possibly as the result of nonuniform mixing of the iridium with the dredge sediments. Then too, as suggested by the hopper samples, since rehandling of previously dredged tagged sediment yielded an initial iridium content, the usual tagged sediment addition resulted in an iridium concentration higher than the theoretical concentration described above.

130. The large number of data points obtained from the grid pattern was a challenging problem in analysis and presentation. The solution was the creation of a series of computer-prepared graphic displays* of the test area showing the distribution of the tagged sediments over space and time. Figures 21, 22, and 23 show the sediment distribution for May, August, and October 1974 as follows:

Sediment Layer	May	August	October
Layer A 0-25.4 mm (0-1 in.)	Figure 21a	Figure 22a	Figure 23a
Layer B 25.4-127 mm (1-5 in.)	Figure 21b	Figure 22b	Figure 23b
Layer C 127-229 mm (5-9 in.)	Figure 21c	Figure 22c	Figure 23c

131. The displays for May indicate that traced dredged sediments had circulated to all parts of the test area and were deposited at the three sample depths. In contrast, the August presentations show that in the first 229 mm (9 in.) of sediment in many parts of the test area there were essentially no traced dredged materials; while in the areas where traced dredged materials were present, their concentration was lower than those in the May period. In October a dramatic increase in the concentration of traced dredged sediments in each of the three layers was noted as compared with the August displays. This increase

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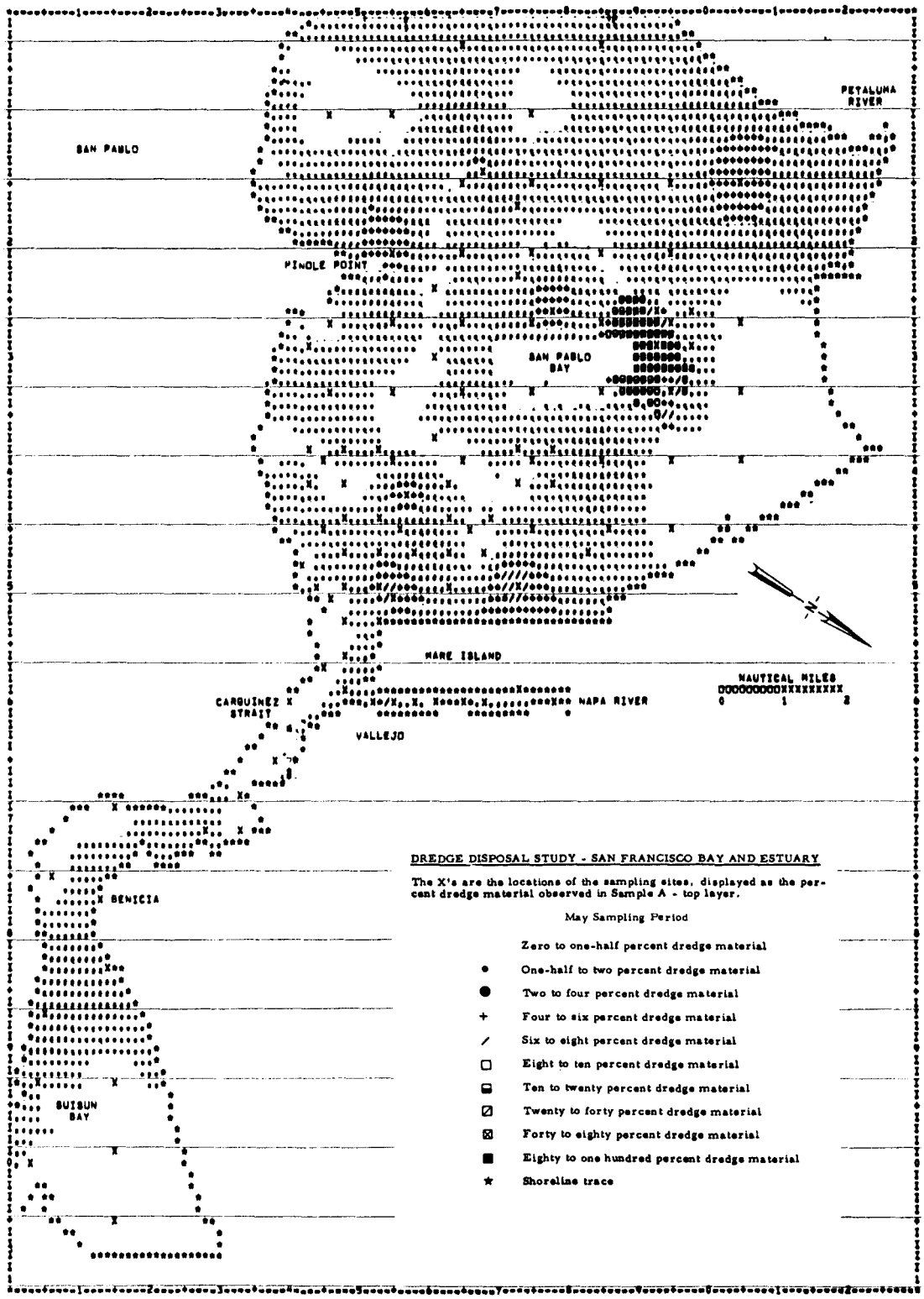
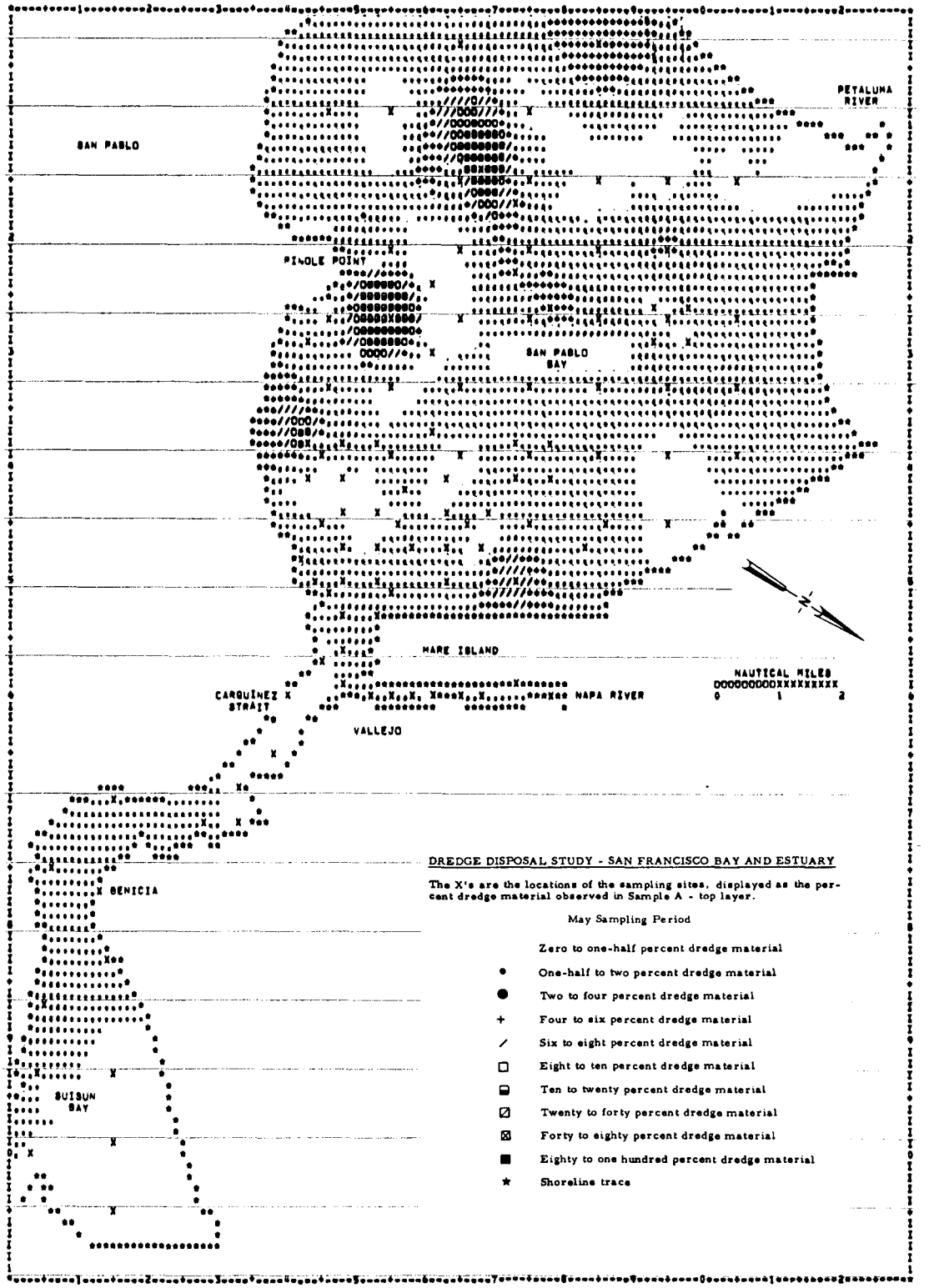
* The plots were prepared by the U. S. Army Corps of Engineers, Hydrologic Engineering Center, Davis, California.



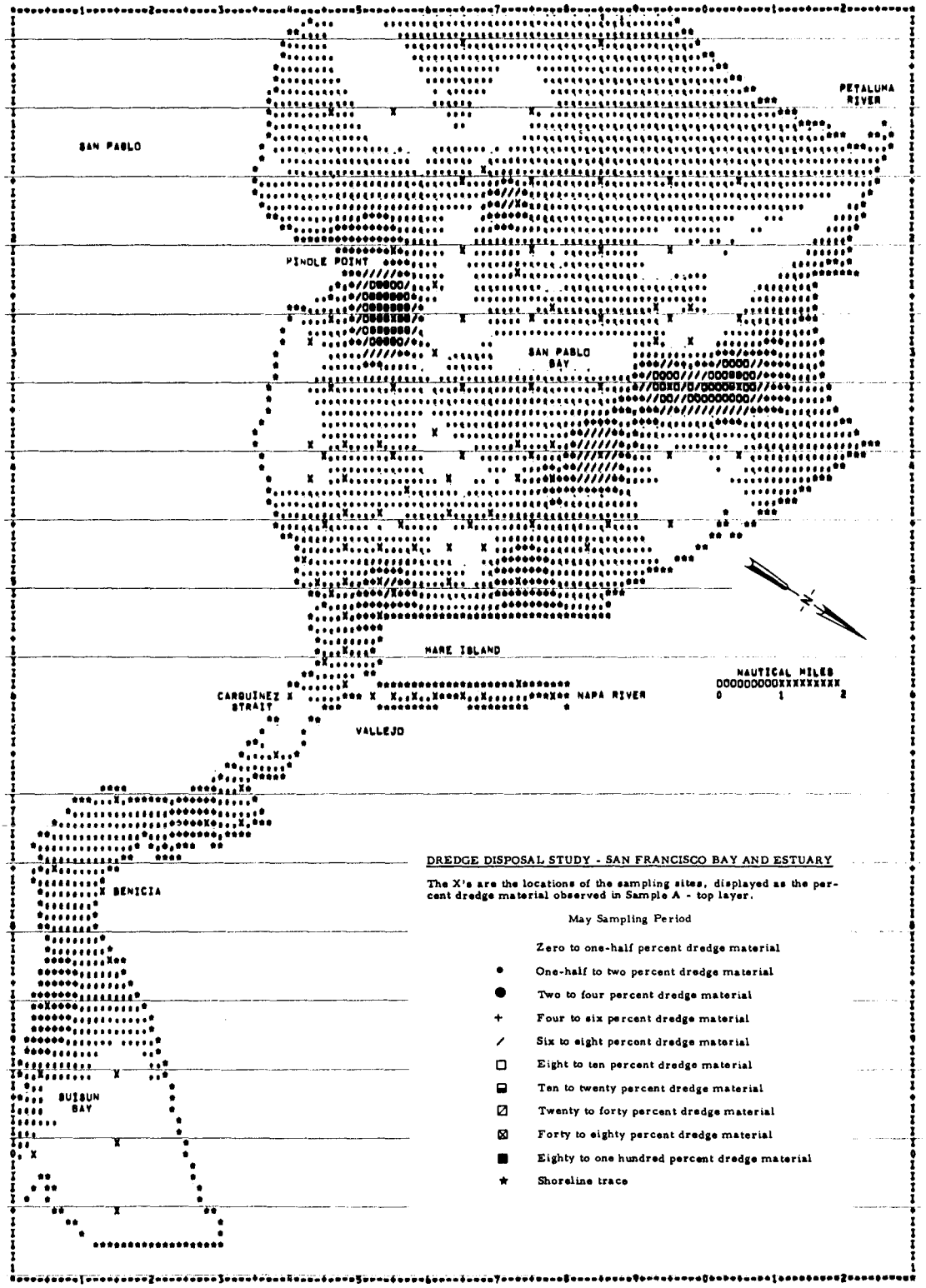
a. Layer A (0-25.4 mm)

Figure 21. May sampling period (sheet 1 of 3)



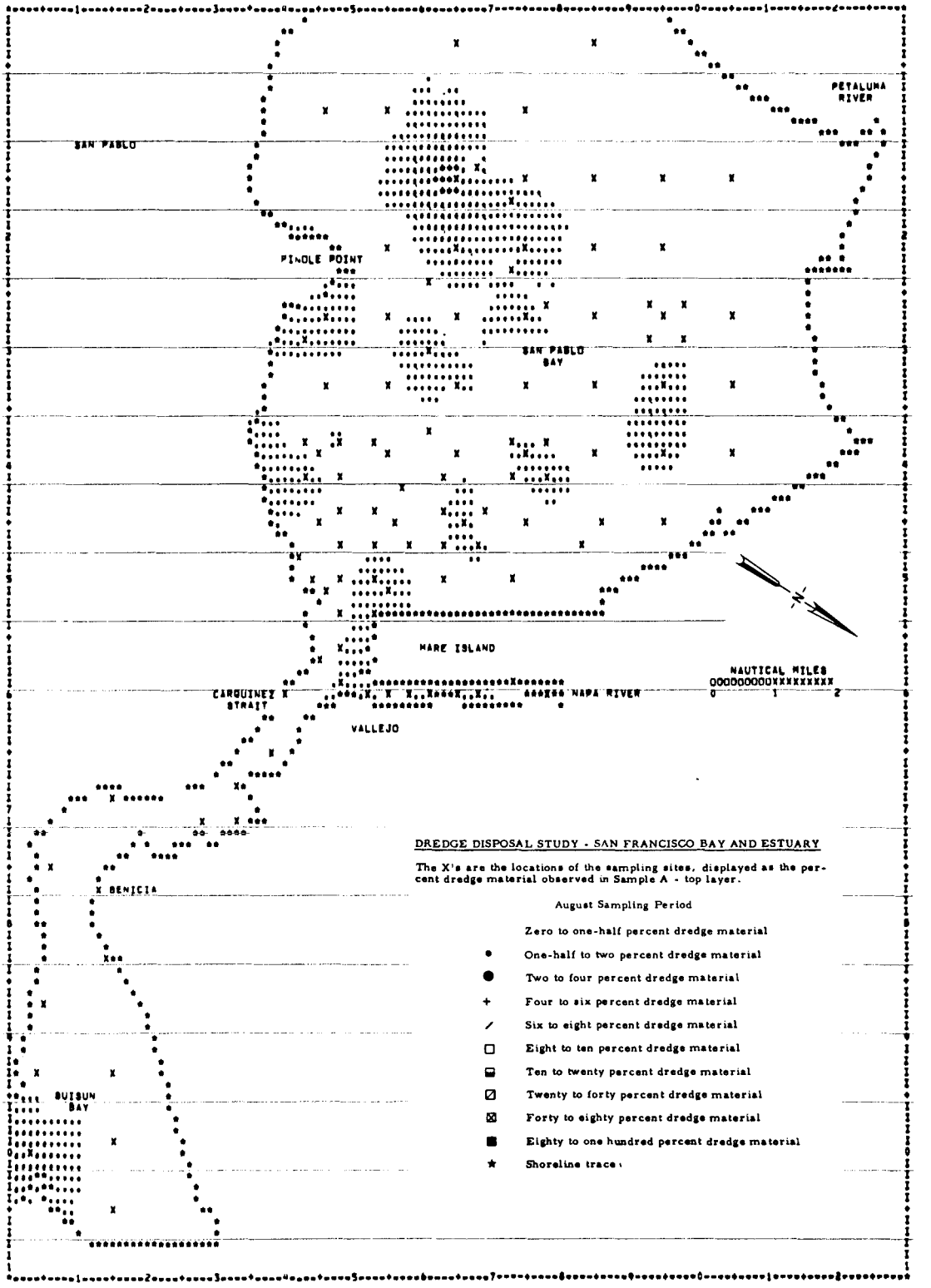
b. Layer B (25.4-127 mm)

Figure 21 (sheet 2 of 3)



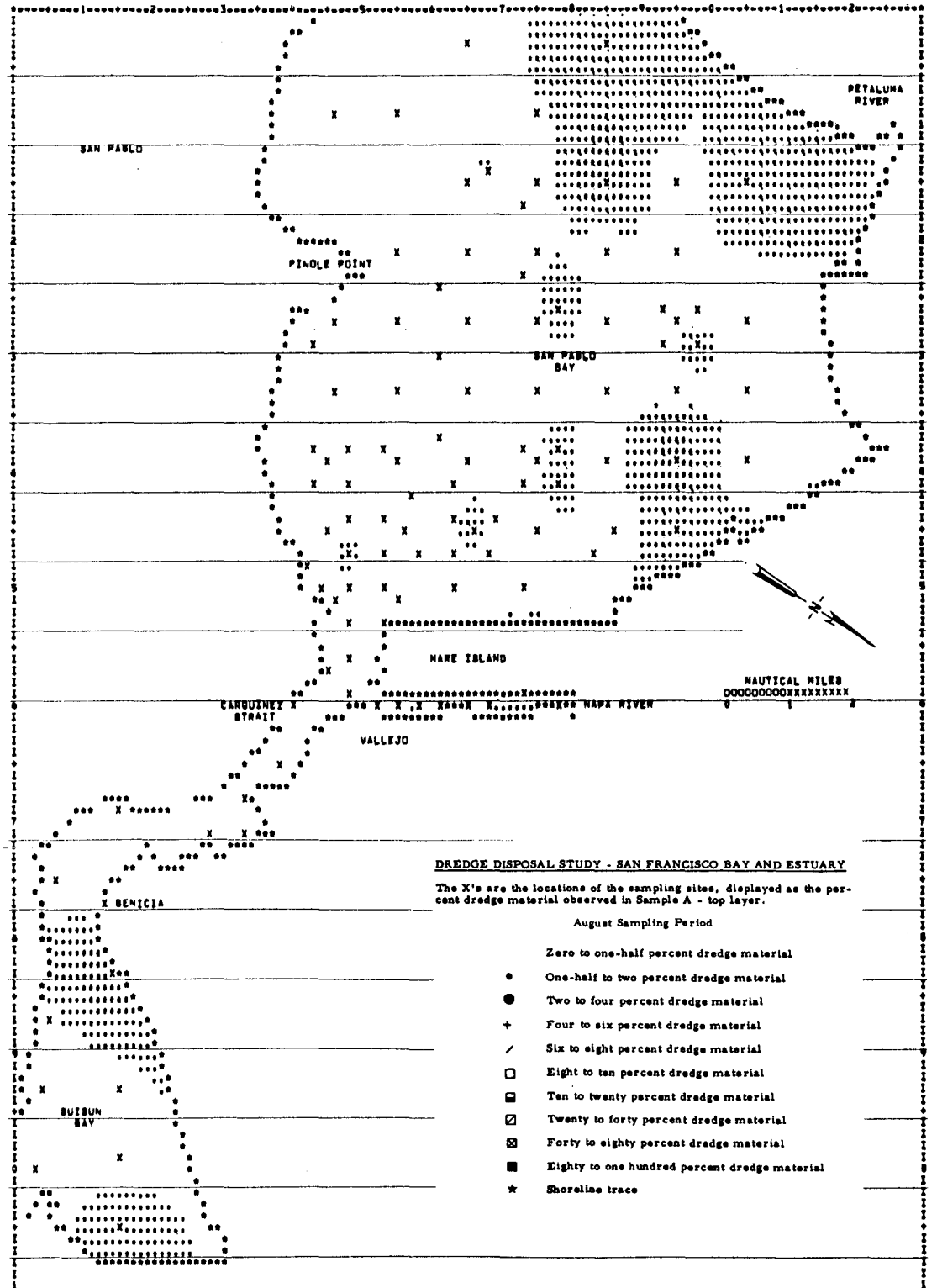
c. Layer C (127-228.6 mm)

Figure 21 (sheet 3 of 3)



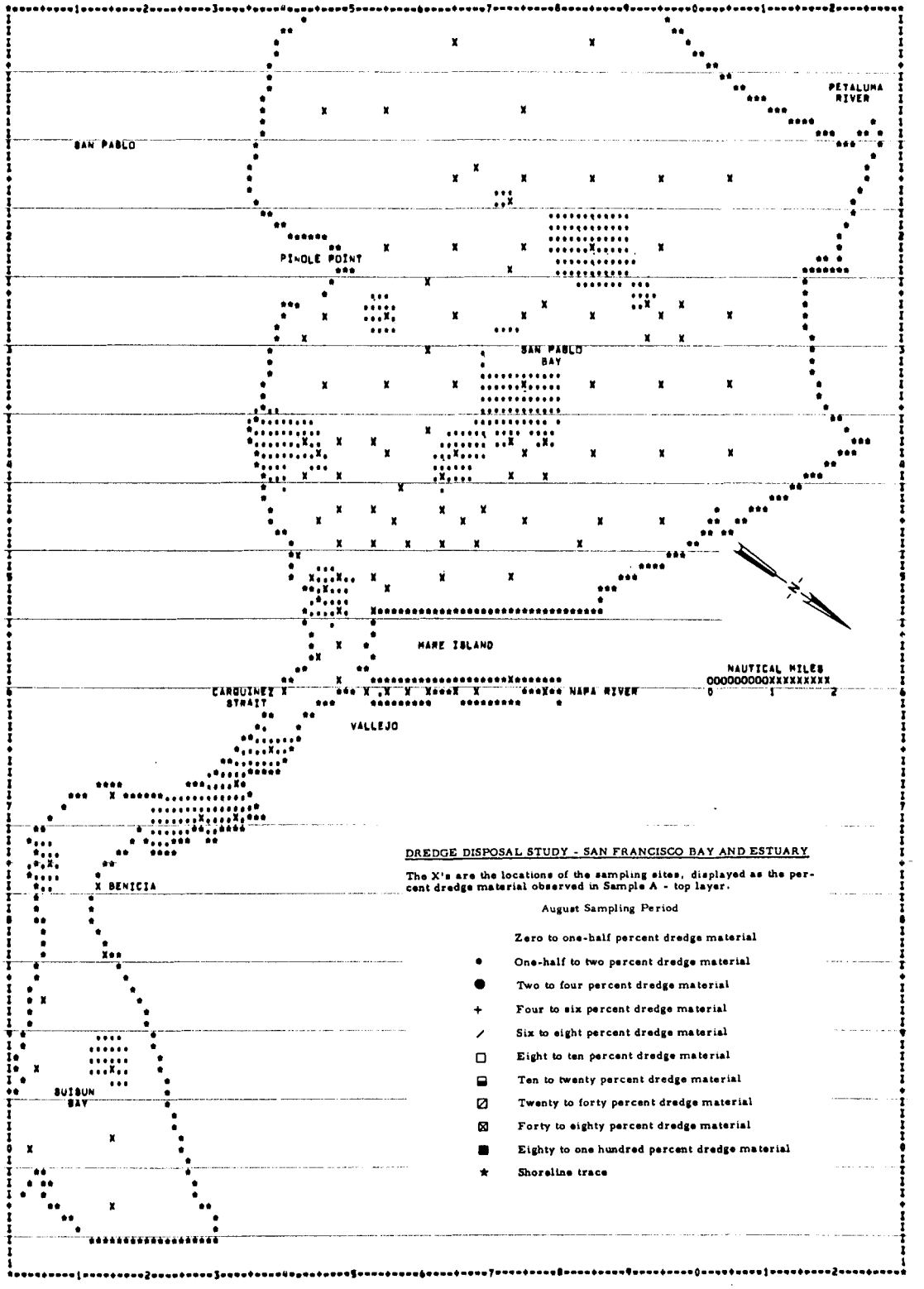
a. Layer A (0-25.4 mm)

Figure 22. August sampling period (sheet 1 of 3)



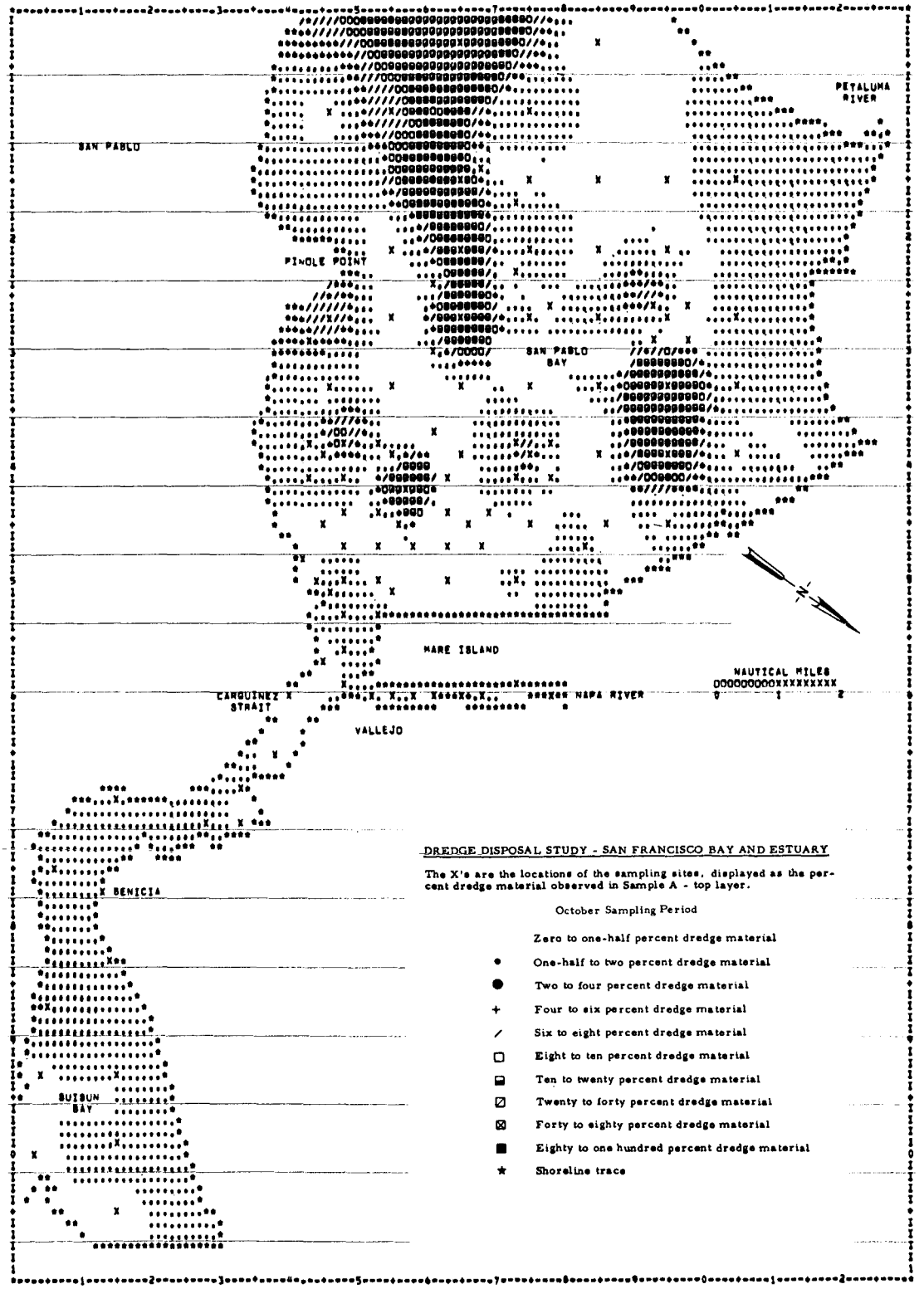
b. Layer B (25.4-127 mm)

Figure 22 (sheet 2 of 3)



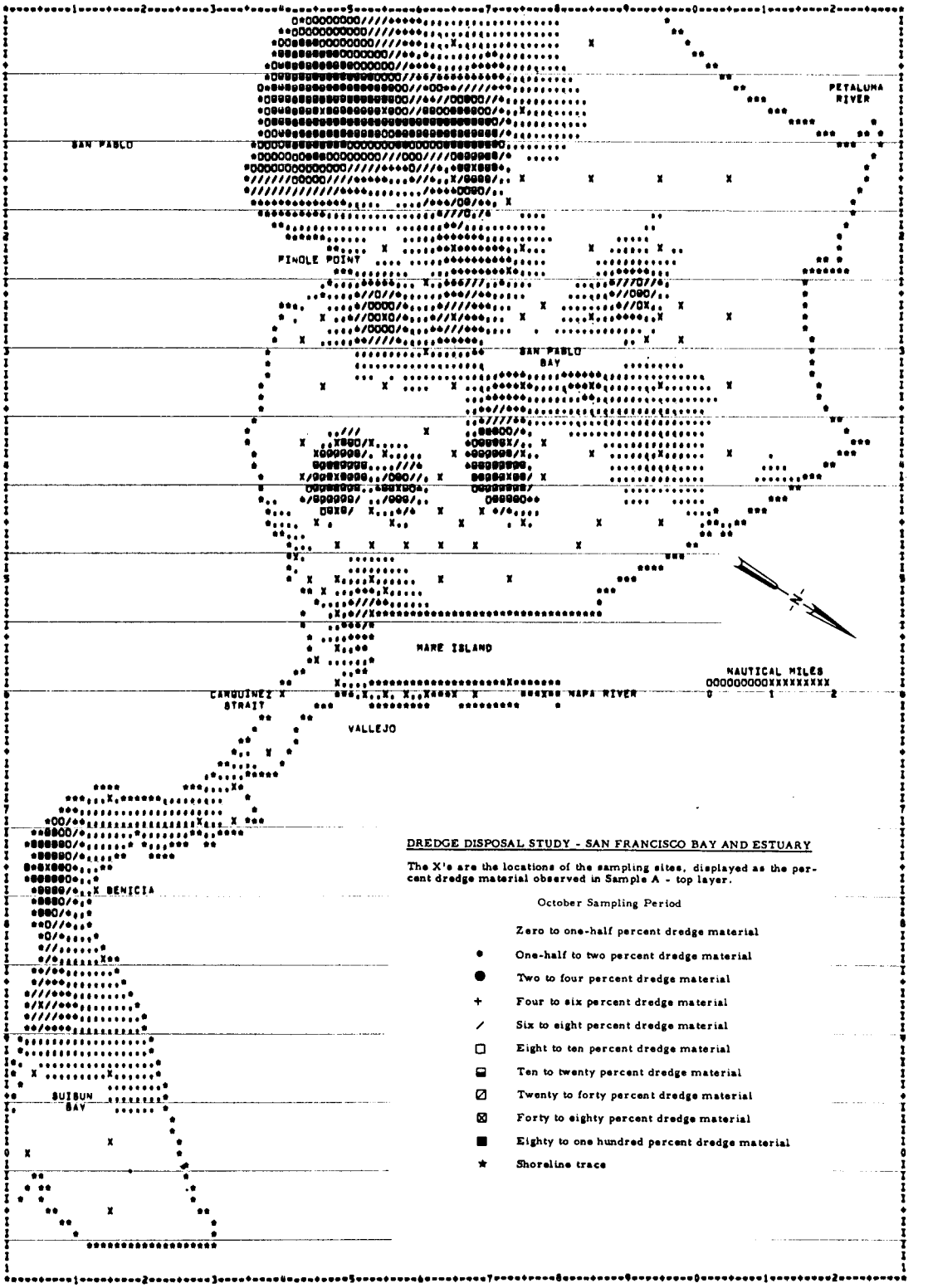
c. Layer C (127-228.6 mm)

Figure 22 (sheet 3 of 3)



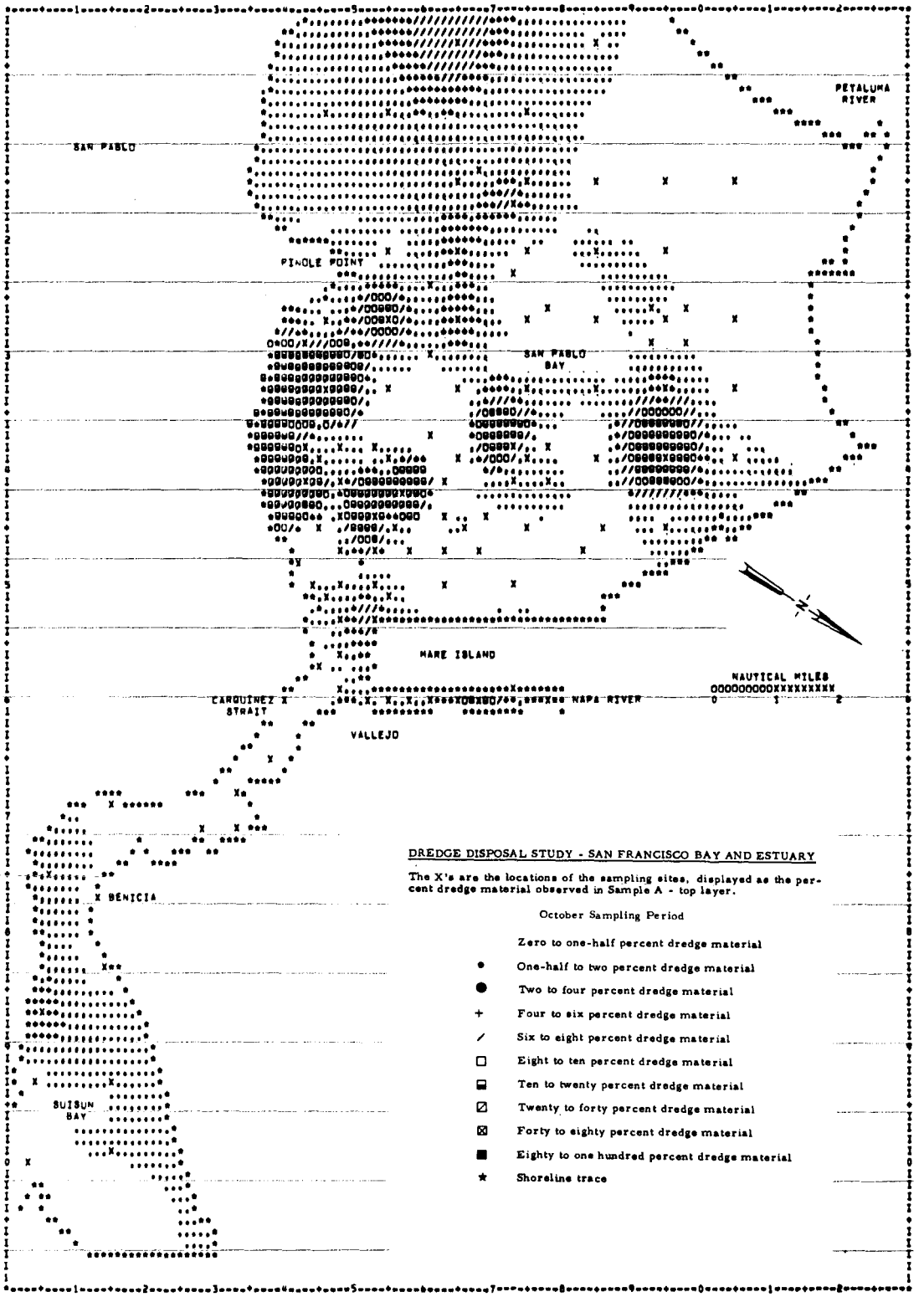
a. Layer A (0-25.4 mm)

Figure 23. October sampling period (sheet 1 of 3)



b. Layer B (25.4-127 mm)

Figure 23 (sheet 2 of 3)



c. Layer C (127-228.6 mm)

Figure 23 (sheet 3 of 3)

resulted from the September-October 1974 dredging of the Mare Island Strait which redistributed the tagged sediments previously introduced in the February-March 1974 dredging. In the authors' opinions, the October results, occurring seven months after the introduction of the traced sediments, provide conclusive evidence of the success of the sediment tracing technique developed.

132. Similar figures have been plotted (not included) for each month from April to December. In April the traced sediment had circulated to all locations in the test area. The traced sediment concentrations then proceeded to decline through September, as illustrated in the May to August comparison. After the October increase, the concentration decreased again in November and December. These changing patterns can result from tagged particles returning to the Mare Island Strait, tagged particles being carried out of the test area, dilution of the tagged particles with inert particles, or tagged particles being covered by a new layer of inert particles. An attempt will be made to evaluate these separate effects in the San Francisco District report.[10]

Mare Island Strait profile samples

133. The locations and iridium concentrations of the profile samples collected in the Mare Island Strait just prior to the September-October 1974 dredging operation is shown in Figure 24. Concentrations of traced dredged materials are given for layers B and C and, where available, for layers D and E. Layers B and C were determined by dividing the sediment column received in a 762-mm (30-in.) sampling tube into two equal sections. Thus, the B and C layers represent the material residing in the first 762 mm (30 in.) of sediment below the surface. In some cases, a second core was obtained by pushing another 762-mm (30-in.) sampling tube into the sediment layer 762 to 1524 mm (30 to 60 in.) below the surface. This tube was then equally divided and designated D and E layers. The iridium concentration gradients defined by layers A-E indicate that 1524 mm (60 in.) was not sufficiently deep to account for all the traced dredge material and that indeed the deeper sediments may have had a higher concentration than the layer E samples. Verification of the higher concentrations in the deeper sediments was

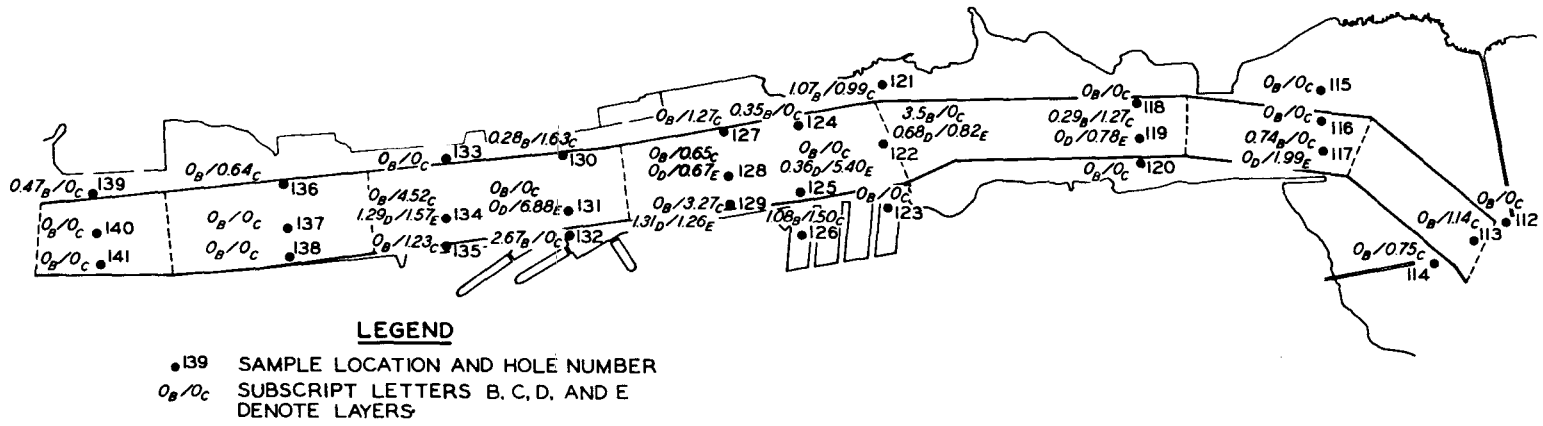


Figure 24. Mare Island profile samples

not possible because the dredge removed more than a 1524-mm (60 in.) depth of material in Mare Island Strait during the September-October dredging operation. As a result, the Mare Island Strait profile data cannot be used to rigorously account for the high traced sediment concentrations detected throughout the test area in the October sampling.

134. In an attempt to determine when and how much traced dredge sediments reentered the Mare Island Strait during the entire testing period, other data were analyzed. Figure 25 shows the data collected for the March-December sampling of holes 1-6 and 63-64. These holes are located in the Mare Island Strait, as shown in Figures 11 and 17. In Figure 25, sample A is for the 0-25.4-mm (0-1-in.) layer of sediment, and each sample from B on is for an additional 101.6 mm (4 in.) of sediment.

135. In the first sampling periods of March, during dredging and tagged sediments introduction, the concentrations of tagged sediments sampled from the Strait and those collected from the dredge's hoppers (Table 12) show a reasonable relationship. After March, the concentrations were lower in an equivalent layer, but a similar concentration can often be seen (Figure 25) in layers of greater depth, suggesting a continuous buildup of sediment above the original heavy influx immediately following dredging.

Samples from outside test area

136. Table 13 lists the stations sampled outside of the tracer program test area and the percentage of traced sediments noted at each location. The locations of the sampling stations can be seen in Figure 16. The data indicate some tagged sediments to be in the area adjacent to the cities of Oakland and Alameda. All of the samples were taken in the September-December 1974 period, six months after the original introduction of the tagged sediments but during and after the redredging. Thus, it is not possible to determine the arrival time of the traced material.

Conclusions

137. All objectives of the EERL-SRI joint study to identify,

COORDINATES	HOLE NO.	LOCATION
G H 9 10	1	MARE ISLAND STRAIT

SAMPLING DATES	14MAR74	27MAR74	9APR74	7MAY74	14JUN74	25JUL74	21AUG74	18SEP74	18OCT74	21NOV74	5DEC74
DEPTH OF SEDIMENT BELOW MLLW (FT)	32.0	34.0	33.0	20.5	30.0	29.5	29.0	27.5	31.0	35.0	33.0
THICKNESS OF LAYERS (IN)											
FLUFF	0.5	0.5	1.0	5.0	17.0	7.0	4.0	3.0	3.0	6.0	1.0
ACTIVE	25.0	27.0	20.0	10.0	0.0	20.0	41.0	46.0	13.0	16.0	16.0
INACTIVE	0.0	0.0	5.0	4.0	0.0	0.0	3.0	0.0	4.0	2.0	4.0
SAMPLE A	1016	3856	3658	1354	1780	2062	2431	2695	3028	3328	3544
G.DRY/CC.WET MUD	0.745	0.549	0.208	0.574	0.446	0.641	0.652	0.478	0.487	0.439	0.558
G.IR/G.DRY MUD	1.33E-08	6.50E-10	9.82E-10	5.25E-10	3.65E-10	5.10E-10	6.68E-10	2.54E-10	3.12E-10	6.72E-10	2.86E-10
% DREDGE MATERIAL	66.840	1.711	3.415	1.072	0.250	0.995	1.806	0.000	0.000	1.824	0.000
SAMPLE B	1017	3857	3659	1355	1781	2063	2432	2696	3029	3329	3545
G.DRY/CC.WET MUD	0.376	0.494	0.550	0.457	0.425	0.530	0.490	0.471	0.557	0.534	0.490
G.IR/G.DRY MUD	9.66E-09	1.58E-09	3.66E-10	4.65E-10	7.05E-10	3.09E-10	2.93E-10	5.14E-11	-BDL-	3.76E-10	3.71E-10
% DREDGE MATERIAL	47.940	6.501	0.254	0.762	1.997	0.000	0.000	0.000	0.000	0.307	0.284
SAMPLE C	1018	3858	3660	1356	1782	2064	2433	2697	3030	4733	3546
G.DRY/CC.WET MUD	0.506	0.556	0.609	0.417	0.498	0.548	0.493	0.541	0.617	0.545	0.580
G.IR/G.DRY MUD	9.16E-09	8.32E-10	2.53E-10	7.94E-10	3.20E-10	3.28E-10	9.83E-11	3.72E-10	3.63E-09	8.00E-10	1.08E-10
% DREDGE MATERIAL	45.364	2.645	0.000	2.449	0.020	0.059	0.000	0.290	16.986	2.480	0.000
SAMPLE D	4328	4620								4732	
G.DRY/CC.WET MUD	0.601	0.439								0.647	
G.IR/G.DRY MUD	1.32E-10	1.01E-09								3.58E-10	
% DREDGE MATERIAL	0.000	3.552								0.218	
SAMPLE E	1020										
G.DRY/CC.WET MUD	0.544										
G.IR/G.DRY MUD	1.86E-08										
% DREDGE MATERIAL	93.831										
SAMPLE F		4621									
G.DRY/CC.WET MUD		0.490									
G.IR/G.DRY MUD		2.05E-09									
% DREDGE MATERIAL		8.870									
SAMPLE G	4329										
G.DRY/CC.WET MUD	0.345										
G.IR/G.DRY MUD	7.66E-10										
% DREDGE MATERIAL	2.310										
SAMPLE H											
G.DRY/CC.WET MUD											
G.IR/G.DRY MUD											
% DREDGE MATERIAL											

COORDINATES	HOLE NO.	LOCATION
G E 9 10	2	MARE ISLAND STRAIT

SAMPLING DATES	15MAR74	27MAR74	9APR74	7MAY74	14JUN74	25JUL74	21AUG74	18SEP74	18OCT74	21NOV74	5DEC74
DEPTH OF SEDIMENT BELOW MLLW (FT)	34.0	31.5	32.0	28.5	27.0	26.5	26.5	27.0	36.5	37.5	36.0
THICKNESS OF LAYERS (IN)											
FLUFF	0.0	0.0	1.0	7.0	24.0	15.0	4.0	2.0	0.0	7.0	2.0
ACTIVE	24.0	17.0	20.0	9.0	0.0	12.0	39.0	50.0	29.0	16.0	27.0
INACTIVE	0.0	0.0	5.0	5.0	0.0	0.0	27.0	0.0	0.0	0.0	0.0
SAMPLE A	1012	3892	3661	1324	1768	2065	2404	2698	3031	3289	3448
G.DRY/CC.WET MUD	0.575	0.412	0.403	0.405	0.477	0.551	0.605	0.460	0.525	0.246	0.435
G.IR/G.DRY MUD	2.67E-08	4.78E-11	3.31E-10	2.14E-09	1.29E-09	5.13E-10	1.57E-10	2.87E-10	2.15E-09	6.98E-10	3.89E-10
% DREDGE MATERIAL	135.049	0.000	0.079	9.338	4.973	1.013	0.000	0.000	9.400	1.957	0.376
SAMPLE B	4667	3893	3662	1325	1769	2066	2405	2699	3032	3290	3449
G.DRY/CC.WET MUD	0.463	0.406	0.480	0.457	0.371	0.326	0.432	0.447	0.372	0.352	0.349
G.IR/G.DRY MUD	4.28E-10	5.85E-10	4.10E-10	1.48E-09	4.80E-10	6.48E-10	3.16E-10	3.02E-10	2.23E-10	9.33E-11	2.33E-10
% DREDGE MATERIAL	0.573	1.381	0.482	5.948	0.839	1.704	0.000	0.000	0.000	0.000	0.000
SAMPLE C	4668	3894	3663	1326	1770	2067	2406	2700	3033	3291	3450
G.DRY/CC.WET MUD	0.559	0.457	0.506	0.444	0.449	0.459	0.410	0.395	0.539	0.395	0.398
G.IR/G.DRY MUD	2.01E-10	1.43E-09	9.11E-10	9.42E-10	3.15E-10	4.66E-10	3.93E-10	2.38E-10	8.99E-11	4.80E-10	4.04E-10
% DREDGE MATERIAL	0.000	5.709	3.052	3.208	0.000	0.767	0.397	0.000	0.000	0.840	0.451
SAMPLE D	4669	4139								4734	
G.DRY/CC.WET MUD	0.481	0.469								0.350	
G.IR/G.DRY MUD	6.69E-11	1.31E-10								5.00E-10	
% DREDGE MATERIAL	0.000	0.000								0.945	
SAMPLE E	4670									4735	
G.DRY/CC.WET MUD	0.674									0.490	
G.IR/G.DRY MUD	1.48E-10									3.43E-10	
% DREDGE MATERIAL	0.000									0.137	
SAMPLE F	4671	4140									
G.DRY/CC.WET MUD	0.569	0.526									
G.IR/G.DRY MUD	3.56E-10	2.53E-10									
% DREDGE MATERIAL	0.203	0.000									
SAMPLE G	4672										
G.DRY/CC.WET MUD	0.540										
G.IR/G.DRY MUD	2.10E-10										
% DREDGE MATERIAL	0.000										
SAMPLE H											
G.DRY/CC.WET MUD											
G.IR/G.DRY MUD											
% DREDGE MATERIAL											

Figure 25. Data sheets for holes 1-6 and 63-64, Mare Island Strait (sheet 1 of 4)

COORDINATES	HOLE NO.	LOCATION
G A 9 10	3	MARE ISLAND STRAIT

SAMPLING DATES	6MAR74	27MAR74	9APR74	7MAY74	14JUN74	25JUL74	21AUG74	18SEP74	18OCT74	21NOV74	5DEC74
DEPTH OF SEDIMENT BELOW MLLW (FT)	24.0	31.0	31.0	33.0	31.5	30.0	29.5	29.0	36.5	36.5	37.5
THICKNESS OF LAYERS (IN)											
FLUFF	0.0	0.0	1.0	7.5	0.0	3.0	2.0	2.0	2.0	4.0	1.0
ACTIVE	18.0	15.0	12.0	5.0	21.0	22.0	45.0	51.0	22.0	19.0	19.0
INACTIVE	0.0	0.0	5.0	7.0	0.0	0.0	0.0	0.0	4.0	4.0	5.0
SAMPLE A	3898	3859	3676	1330	1762	2068	2440	2701	3055	3292	3361
G.DRY/CC.WET MUD	0.697	0.376	0.660	0.554	0.569	0.422	0.518	0.509	0.396	0.458	0.361
G.IR/G.DRY MUD	-BDL-	7.74E-10	-BDL-	3.12E-10	1.02E-09	2.88E-10	4.81E-10	2.63E-10	-BDL-	7.59E-10	1.90E-10
% DREDGE MATERIAL	0.000	2.347	0.000	0.000	3.633	0.000	0.844	0.000	0.000	2.270	0.000
SAMPLE B	3899	3860	3677	1331	1763	2069	2441	2702	3056	3293	3362
G.DRY/CC.WET MUD	0.540	0.499	0.499	0.462	0.444	0.531	0.527	0.509	0.543	0.488	0.424
G.IR/G.DRY MUD	2.80E-10	3.48E-09	1.58E-09	2.84E-10	3.57E-10	3.39E-10	1.20E-10	2.51E-10	7.46E-10	3.88E-10	3.71E-10
% DREDGE MATERIAL	0.000	16.244	6.478	0.000	0.211	0.117	0.000	0.000	2.204	0.371	0.285
SAMPLE C	3900	3861	3678	1332	1764	2070	2442	2703	3057	3294	3363
G.DRY/CC.WET MUD	0.588	0.428	0.608	0.529	0.546	0.491	0.556	0.590	0.543	0.611	0.475
G.IR/G.DRY MUD	-BDL-	3.05E-11	4.96E-10	4.56E-10	2.17E-10	4.73E-10	3.03E-10	3.40E-10	1.00E-09	1.51E-10	4.16E-10
% DREDGE MATERIAL	0.000	0.000	0.925	0.721	0.000	0.805	0.000	0.122	3.515	0.000	0.512
SAMPLE D	4141	4143								4736	
G.DRY/CC.WET MUD	0.573	0.707								0.479	
G.IR/G.DRY MUD	1.74E-10	1.28E-10								6.67E-10	
% DREDGE MATERIAL	0.000	0.000								1.800	
SAMPLE E											
G.DRY/CC.WET MUD											
G.IR/G.DRY MUD											
% DREDGE MATERIAL											
SAMPLE F	4142										
G.DRY/CC.WET MUD	0.618										
G.IR/G.DRY MUD	1.51E-11										
% DREDGE MATERIAL	0.000										
SAMPLE G		4144								4737	
G.DRY/CC.WET MUD		0.631								0.549	
G.IR/G.DRY MUD		4.30E-09								5.81E-10	
% DREDGE MATERIAL		20.442								1.360	
SAMPLE H											
G.DRY/CC.WET MUD											
G.IR/G.DRY MUD											
% DREDGE MATERIAL											

COORDINATES	HOLE NO.	LOCATION
F H 9 10	4	MARE ISLAND STRAIT

SAMPLING DATES	14MAR74	27MAR74	9APR74	7MAY74	14JUN74	25JUL74	21AUG74	18SEP74	18OCT74	21NOV74	5DEC74
DEPTH OF SEDIMENT BELOW MLLW (FT)	30.0	30.0	29.0	32.0	31.0	29.5	29.0	28.5	31.5	35.5	32.0
THICKNESS OF LAYERS (IN)											
FLUFF	6.5	-NA-	2.0	9.0	0.0	2.0	2.5	3.0	1.0	1.0	2.0
ACTIVE	14.0	-NA-	15.0	16.0	21.0	20.0	49.0	22.0	23.0	23.0	24.0
INACTIVE	0.0	-NA-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.0	0.0
SAMPLE A	1042	3835	3703	1321	1765	2083	2437	2704	3010	3295	3412
G.DRY/CC.WET MUD	0.348	0.512	0.680	0.336	0.467	0.378	0.612	0.425	0.469	0.496	0.532
G.IR/G.DRY MUD	9.87E-09	3.42E-10	1.72E-09	4.56E-10	2.72E-10	3.25E-10	4.14E-10	-BDL-	4.82E-10	2.71E-10	1.79E-10
% DREDGE MATERIAL	48.973	0.135	7.203	0.718	0.000	0.047	0.505	0.000	0.851	0.000	0.000
SAMPLE B	1044	3836	3704	1322	1766	2084	2438	2705	3011	3296	3413
G.DRY/CC.WET MUD	0.364	0.750	0.582	0.440	0.395	0.708	0.527	0.503	0.597	0.482	0.671
G.IR/G.DRY MUD	7.73E-09	1.20E-09	8.20E-10	7.48E-10	3.84E-10	1.16E-09	4.38E-10	5.29E-10	3.33E-10	-BDL-	2.32E-10
% DREDGE MATERIAL	38.011	4.520	2.584	2.218	0.348	4.343	0.623	1.091	0.086	0.000	0.000
SAMPLE C	1043	3837	3705	1323	1767	2085	2439	2706	3012	3297	3414
G.DRY/CC.WET MUD	0.665	0.510	0.656	0.447	0.431	0.596	0.558	0.499	0.568	0.584	0.671
G.IR/G.DRY MUD	4.32E-09	6.73E-09	1.30E-09	9.68E-10	3.08E-10	6.13E-10	9.47E-11	1.85E-10	4.99E-10	2.81E-10	4.13E-10
% DREDGE MATERIAL	20.537	32.911	5.040	3.343	0.000	1.522	0.000	0.000	0.937	0.000	0.500
SAMPLE D	4332	4145								4738	
G.DRY/CC.WET MUD	0.635	0.544								0.521	
G.IR/G.DRY MUD	2.63E-10	6.45E-11								8.78E-10	
% DREDGE MATERIAL	0.000	0.000								2.881	
SAMPLE E											
G.DRY/CC.WET MUD											
G.IR/G.DRY MUD											
% DREDGE MATERIAL											
SAMPLE F	4333									4739	
G.DRY/CC.WET MUD	0.583									0.539	
G.IR/G.DRY MUD	4.88E-10									5.07E-10	
% DREDGE MATERIAL	0.884									0.980	
SAMPLE G											
G.DRY/CC.WET MUD											
G.IR/G.DRY MUD											
% DREDGE MATERIAL											
SAMPLE H		4146									
G.DRY/CC.WET MUD		0.713									
G.IR/G.DRY MUD		3.91E-10									
% DREDGE MATERIAL		0.383									

Figure 25 (sheet 2 of 4)

COORDINATES	HOLE NO.	LOCATION
F E 9 10	5	MARE ISLAND STRAIT

SAMPLING DATES	8MAR74	27MAR74	15APR74	7MAY74	14JUN74	25JUL74	21AUG74	18SEP74	18OCT74	21NOV74	5DEC74
DEPTH OF SEDIMENT BELOW MLLW (FT)	24.6	35.0	35.0	34.0	35.5	35.5	35.0	35.0	38.0	37.5	37.5
THICKNESS OF LAYERS (IN)											
FLUFF	0.0	0.5	1.5	6.0	9.0	1.0	1.0	2.0	5.0	2.0	0.0
ACTIVE	18.0	17.0	8.0	9.0	13.0	9.0	22.0	14.0	18.0	17.0	2.0
INACTIVE	0.0	5.0	8.0	5.0	0.0	5.0	0.0	5.0	4.0	10.0	19.0
SAMPLE A	1096	3790	1117	1342	1783	2071	2407	2707	3034	3349	3442
G.DRY/CC.WET MUD	0.415	0.279	0.323	0.861	0.526	0.595	0.679	0.582	0.517	0.438	0.501
G.IR/G.DRY MUD	1.78E-09	4.51E-10	1.68E-09	5.27E-10	2.80E-10	1.90E-10	2.10E-10	3.26E-10	1.16E-10	1.88E-10	7.77E-10
% DREDGE MATERIAL	7.492	0.692	7.001	1.085	0.000	0.000	0.000	0.051	0.000	0.000	2.364
SAMPLE B	1098	3791	1118	1343	1784	2072	2408	2708	3035	3350	3443
G.DRY/CC.WET MUD	0.542	0.465	0.564	0.569	0.453	0.498	0.588	0.548	0.547	0.531	0.517
G.IR/G.DRY MUD	2.24E-09	6.99E-10	1.72E-09	1.02E-09	4.18E-10	3.17E-10	4.46E-12	4.10E-10	5.73E-10	2.07E-11	3.07E-10
% DREDGE MATERIAL	9.852	1.963	7.184	3.625	0.524	0.005	0.000	0.484	1.319	0.000	0.000
SAMPLE C	1097	3792	1119	1344	1785	2073	2409	2709	3036	3351	3444
G.DRY/CC.WET MUD	0.538	0.493	0.582	0.543	0.547	0.656	0.580	0.595	0.573	0.625	0.521
G.IR/G.DRY MUD	3.43E-09	1.60E-09	1.00E-09	3.58E-10	5.42E-10	-BDL-	4.77E-10	4.76E-10	3.04E-10	7.16E-11	6.03E-10
% DREDGE MATERIAL	15.947	6.586	3.520	0.215	1.160	0.000	0.825	0.818	0.000	0.000	1.472
SAMPLE D	4514	4147								4740	
G.DRY/CC.WET MUD	0.586	0.527								0.565	
G.IR/G.DRY MUD	1.12E-09	1.04E-10								-BDL-	
% DREDGE MATERIAL	4.109	0.000								0.000	
SAMPLE E		4148									
G.DRY/CC.WET MUD		0.532									
G.IR/G.DRY MUD		5.65E-11									
% DREDGE MATERIAL		0.000									
SAMPLE F											
G.DRY/CC.WET MUD											
G.IR/G.DRY MUD											
% DREDGE MATERIAL											
SAMPLE G	4515									4741	
G.DRY/CC.WET MUD	0.636									0.638	
G.IR/G.DRY MUD	9.98E-11									2.51E-10	
% DREDGE MATERIAL	0.000									0.000	
SAMPLE H											
G.DRY/CC.WET MUD											
G.IR/G.DRY MUD											
% DREDGE MATERIAL											

COORDINATES	HOLE NO.	LOCATION
F B 9 10	6	MARE ISLAND STRAIT

SAMPLING DATES	8MAR74	27MAR74	15APR74	7MAY74	14JUN74	25JUL74	16AUG74	18SEP74	18OCT74	21NOV74	5DEC74
DEPTH OF SEDIMENT BELOW MLLW (FT)	28.0	37.0	32.0	29.3	33.0	35.0	36.0	32.0	33.5	41.5	34.5
THICKNESS OF LAYERS (IN)											
FLUFF	0.5	0.5	2.5	3.0	4.5	2.0	2.0	0.0	5.0	0.0	0.0
ACTIVE	15.0	17.0	11.0	9.0	10.0	25.0	6.0	9.0	11.0	20.0	3.0
INACTIVE	0.0	0.0	12.0	4.0	8.0	0.0	12.0	9.0	9.0	5.0	21.0
SAMPLE A	1081	3862	1165	1327	1774	2086	2395	2710	3037	3235	3358
G.DRY/CC.WET MUD	0.560	0.365	0.497	0.674	0.662	0.446	0.616	0.648	0.603	0.527	0.426
G.IR/G.DRY MUD	2.87E-09	5.94E-11	9.95E-10	7.97E-10	7.30E-10	4.46E-10	7.29E-10	6.10E-10	6.25E-10	6.65E-10	1.66E-10
% DREDGE MATERIAL	13.094	0.000	3.484	2.469	2.122	0.666	2.119	1.507	1.586	1.790	0.000
SAMPLE B	1083	3863	1166		1775	2087	2396	2711	3038	3236	3359
G.DRY/CC.WET MUD	0.750	0.413	0.646	LOST	0.647	0.495	0.596	0.583	0.565	0.774	0.593
G.IR/G.DRY MUD	3.12E-09	8.18E-10	2.11E-09	SAMPLE	4.53E-10	6.51E-10	2.64E-10	3.86E-10	4.94E-10	6.15E-11	3.41E-10
% DREDGE MATERIAL	14.399	2.576	9.220		0.705	1.717	0.000	0.360	0.914	0.000	0.127
SAMPLE C	1082	3864	1167	1329	1776	2088	2397	2712	3039	3237	3360
G.DRY/CC.WET MUD	0.612	0.620	0.628	0.551	0.587	0.625	0.604	0.529	0.656	0.724	0.552
G.IR/G.DRY MUD	1.15E-09	-BDL-	9.54E-10	2.66E-10	6.18E-10	5.18E-10	9.00E-11	4.05E-10	5.41E-10	3.92E-11	3.67E-10
% DREDGE MATERIAL	4.297	0.000	3.273	0.000	1.551	1.037	0.000	0.455	1.157	0.000	0.262
SAMPLE D	4149									4742	
G.DRY/CC.WET MUD	0.600									0.667	
G.IR/G.DRY MUD	5.74E-10									4.24E-10	
% DREDGE MATERIAL	1.323									0.552	
SAMPLE E											
G.DRY/CC.WET MUD											
G.IR/G.DRY MUD											
% DREDGE MATERIAL											
SAMPLE F											
G.DRY/CC.WET MUD											
G.IR/G.DRY MUD											
% DREDGE MATERIAL											
SAMPLE G	4150									4743	
G.DRY/CC.WET MUD	0.650									0.740	
G.IR/G.DRY MUD	1.52E-10									2.70E-10	
% DREDGE MATERIAL	0.000									0.000	
SAMPLE H											
G.DRY/CC.WET MUD											
G.IR/G.DRY MUD											
% DREDGE MATERIAL											

Figure 25 (sheet 3 of 4)

COORDINATES	HOLE NO.	LOCATION							
H C 9 9	63	MARE ISLAND STRAIT							
SAMPLING DATES	22APR74	7MAY74	14JUN74	25JUL74	21AUG74	16SEP74	18OCT74	21NOV74	5DEC74
DEPTH OF SEDIMENT BELOW MLLW (FT)	22.0	21.0	20.0	18.5	20.5	21.0	23.0	22.5	20.5
THICKNESS OF LAYERS (IN)									
FLUFF	2.0	1.5	2.5	1.0	1.0	1.0	1.0	0.0	0.0
ACTIVE	6.0	8.0	7.0	8.0	11.0	10.0	11.0	6.0	4.0
INACTIVE	6.0	8.0	6.0	6.0	8.0	4.0	7.0	14.0	14.0
SAMPLE A	1267	1345	1759	2077	2443	2689	3058	3298	3502
G.DRY/CC.WET MUD	0.611	0.711	0.606	0.674	0.599	0.529	0.486	0.592	0.678
G.IR/G.DRY MUD	5.82E-10	7.54E-10	5.27E-10	5.56E-09	2.13E-10	-BDL-	1.71E-10	2.48E-10	1.52E-10
% DREDGE MATERIAL	1.364	2.249	1.081	26.914	0.000	0.000	0.000	0.000	0.000
SAMPLE B	1268	1346	1760	2078	2444	2690	3059	3299	3503
G.DRY/CC.WET MUD	0.528	0.588	0.593	0.492	0.575	0.574	0.567	0.574	0.563
G.IR/G.DRY MUD	4.78E-10	4.83E-10	6.61E-10	2.23E-09	1.07E-09	3.21E-10	3.16E-10	8.52E-11	1.01E-09
% DREDGE MATERIAL	0.833	0.856	1.768	9.829	3.870	0.026	0.002	0.000	3.571
SAMPLE C	1269	1347	1761	2079	2445	2691	3060	3300	3504
G.DRY/CC.WET MUD	0.554	0.579	0.592	0.598	0.563	0.563	0.607	0.668	0.426
G.IR/G.DRY MUD	1.99E-10	4.79E-10	1.52E-10	3.04E-09	7.74E-11	1.54E-10	1.13E-09	2.61E-10	5.31E-10
% DREDGE MATERIAL	0.000	0.834	0.000	13.968	0.000	0.000	4.167	0.000	1.105
SAMPLE D								4785	
G.DRY/CC.WET MUD								0.638	
G.IR/G.DRY MUD								3.01E-11	
% DREDGE MATERIAL								0.000	
SAMPLE E								4786	
G.DRY/CC.WET MUD								0.571	
G.IR/G.DRY MUD								1.94E-10	
% DREDGE MATERIAL								0.000	
SAMPLE F									
G.DRY/CC.WET MUD									
G.IR/G.DRY MUD									
% DREDGE MATERIAL									
SAMPLE G									
G.DRY/CC.WET MUD									
G.IR/G.DRY MUD									
% DREDGE MATERIAL									
SAMPLE H									
G.DRY/CC.WET MUD									
G.IR/G.DRY MUD									
% DREDGE MATERIAL									

COORDINATES	HOLE NO.	LOCATION							
H H 9 10	64	MARE ISLAND STRAIT							
SAMPLING DATES	22APR74	7MAY74	14JUN74	23JUL74	21AUG74	18SEP74	18OCT74	21NOV74	5DEC74
DEPTH OF SEDIMENT BELOW MLLW (FT)	25.5	25.5	26.5	23.0	22.5	23.0	28.0	25.5	26.5
THICKNESS OF LAYERS (IN)									
FLUFF	1.0	1.5	2.0	0.0	0.0	0.0	1.0	0.0	0.0
ACTIVE	10.0	4.0	7.0	5.0	6.0	6.0	5.0	4.0	2.0
INACTIVE	14.0	11.0	8.0	12.0	10.0	14.0	10.0	21.0	21.0
SAMPLE A	1228	1357	1771	1999	2434	2713	3040	3304	3505
G.DRY/CC.WET MUD	0.348	0.580	0.630	0.690	0.763	0.465	0.594	0.515	0.694
G.IR/G.DRY MUD	5.17E-09	6.77E-10	4.00E-10	3.60E-10	3.06E-10	-BDL-	-BDL-	4.91E-10	8.12E-11
% DREDGE MATERIAL	24.872	1.854	0.429	0.224	0.000	0.000	0.000	0.900	0.000
SAMPLE B	1229	1358	1772	2000	2435	2714	3041	3305	3506
G.DRY/CC.WET MUD	0.566	0.543	0.586	0.524	0.610	0.567	0.585	0.599	0.660
G.IR/G.DRY MUD	5.38E-09	7.74E-10	5.30E-10	1.84E-10	4.32E-10	4.23E-10	8.45E-11	2.91E-10	1.58E-10
% DREDGE MATERIAL	25.954	2.350	1.098	0.000	0.593	0.548	0.000	0.000	0.000
SAMPLE C	1230	1359	1773	2001	2436	2715	3042	3306	3507
G.DRY/CC.WET MUD	0.604	0.580	0.567	0.535	0.626	0.604	0.671	0.594	0.520
G.IR/G.DRY MUD	1.52E-09	7.73E-10	5.44E-10	2.21E-10	3.18E-11	3.93E-10	4.19E-10	2.57E-10	2.48E-10
% DREDGE MATERIAL	6.182	2.343	1.170	0.000	0.000	0.395	0.528	0.000	0.000
SAMPLE D								4787	
G.DRY/CC.WET MUD								0.595	
G.IR/G.DRY MUD								-BDL-	
% DREDGE MATERIAL								0.000	
SAMPLE E									
G.DRY/CC.WET MUD									
G.IR/G.DRY MUD									
% DREDGE MATERIAL									
SAMPLE F								4788	
G.DRY/CC.WET MUD								0.585	
G.IR/G.DRY MUD								1.60E-09	
% DREDGE MATERIAL								6.563	
SAMPLE G									
G.DRY/CC.WET MUD									
G.IR/G.DRY MUD									
% DREDGE MATERIAL									
SAMPLE H									
G.DRY/CC.WET MUD									
G.IR/G.DRY MUD									
% DREDGE MATERIAL									

Figure 25 (sheet 4 of 4)

Table 13

Samples from Outside Test Area

Location	Depth*	Date	Percent IR in Dredge Material	Grams Dry/cc Wet Mud
H142	A	092474	0	1.222E+00
H142	B	092474	0	9.266E-01
H142	C	092474	0.670	9.249E-01
H142	D	092474	0	7.902E-01
H143	A	092474	3.517	6.071E-01
H143	B	092474	1.717	5.506E-01
H143	C	092474	0	4.328E-01
H144	A	092474	0.381	4.821E-01
H144	B	092474	0	3.983E-01
H144	C	092474	0	5.123E-01
H145	A	092774	0	6.139E-01
H145	B	092774	0	3.635E-01
H145	C	092774	0	4.427E-01
H146	A	092774	0.693	6.694E-01
H146	B	092774	1.240	3.639E-01
H146	C	092774	4.380	5.425E-01
H146	D	092774	0.569	5.412E-01
H146	G	092774	0	5.102E-01
H147	A	102974	2.525	1.383E+00
H147	B	102974	0.973	6.427E-01
H148	A	102974	0	7.533E-01
H148	B	102974	0	4.805E-01
H148	C	102974	0	4.143E-01
H149	A	103074	1.097	6.897E-01
H149	B	103074	0	9.438E-01
H149	C	103074	0	9.442E-01
H150	A	103074	0	8.063E-01
H150	B	103074	0	5.924E-01
H150	C	103074	0	5.145E-01

(Continued)

* A = 0-25.4 mm (0-1 in.).
B = 25.4-127 mm (1-5 in.).
C = 127-229 mm (5-9 in.).
D = 229-330 mm (9-13 in.).
G = 533-635 mm (21-25 in.).

Table 13 (Concluded)

Location	Depth	Date	Percent IR in Dredge Material	Grams Dry/cc Wet Mud
H151	A	103174	0	8.628E-01
H151	B	103174	0	7.373E-01
H151	C	103174	0.371	7.864E-01
H152	A	112674	0	6.735E-01
H152	B	112674	0	6.818E-01
H152	C	112674	0	6.978E-01
H153	A	112674	0	1.296E+00
H153	B	112674	0	1.605E+00
H153	C	112674	0	1.563E+00
H154	A	112674	0	5.678E-01
H154	B	112674	0.057	5.300E-01
H154	C	112674	2.411	6.973E-01
H154	D	112674	0.402	8.530E-01
H155	A	112674	0	6.711E-01
H155	B	112674	0	7.330E-01
H155	C	112674	0	6.685E-01
H156	A	112674	0	5.647E-01
H156	B	112674	0	8.604E-01
H156	C	112674	0	9.253E-01
H157	A	121974	0	8.521E-01
H157	B	121974	0	8.126E-01
H157	C	121974	0	7.950E-01
H158	A	121974	0	6.601E-01
H158	B	121974	0	4.938E-01
H158	C	121974	0	3.669E-01
H159	A	121974	0	7.351E-01
H159	B	121974	0	6.440E-01
H159	C	121974	0	7.180E-01
H160	A	121974	0.013	8.579E-01
H160	B	121974	0	8.913E-01
H160	C	121974	0.179	5.829E-01
H161	A	121974	0	9.161E-01
H161	B	121974	0	7.623E-01
H161	C	121974	0	8.569E-01

develop, and demonstrate a suitable tracer for following the movement of dredged sediment in the San Francisco Bay were successfully accomplished.

138. Iridium was found to be the most cost-effective chemical element for tagging and tracing sediments in the San Francisco Bay. Although iridium would probably be effective in most areas because of its low natural abundance and neutronic properties, other chemical elements may be more cost-effective for tracing dredged sediments in other locations.

139. The sediment-tagging procedure yielded a workable and practical tracer that was capable of identifying dredged sediment concentrations as low as one percent.

140. From the Mare Island Strait, 2,000,000 yd^3 of dredged sediments were tagged with iridium. Approximately 4,000 samples were collected and analyzed over a period of almost a year. The data will be used to define the deposition, dispersion, and long-term circulation patterns of sediments dredged from the Mare Island Strait.

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