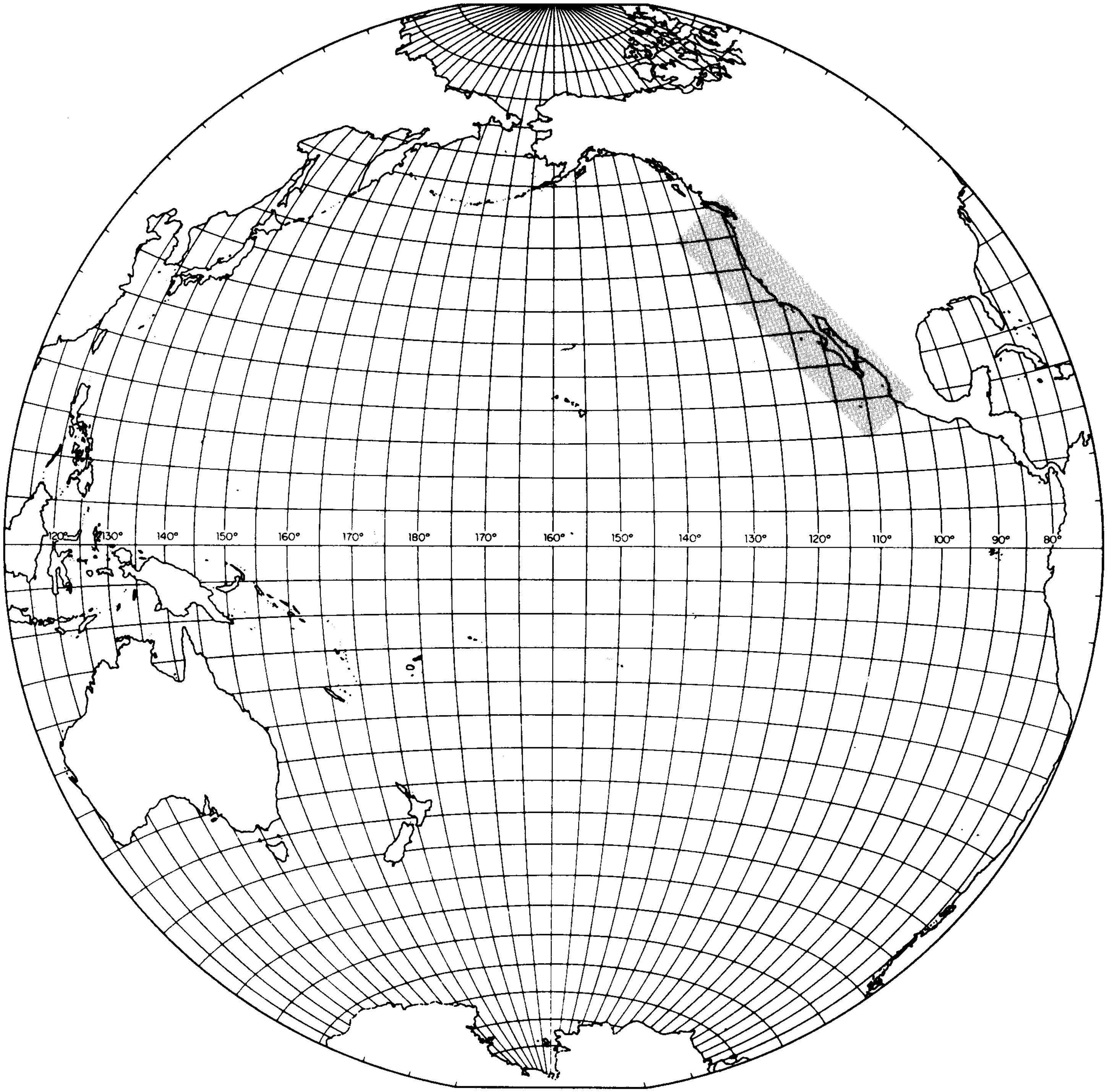
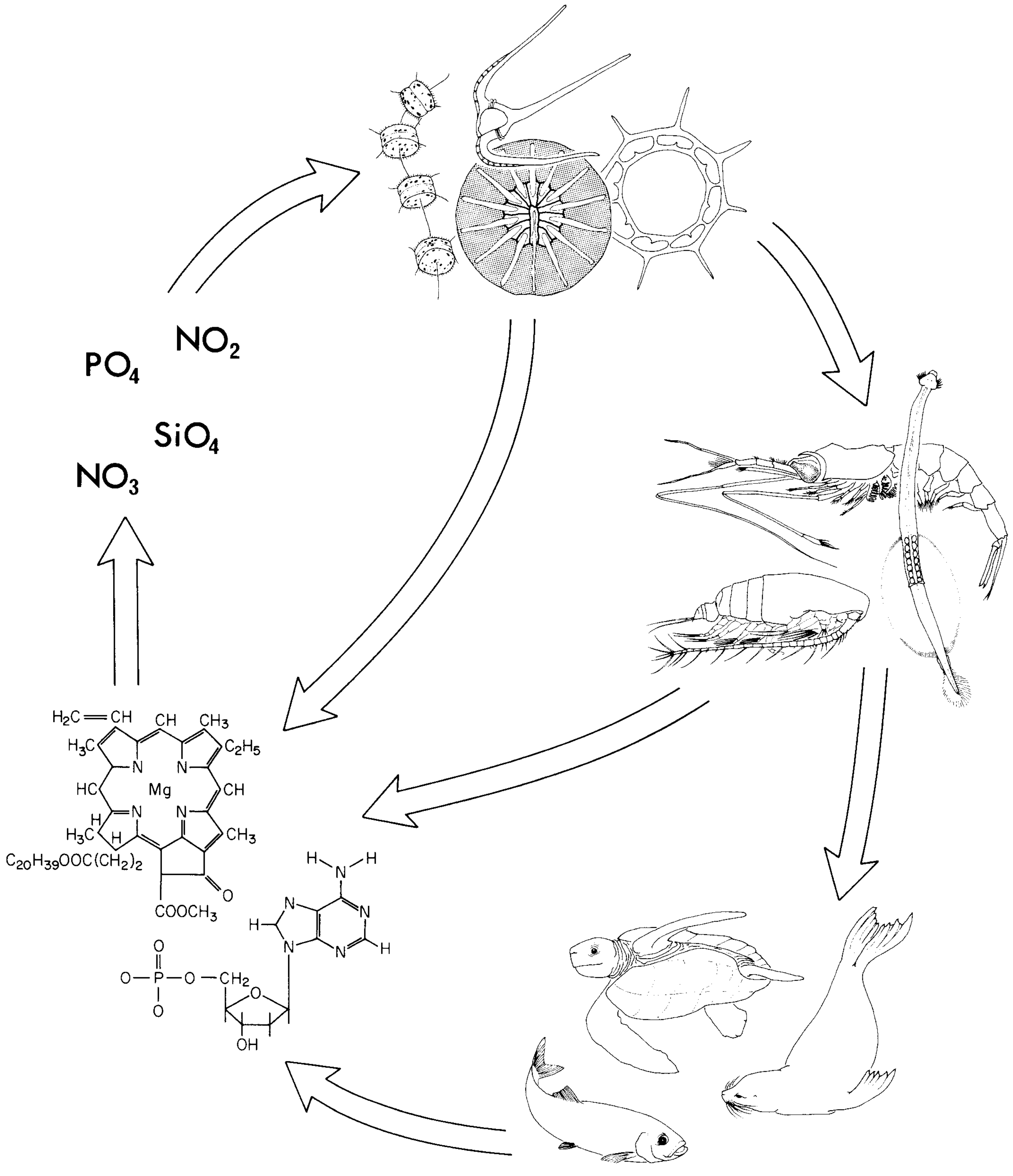
STATE OF CALIFORNIA
MARINE RESEARCH COMMITTEE



CALIFORNIA COOPERATIVE OCEANIC FISHERIES INVESTIGATIONS

ATLAS No. 20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CALIFORNIA COOPERATIVE OCEANIC FISHERIES INVESTIGATIONS

Atlas No. 20

STATE OF CALIFORNIA
MARINE RESEARCH COMMITTEE

Cooperating Agencies:
CALIFORNIA ACADEMY OF SCIENCES
CALIFORNIA DEPARTMENT OF FISH AND GAME
STANFORD UNIVERSITY, HOPKINS MARINE STATION
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION, NATIONAL MARINE FISHERIES SERVICE
UNIVERSITY OF CALIFORNIA, SCRIPPS INSTITUTION OF OCEANOGRAPHY

June, 1974

THE CALCOFI ATLAS SERIES

This is the twentieth in a series of atlases containing data on the hydrography and plankton from the region of the California Current. The field work was carried out by the California Cooperative Oceanic Fisheries Investigations,[1] a program sponsored by the State of California under the direction of the State's Marine Research Committee. The cooperating agencies in the program are:

California Academy of Sciences
California Department of Fish and Game
Stanford University, Hopkins Marine Station
National Oceanic and Atmospheric Administration, National Marine Fisheries Service[2]
University of California, Scripps Institution of Oceanography

CalCOFI atlases[3] are issued as individual units as they become available. They provide processed physical, chemical and biological measurements of the California Current region. Each number may contain one or more contributions. A general description of the CalCOFI program with its objectives appears in the preface of Atlas No. 2.

This atlas was prepared by the Data Collection and Processing Group of the Marine Life Research Program, Scripps Institution of Oceanography.

CalCOFI Atlas Editorial Staff:

Abraham Fleminger and John G. Wyllie, Editors

CalCOFI atlases in this series, through June 1974, are:

No. 1. Anonymous, 1963. CalCOFI atlas of 10-meter temperatures and salinities 1949 through 1959.
No. 2. Fleminger, A., 1964. Distributional atlas of calanoid copepods in the California Current region, Part I.
No. 3. Alvarino, A., 1965. Distributional atlas of Chaetognatha in the California Current region.
No. 4. Wyllie, J.G., 1966. Geostrophic flow of the California Current at the surface and at 200 meters.
No. 5. Brinton, E., 1967. Distributional atlas of Euphausiacea (Crustacea) in the California Current region, Part I.
No. 6. McGowan, J.A., 1967. Distributional atlas of pelagic molluscs in the California Current region.
No. 7. Fleminger, A., 1967. Distributional atlas of calanoid copepods in the California Current region, Part II.
No. 8. Berner, L.D., 1967. Distributional atlas of Thaliacea in the California Current region.
No. 9. Kramer, D., and E. H. Ahlstrom, 1968. Distributional atlas of fish larvae in the California Current region: Northern Anchovy, *Engraulis mordax* (Girard). 1951 through 1965.
No. 10. Isaacs, J. D., A. Fleminger and J. K. Miller, 1969. Distributional atlas of zooplankton biomass in the California Current region: Spring and Fall 1955-1959.
No. 11. Ahlstrom, E. H., 1969. Distributional atlas of fish larvae in the California Current region: jack mackerel, *Trachurus symmetricus,* and Pacific hake, *Merluccius productus,* 1951 through 1966.
No. 12. Kramer, D., 1970, Distributional atlas of fish eggs and larvae in the California Current region: Pacific sardine, *Sardinops caerulea* (Girard). 1951 through 1966.
No. 13. Smith, P. E., 1971. Distributional atlas of zooplankton volume in the California Current region, 1951 through 1966.
No. 14. Isaacs, J. D., A. Fleminger and J. K. Miller, 1971. Distributional atlas of zooplankton biomass in the California Current region: Winter 1955-1959.
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No. 16. Crowe, F. J. and R. A. Schwartzlose, 1972. Release and recovery records of drift bottles in the California Current region, 1955 through 1971.
No. 17. Ahlstrom, E. H., 1972. Distributional atlas of fish larvae in the California Current region: six common mesopelagic fishes—*Vinciguerria lucetia, Triphoturus mexicanus, Stenobrachius leucopsarus, Leuroglossus stilbius, Bathylagus wesethi* and *Bathylagus ochotensis.* 1955 through 1960.
No. 18. Brinton, E., 1973. Distributional atlas of Euphausiacea (Crustacea) in the California Current region. Part II.

No. 19. Bowman, T. E. and M. W. Johnson, 1973. Distributional atlas of calanoid copepods in the California Current region, 1949 and 1950.

No. 20. Thomas, W. H. and D. L. R. Seibert, 1974. Distribution of nitrate, nitrite, phosphate and silicate in the California Current region, 1969.

Owen, R. W., Jr., 1974. Distribution of primary production, plant pigments and Secchi depth in the California Current region, 1969.

Smith, P. E., 1974. Distribution of zooplankton volumes in the California Current region, 1969.

[1] Usually abbreviated CalCOFI, sometimes CALCOFI or CCOFI.

[2] Formerly called U.S. Fish and Wildlife Service, Bureau of Commercial Fisheries.

[3] For citation this issue in the series should be referred to as CalCOFI Atlas No. 20.

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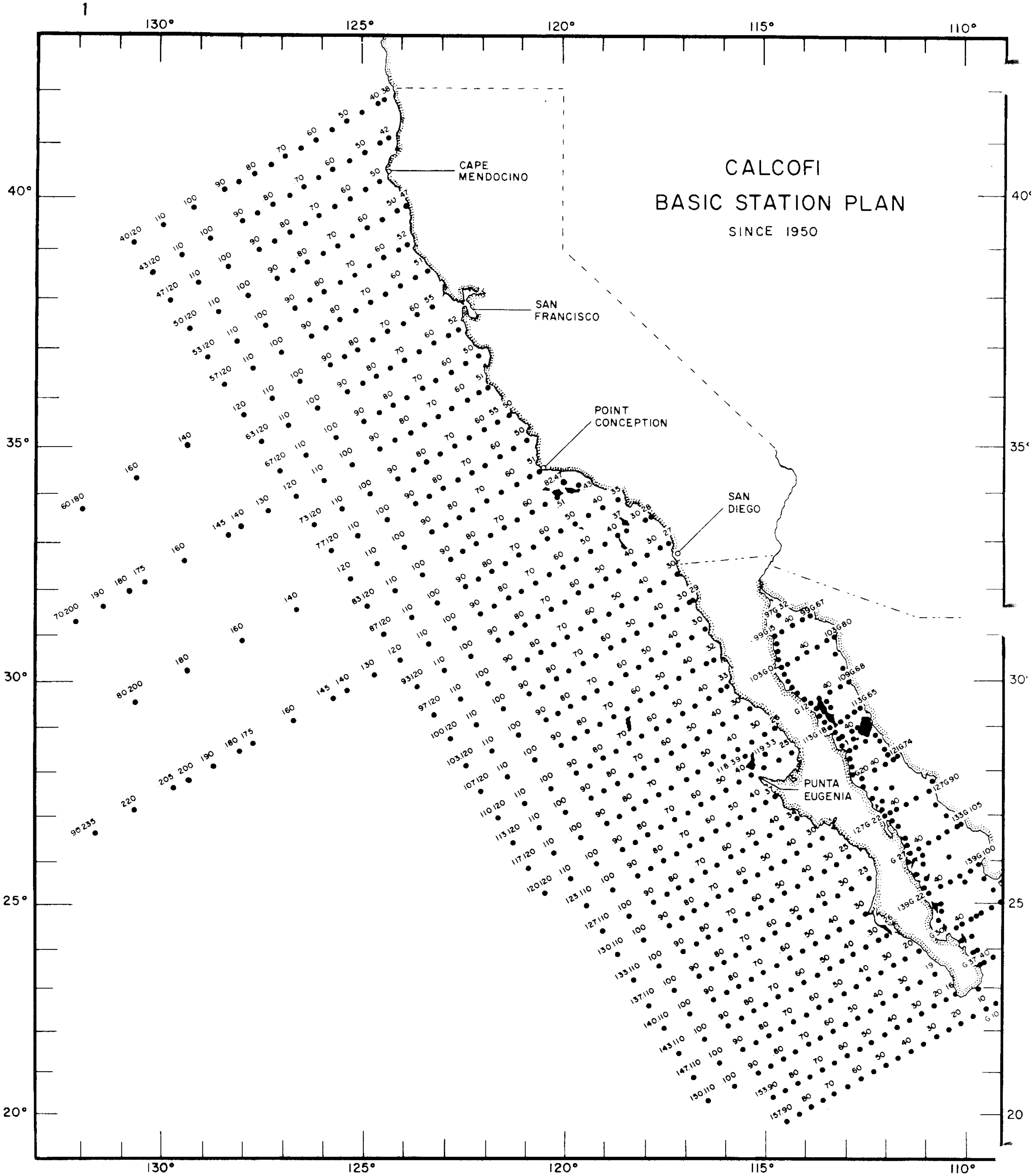

CALCOFI

BASIC STATION PLAN
SINCE 1950

CONTENTS

CalCOFI Atlas No. 20
A. Fleminger and J. G. Wyllie, Editors
Data Collection and Processing Group
Marine Life Research Program
Scripps Institution of Oceanography
La Jolla, California
June, 1974

DISTRIBUTION OF NITRATE, NITRITE, PHOSPHATE AND SILICATE IN THE CALIFORNIA CURRENT REGION, 1969

W. H. Thomas and D. L. R. Seibert[1]

Text

Charts

Introduction

Nutrient levels are important in controlling the productivity of phytoplankton in the sea and in turn the other biota that are dependent on phytoplankton as a food source. Coastal regions where nutrient concentrations are high are areas of major fishing activity. An example is the Peru Current where nutrient replenishment due to widespread upwelling supports the worlds largest fishery.

In the California Current region thousands of nutrient determinations have been made since the CalCOFI program commenced in 1949. Sources of data on nutrient concentrations off California prior to 1969 are summarized in Table 1.

Phosphate data are abundant for the years 1949 to 1951 and moderately so for 1955. However, for nearly all years from 1951 to 1960, no nutrient data were collected by CalCOFI cruises. In 1961, the collecting of chemical data increased with the advent of newer, more reliable methods of analysis, and other nutrients in addition to phosphate were measured. In 1964 to 1966, five nutrients were analyzed during an extensive series of cruises carried out off southern Baja California by the Scripps Tuna Oceanography Research (STOR) project. Chemical nutrients were not measured by the CalCOFI program in 1966 and 1967, but the Food Chain Research Group (FCRG) of the Institute of Marine Resources carried out an extensive time series of analyses at three nearshore stations off La Jolla. Other nearshore data are available for 1959 and 1960.

In 1969 nutrient measurements off California was greatly expanded. A more complete suite of nutrients was analyzed and measurements were obtained in almost every month of the year. It is especially useful that one of the principal nitrogen sources, nitrate, was measured since it has been shown to limit phytoplankton production off Baja California and southern California (Thomas, 1969; Thomas et al, 1974).

In this atlas we present charts of the horizontal distribution of major phytoplankton nutrients, nitrate, nitrite, phosphate and silicate in the California Current region during 1969.

1. Scripps Tuna Oceanography Research Program
Institute of Marine Resources
Scripps Institution of Oceanography, La Jolla, California.

TABLE 1. SOURCES OF NUTRIENT DATA OFF CALIFORNIA AND BAJA CALIFORNIA, 1949-1968

Date	Cruise	Nutrients Analyzed	Remarks:	References
1949	CCOFI	PO_4-P	Nutrient data available from many stations. Seasonal coverage.	Rakestraw et al. (1957)
1950	CCOFI	PO_4-P	Nutrient data available from many stations. Seasonal coverage.	Rakestraw et al. (1960)
1951	CCOFI	PO_4-P	Nutrient data available from many stations. Seasonal coverage.	Reid et al. (1963 a)
1953	Transpac	PO_4-P SiO_3-Si	1 station within California Current Area	Reid et al. (1965 a)
1955	NORPAC	PO_4-P SiO_3-Si	Moderate number of stations	Rakestraw et al. Norpac (1960)
1956	SCOPE	PO_4-P NO_2-N	1 station off southern Baja California	Reid et al. (1963 b)
1959	STOR TO59-1	PO_4-P	3 stations off southern Baja California	Reid et al. (1965 b)
1959	Allan Hancock Foundation	PO_4-P SiO_3-Si	Nearshore surface stations in Southern California Bight, October-November	Chambers (1965)
1960	Allan Hancock Foundation	PO_4-P SiO_3-Si	Nearshore surface stations in Southern California Bight, April	Chambers (1965)
1961	CCOFI 6107-8	PO_4-P SiO_3-Si NO_2-N	Nutrient data available from many stations in July and August	Anon., SIO Ref. 62-16 (1962)
1962	CCOFI 6210-11	PO_4-P SiO_3-Si NO_2-N	Nutrient data available from many stations in October and November	Anon., SIO Ref. 63-25 (1963 a)
1963	CCOFI 6301-2, 6304, 6311	PO_4-P SiO_3-Si NO_2-N	Nutrient data available from many stations in January, February, April, May, November, December (latter 2 months with only a few nearshore stations off southern Baja California)	Anon., SIO Ref. 64-2 (1963 b) Anon., SIO Ref. 64-13 (1964 a) Anon., SIO Ref. 65-1 (1964 b)
1964	CCOFI 6401, 6404, 6407	PO_4-P SiO_3-Si NO_2-N	Nutrient data available from many stations in January, February, March, April, July	Anon., SIO Ref. 65-7 (1965 a) Anon., SIO Ref. 66-20 (1966)
	STOR TO-64-1 TO-64-2	PO_4-P SiO_3-Si NO_2-N NO_3-N NH_4-N	Nutrient data available from many stations off southern Baja California in June and August	Anon., SIO Ref. 69-4 (1969) IMR Ref. 69-8
1965	CCOFI 6501, 6504, 6507	PO_4-P SiO_3-Si NO_2-N	Nutrient data available for many stations in January, February, March, April, June, July, August	Anon., SIO Ref. 66-4 (1965 b) Anon., SIO Ref. 67-16(1967 a) Anon., SIO Ref. 67-17 (1967 b)
	STOR TO-65-1	PO_4-P SiO_3-Si NO_2-N NO_3-N NH_4-N	Many stations off southern Baja California in September	Thomas (Unpublished data)
1966	STOR TO-66-1	PO_4-P SiO_3-Si NO_2-N NO_3-N NH_4-N	Many stations off southern Baja California in November	Thomas (Unpublished data)
1967	FCRG	PO_4-P SiO_3-Si NO_2-N NO_3-N	3 stations off La Jolla occupied weekly for 5-month period April-September	Strickland (1968)
1968	CCOFI 6804, 6806	PO_4-P SiO_3-Si NO_2-N NO_3-N	Nutrient data available for many stations in April, May, June	Anon., SIO-Ref. 71-3 (1971)

Methods

Water samples were collected by Nansen bottles or with a Niskin sampler. Hydrographic casts to 1000 meters were made at selected stations. The data from these stations were used for estimating the abundance of nutrients in the upper 50 meters, by integration, and for the distribution at 100 meters. In addition to the hydrographic stations intermediate positions were sampled at 10-meter depths.

Most of the samples were analyzed immediately after collection by means of the autoanalyzer technique (Strickland and Parsons, 1968). The limits of detection of nitrate, nitrite, phosphate and silicate using these procedures are 0.1, 0.01, 0.03 and 0.1 μg-atoms/liter respectively. In the lattermost cruises of 1969 samples were frozen and processed ashore using the autoanalyzer.

Integration of the data from 0 to 50 meters and the plotting of the 10 meter, 100 meter and intergrated values was carried out with the aid of a CDC 3600 computer; contours were fitted by eye.

10 Meter Nutrients

To illustrate near-surface mixed layer nutrient distributions charts are presented showing contoured values from a depth of 10 meters. Especially high nutrient values were found during periods of seasonal upwelling along the central California coast, Point Conception, Punta Eugenia and Punta Abreojos. Generally lower values were found farther offshore.

Nutrients Integrated 0 - 50 Meters

These data provide a general idea of the nutrients available to phytoplankton in the euphotic zone. Their distributions are similiar to those at 10 meters.

100 Meter Nutrients

These charts show the distribution below the mixed layer. They may vary more due to physical than to biological processes. The distributions show the nutrient levels that might enter the euphotic zone as a result of upwelling or vertical mixing.

Acknowledgements

Technicians of the Data Collecting and Processing Group, Marine Life Research Program, Scripps Institution of Oceanography were responsible for collecting and analyzing the samples and for computing the results. The preparation of these charts was partially supported by the Oceanography Program, National Science Foundation, Grant GA32529X.

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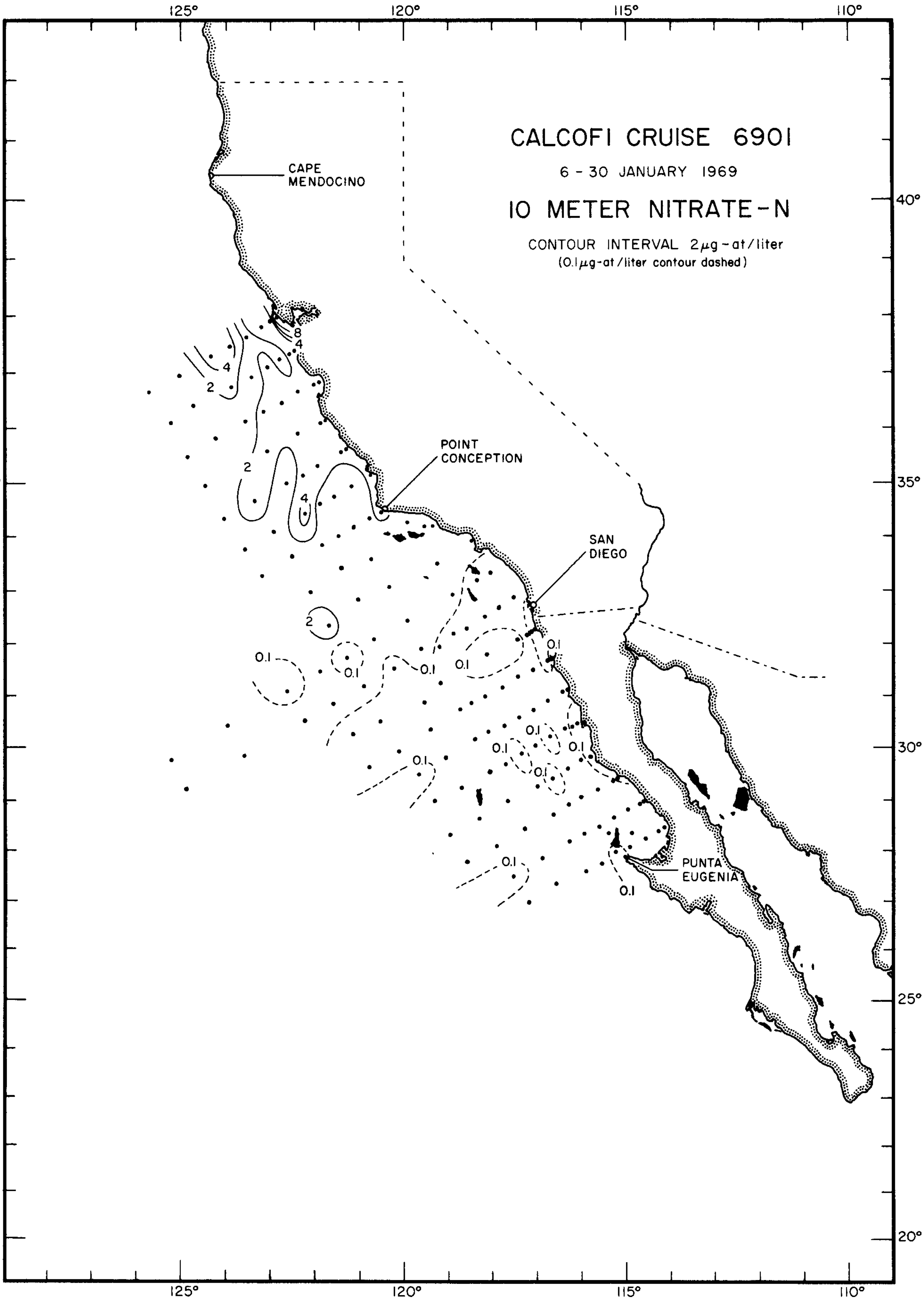

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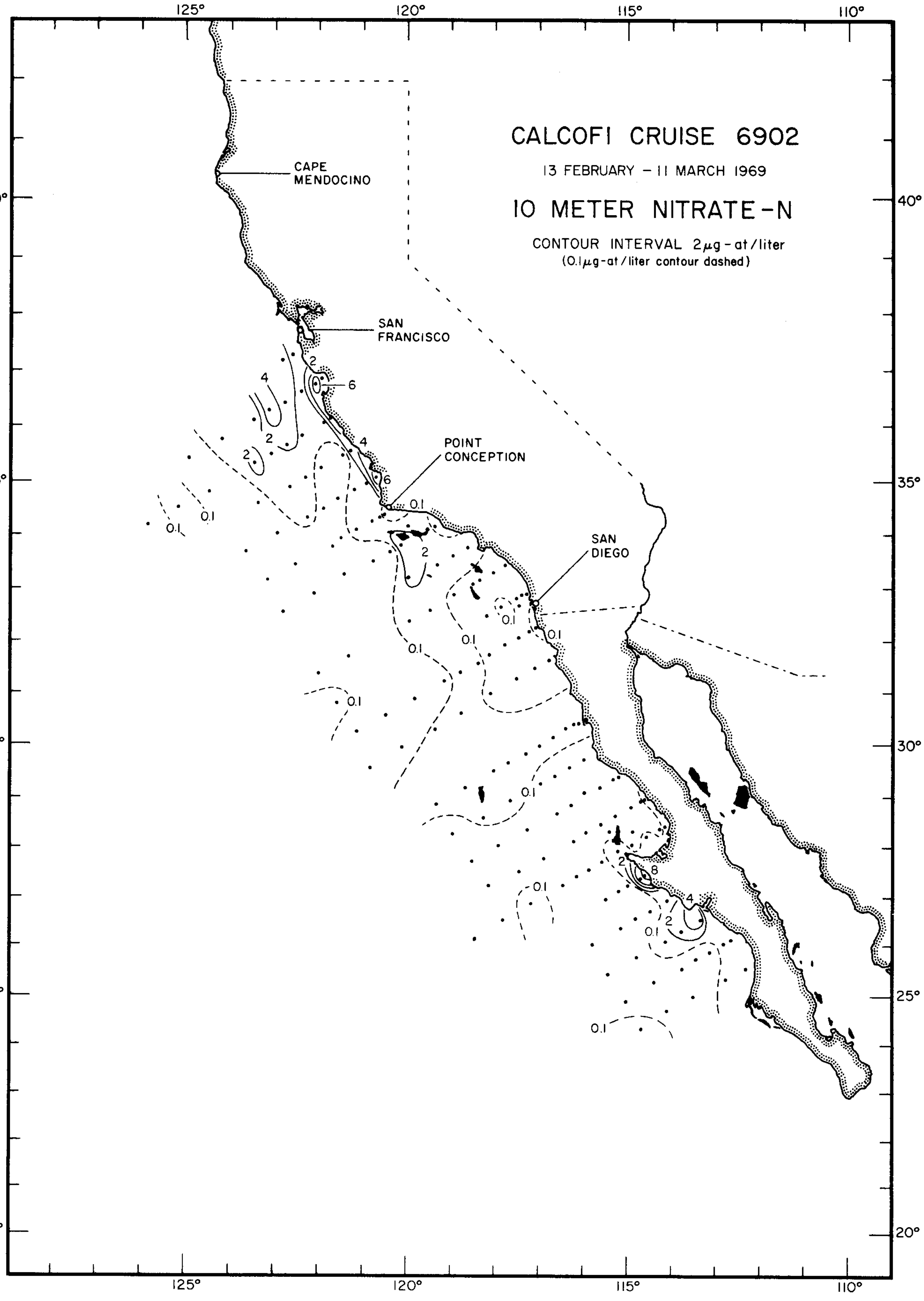

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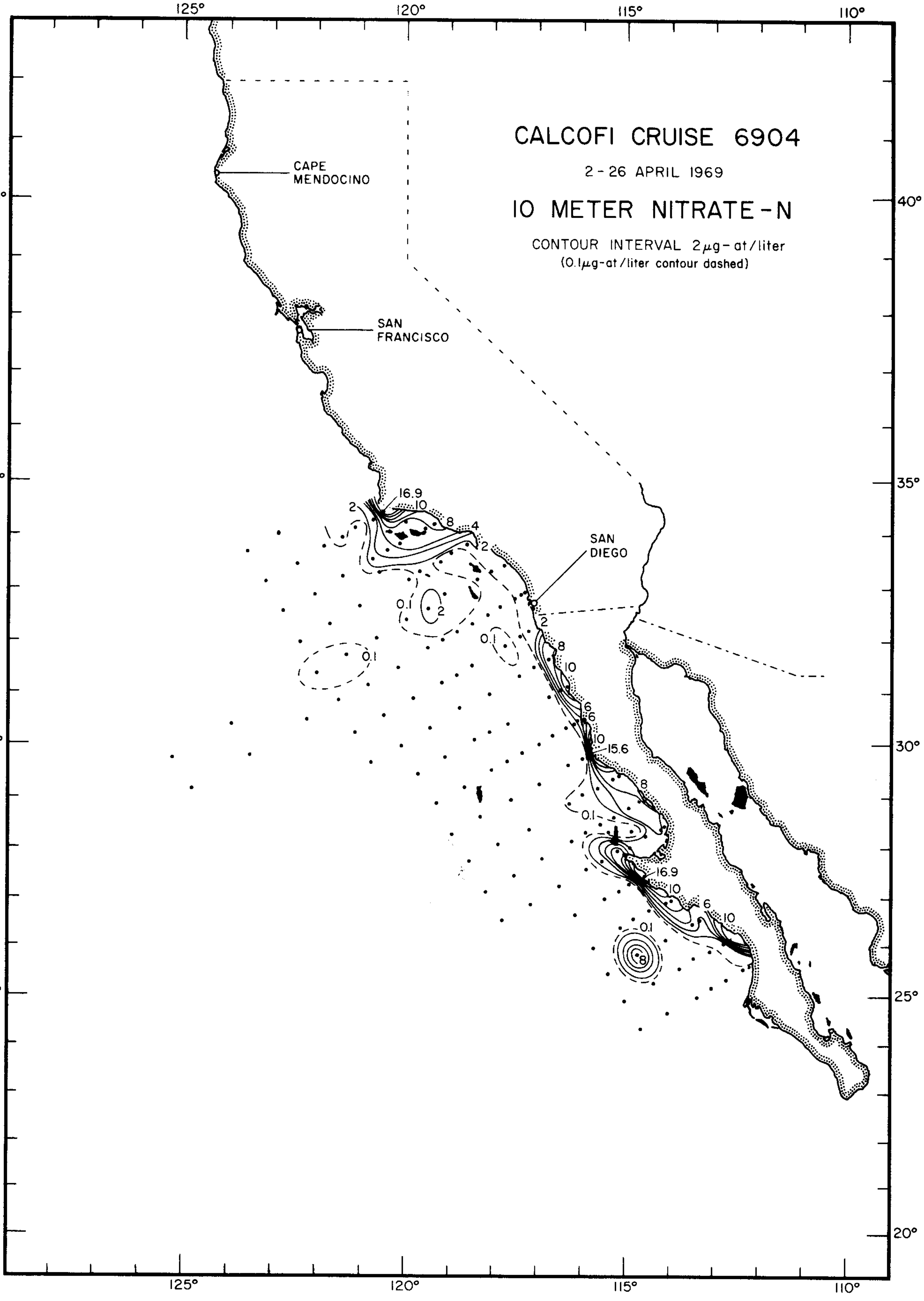

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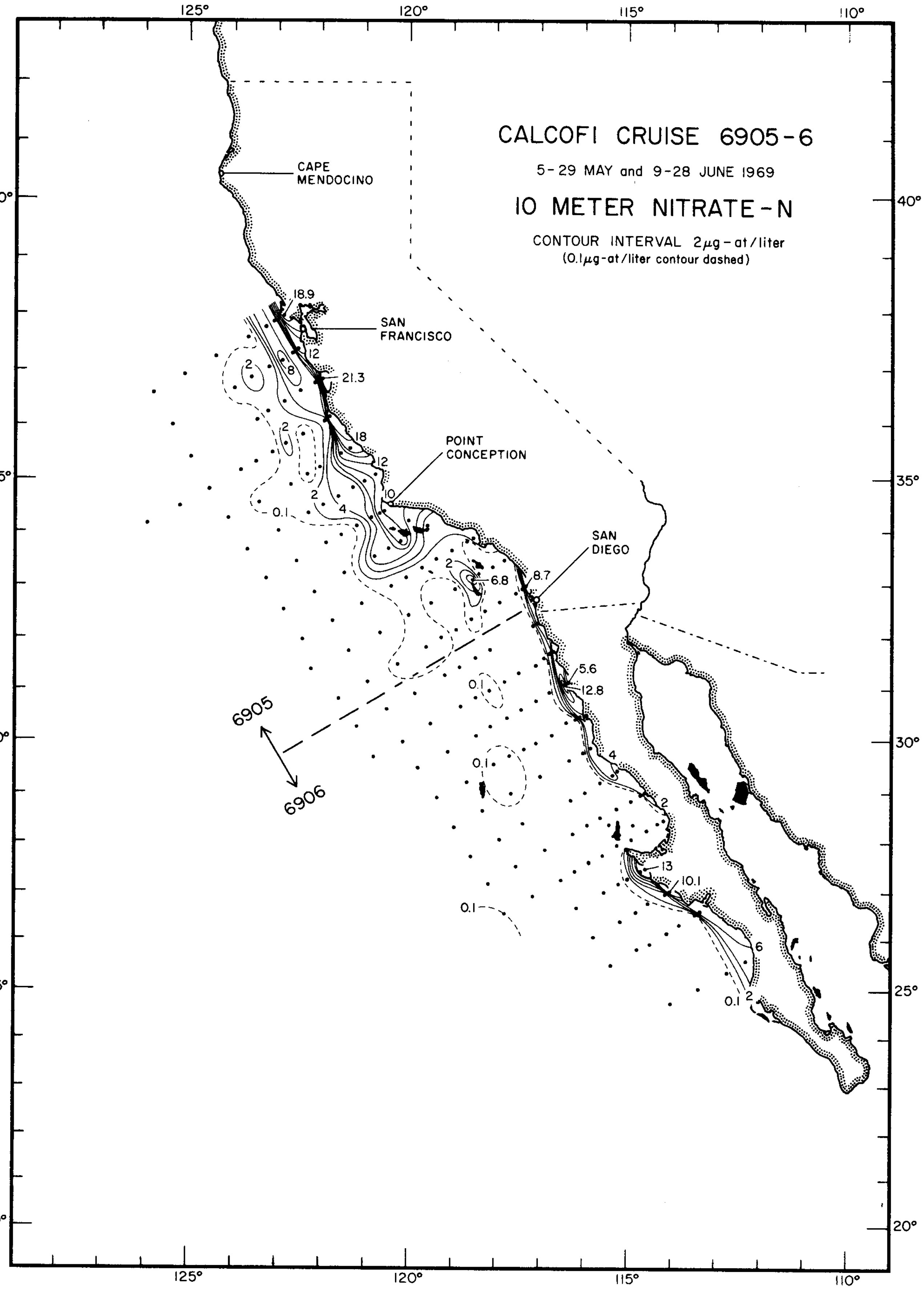

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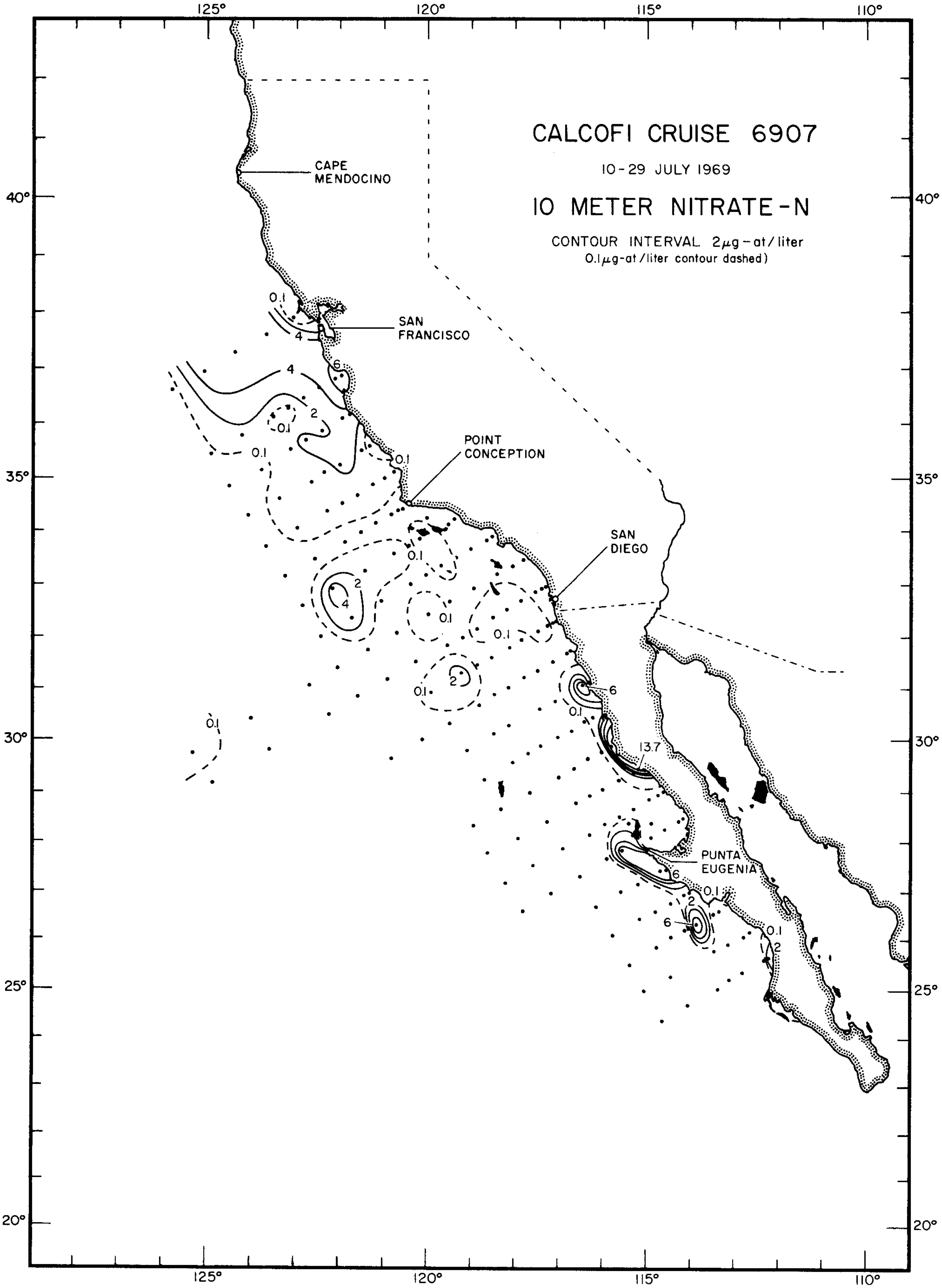

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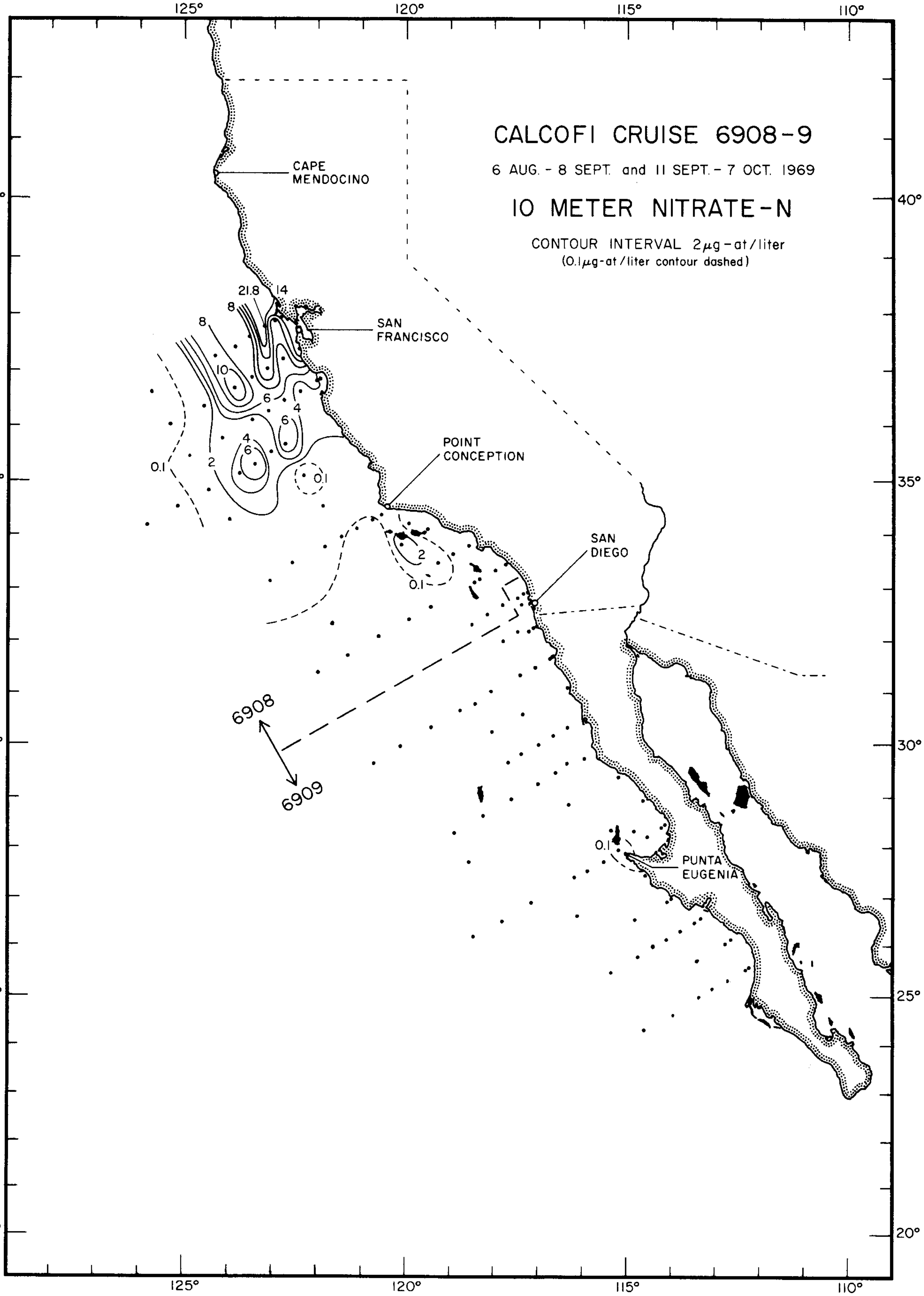
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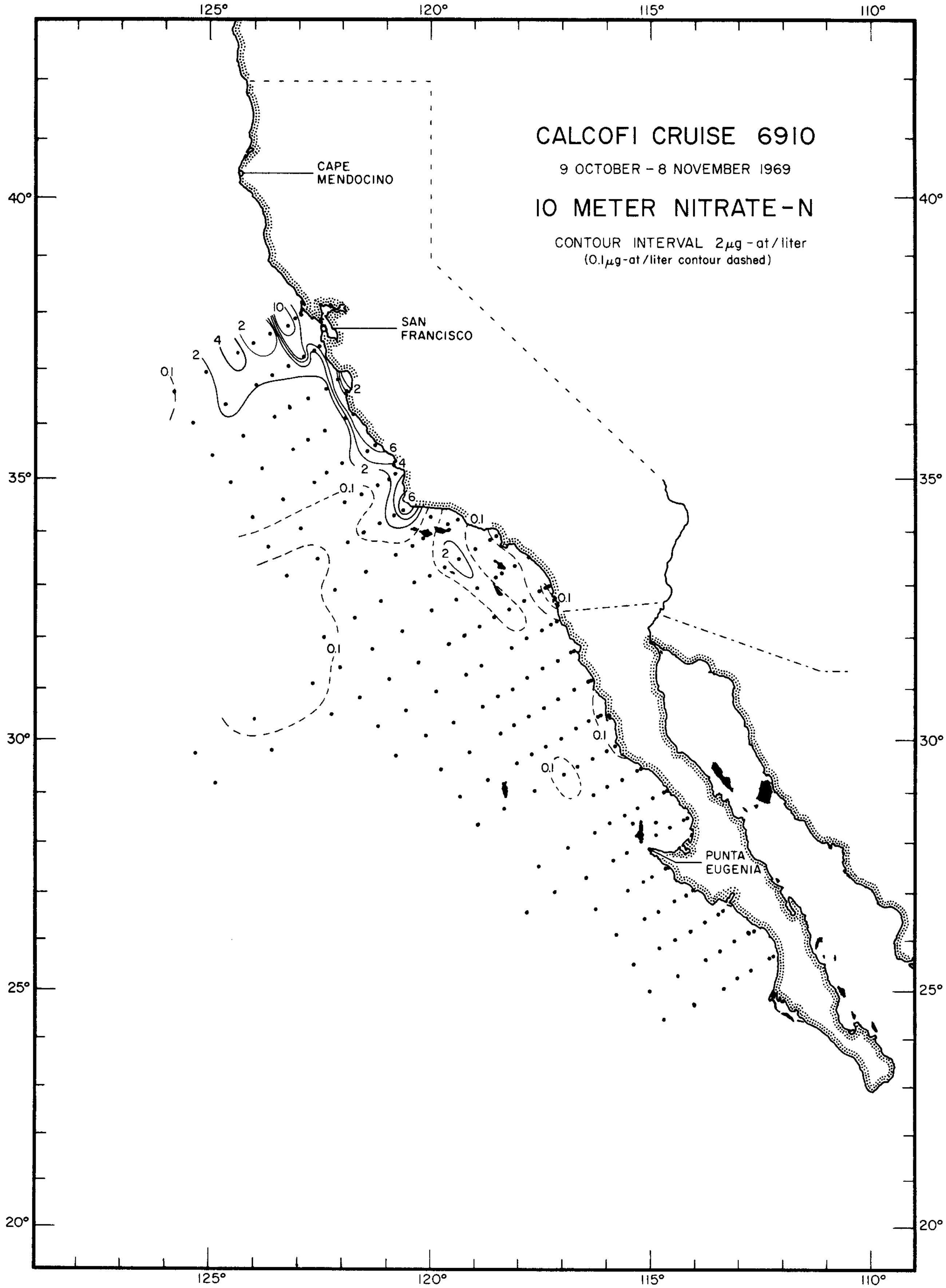
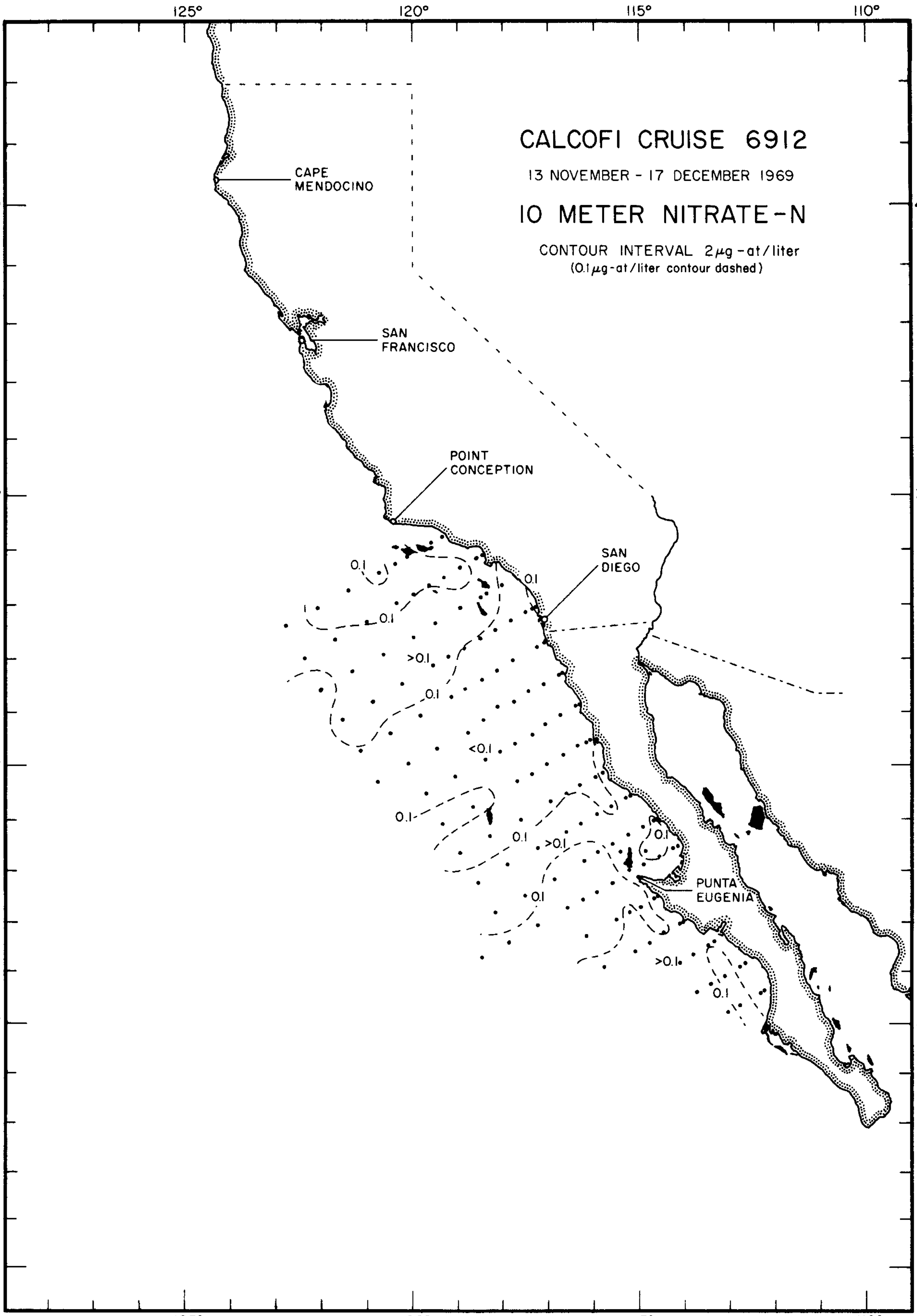
6 AUG. - 8 SEPT. and 11 SEPT. - 7 OCT. 1969
10 METER NITRATE-N
CONTOUR INTERVAL 2μg-at/liter
(0.1μg-at/liter contour dashed)
CAPE MENDOCINO
SAN FRANCISCO
POINT CONCEPTION
SAN DIEGO
PUNTA EUGENIA
6908
6909
125°
120°
115°
110°
40°
35°
30°
25°
20°

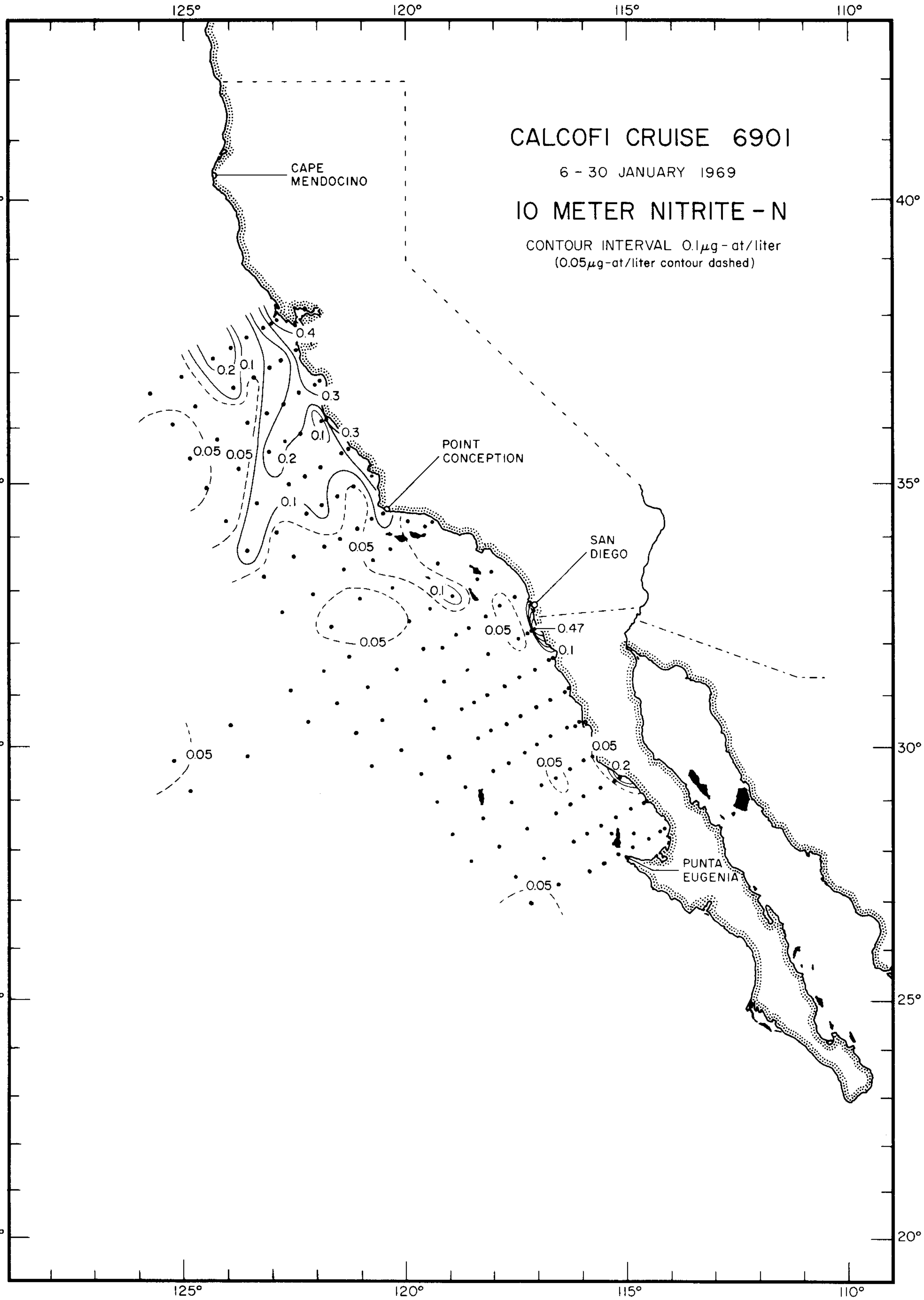


10m NITRATE-N

6910



CALCOFI CRUISE 6912
13 NOVEMBER - 17 DECEMBER 1969
10 METER NITRATE-N
CONTOUR INTERVAL 2µg-at/liter
(0.1µg-at/liter contour dashed)
CAPE MENDOCINO
SAN FRANCISCO
POINT CONCEPTION
SAN DIEGO
PUNTA EUGENIA
125°
120°
115°
110°
40°
35°
30°
25°
20°
0.1
>0.1
<0.1


CALCOFI CRUISE 6901
6 - 30 JANUARY 1969
10 METER NITRITE - N
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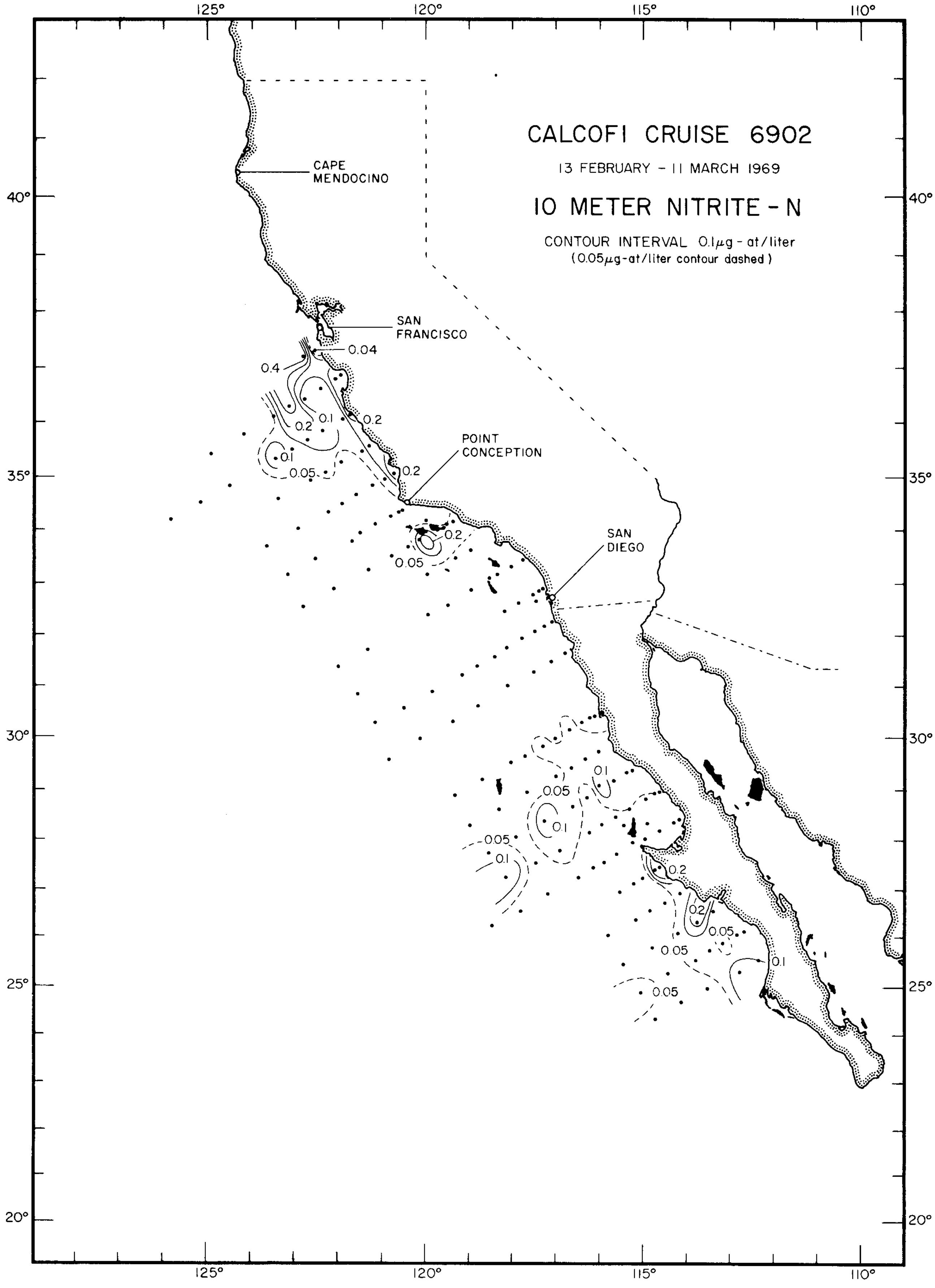
(0.05μg-at/liter contour dashed)
CAPE MENDOCINO
POINT CONCEPTION
SAN DIEGO
PUNTA EUGENIA
125°
120°
115°
110°
40°
35°
30°
25°
20°
0.4
0.3
0.2
0.1
0.05
0.47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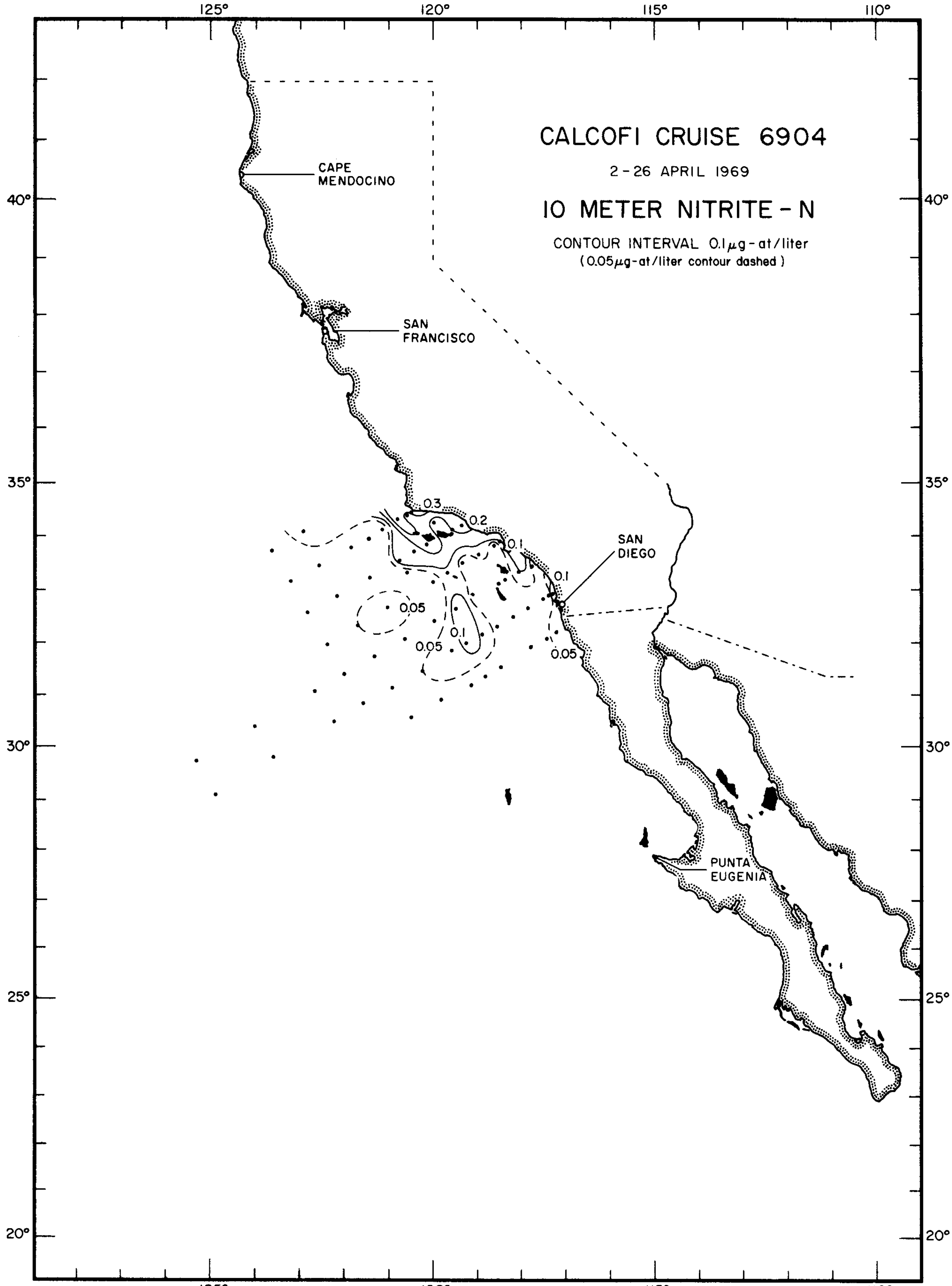
10 METER NITRITE-N
CONTOUR INTERVAL 0.1μg-at/liter
(0.05μg-at/liter contour dashed)
CAPE MENDOCINO
SAN FRANCISCO
POINT CONCEPTION
SAN DIEGO
0.04
0.4
0.1
0.2
0.05
125°
120°
115°
110°
40°
35°
30°
25°
20°



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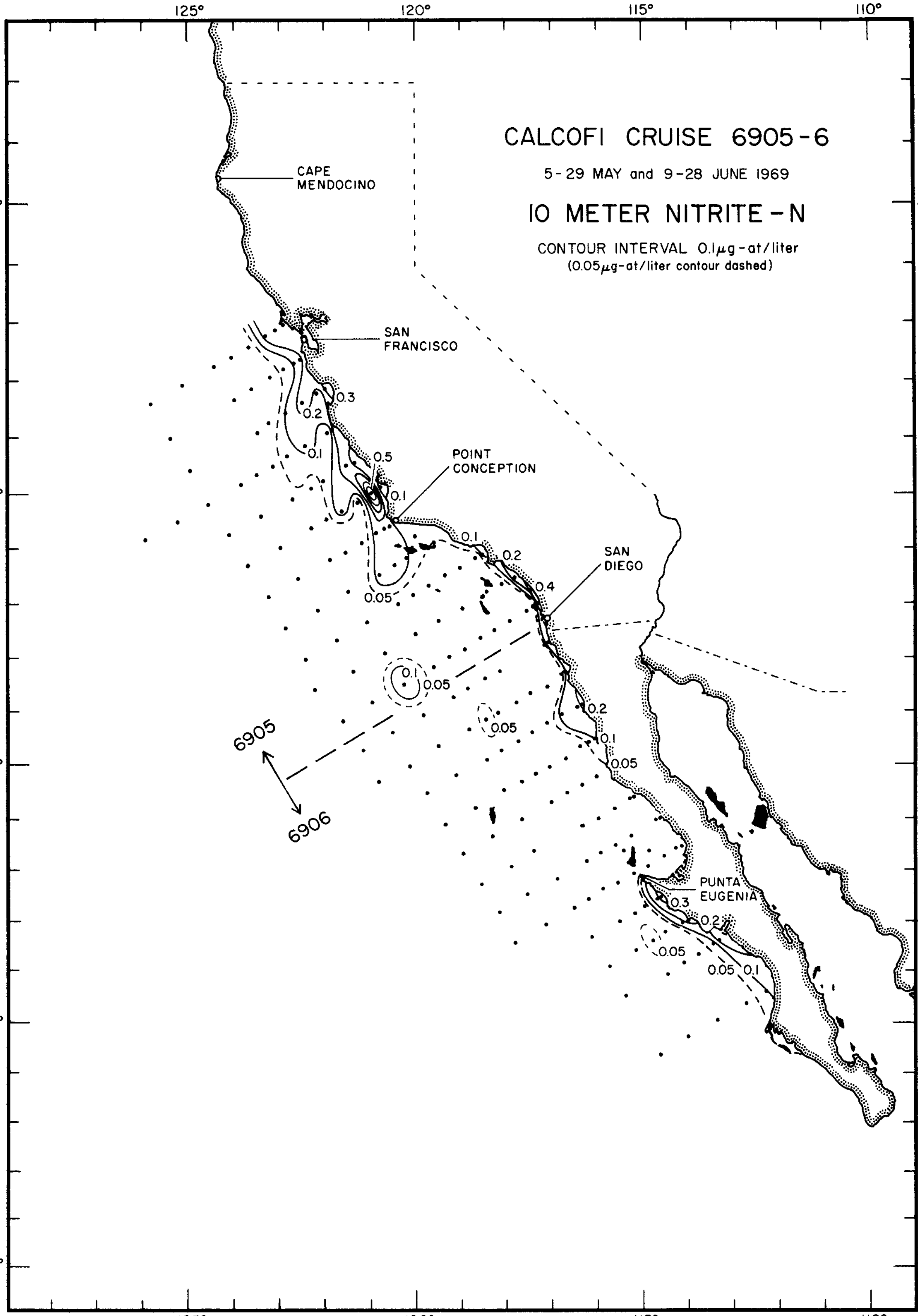

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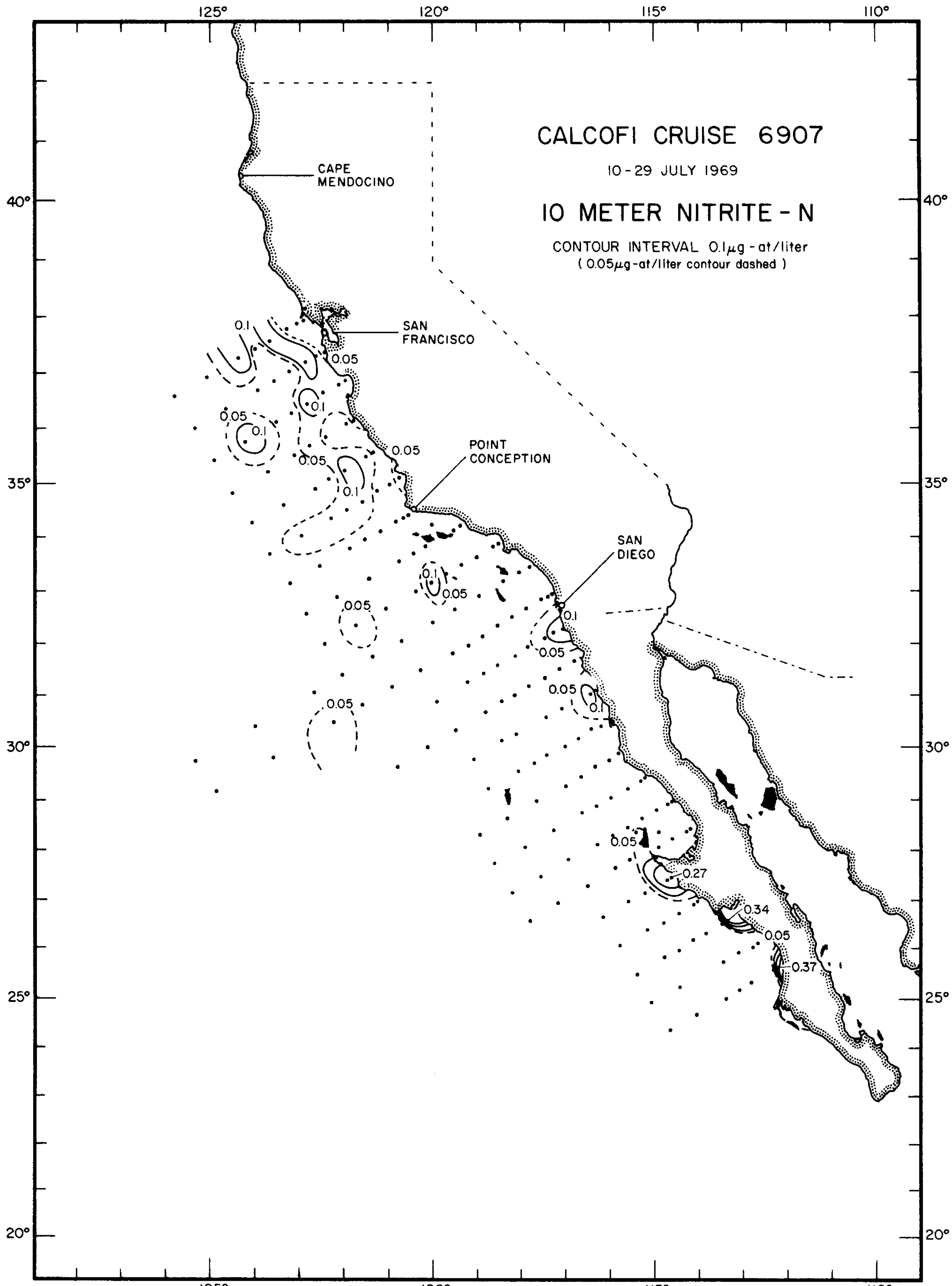
6905-6



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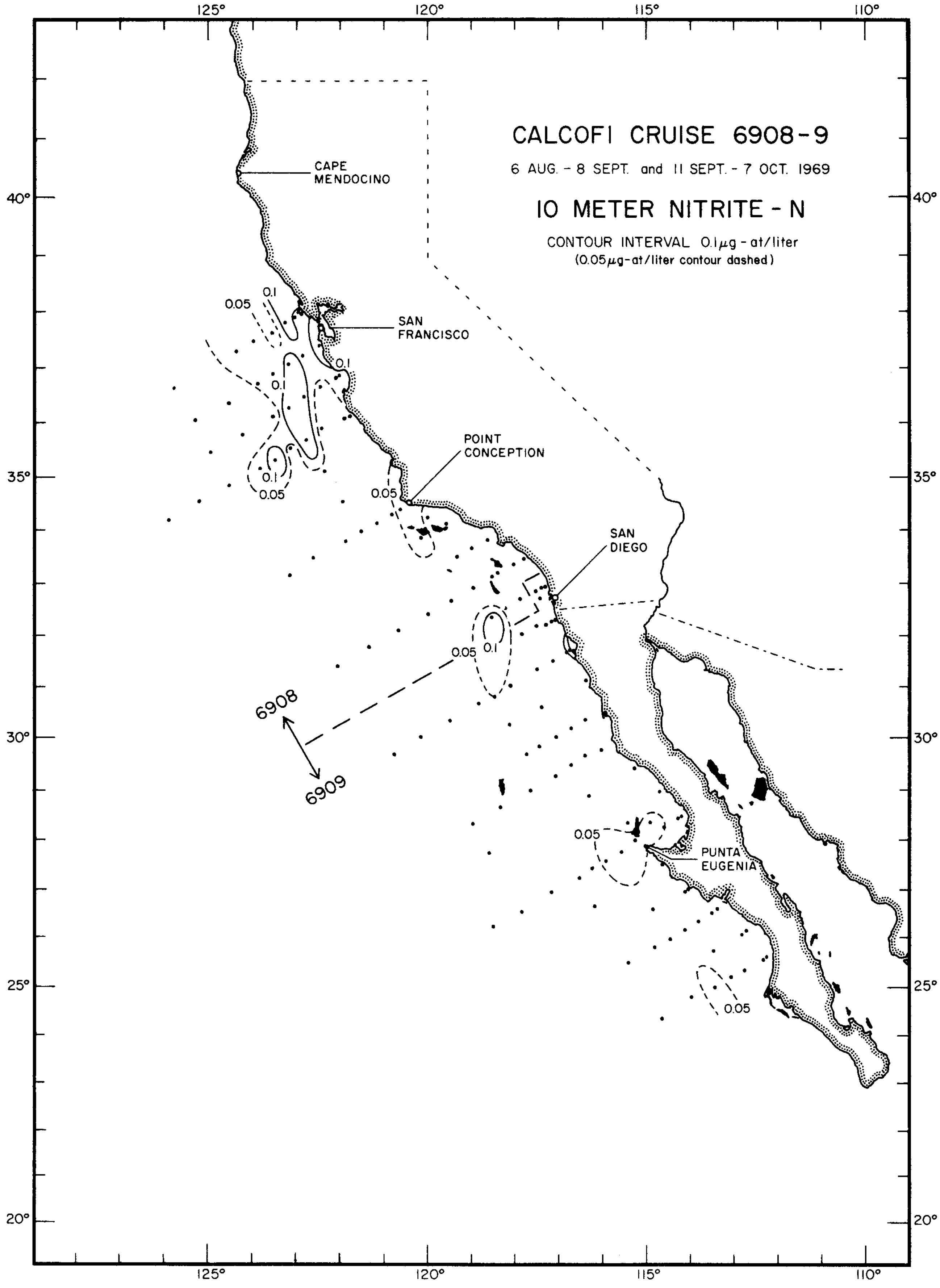

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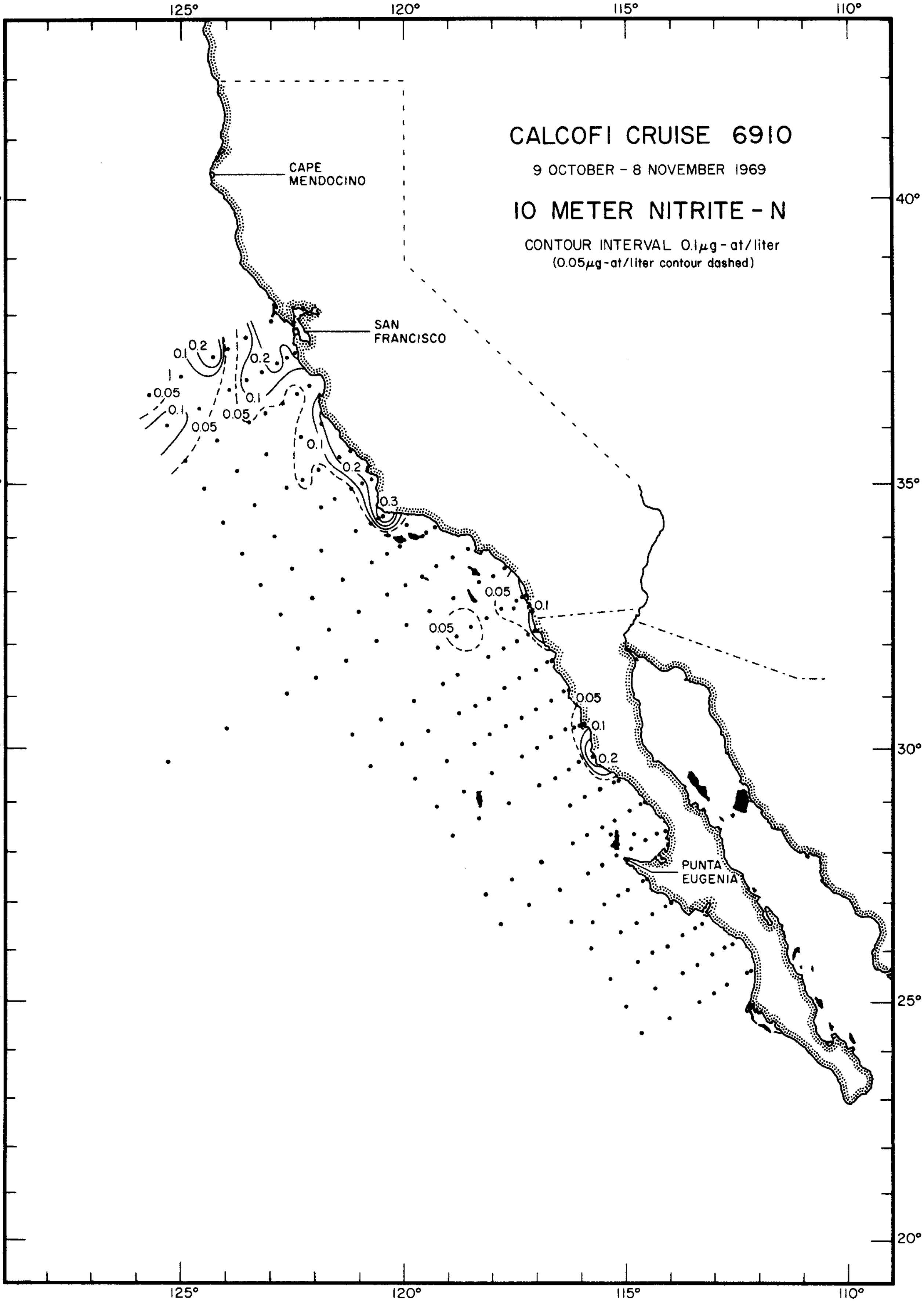

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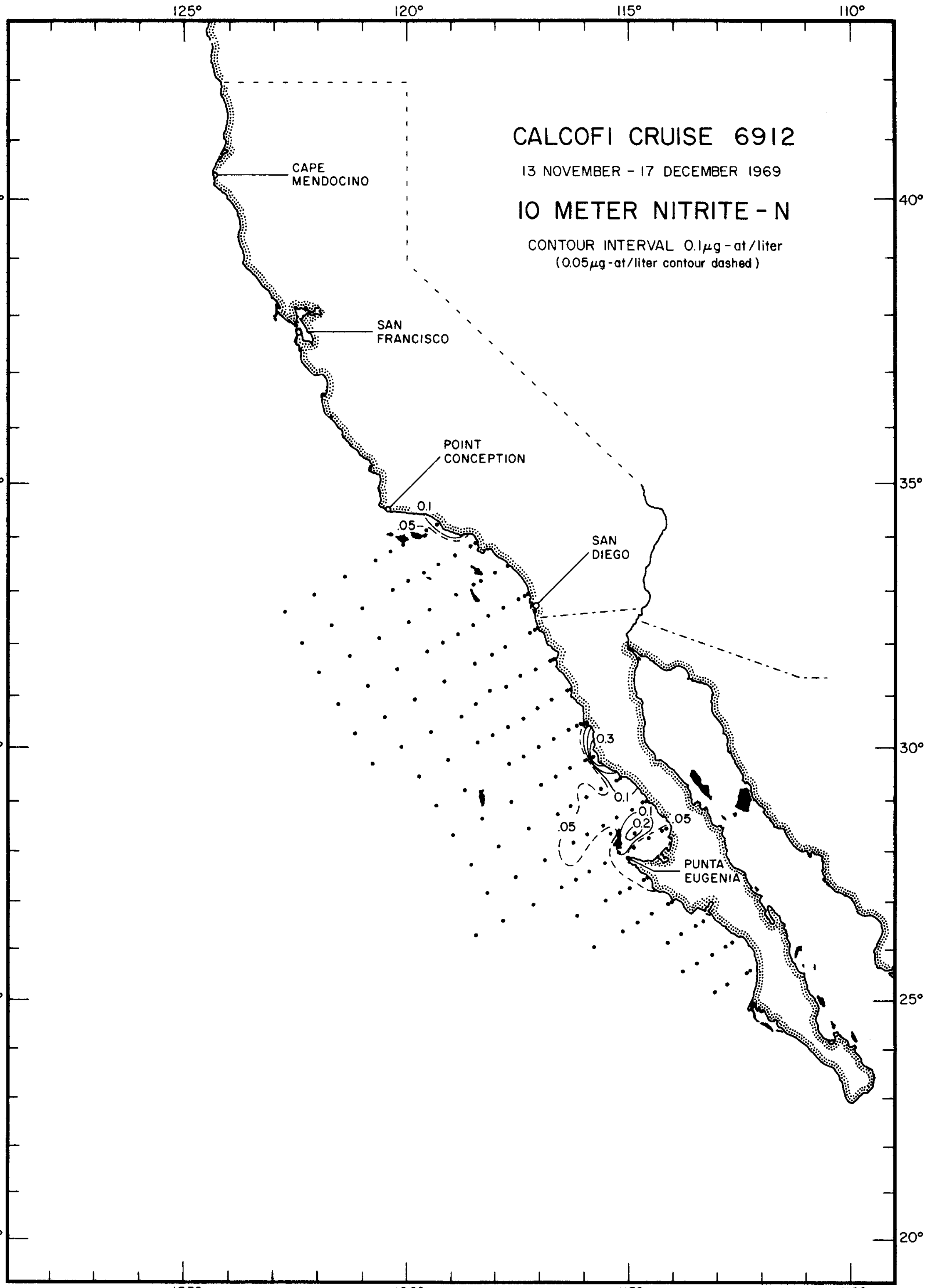

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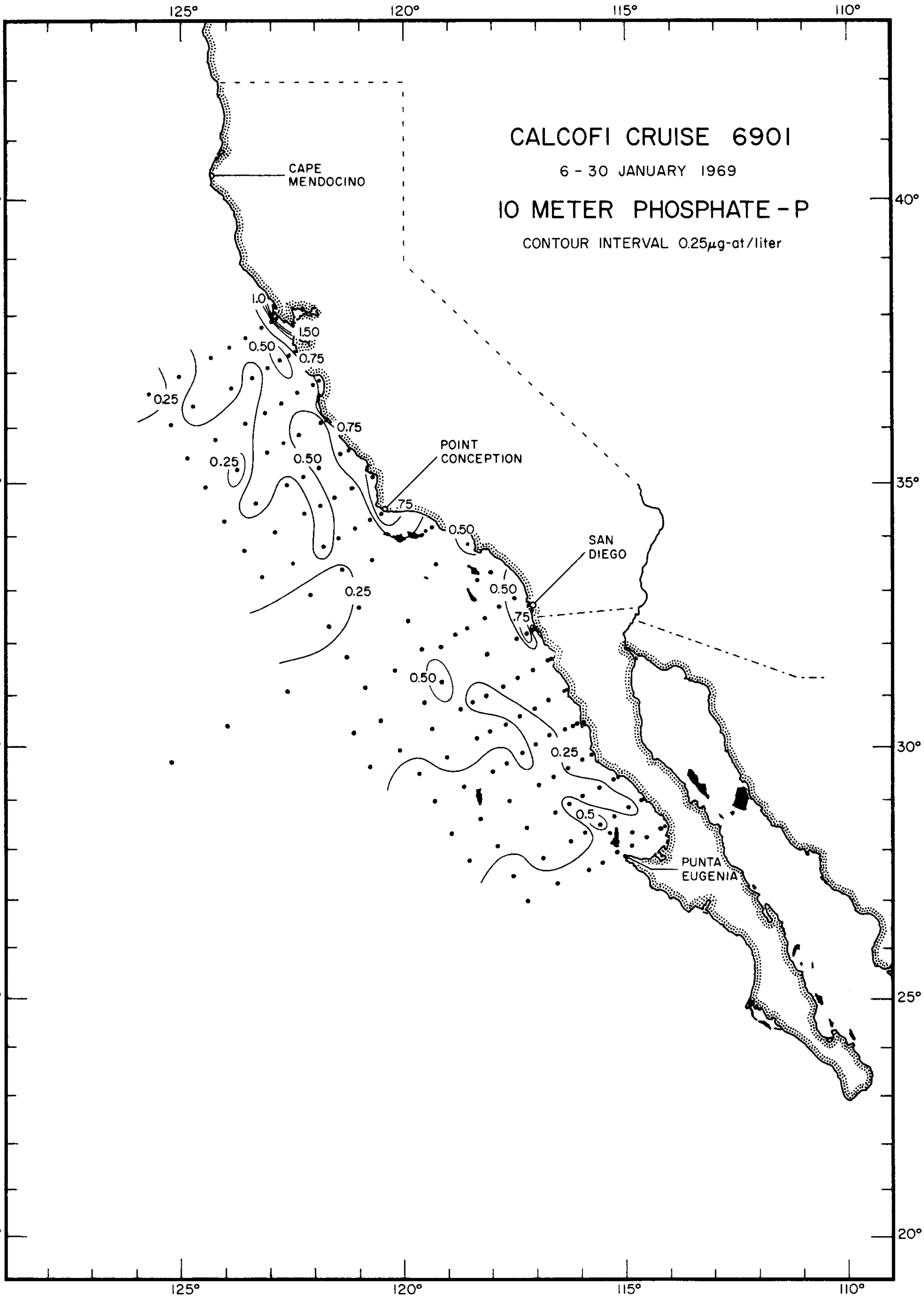

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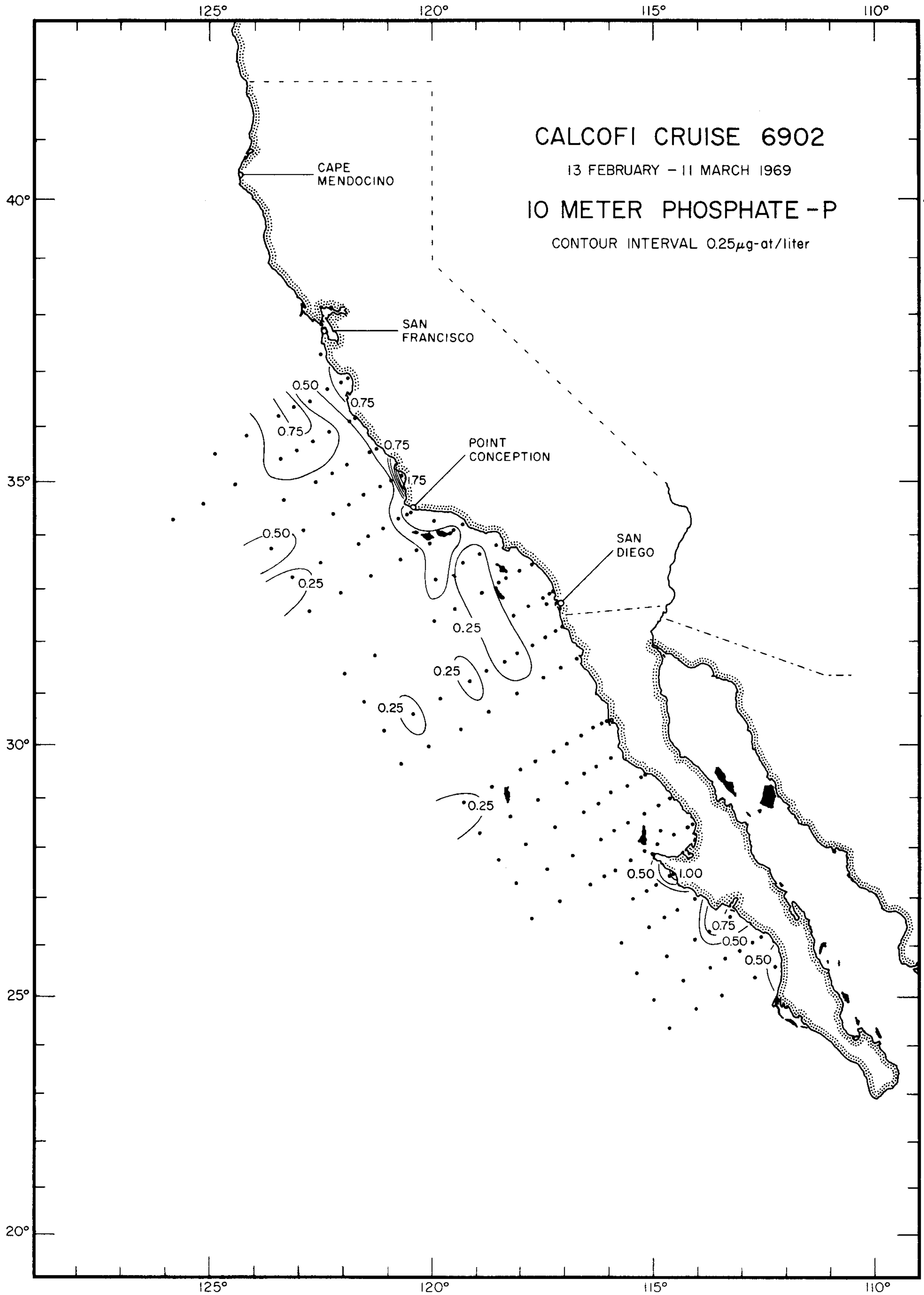

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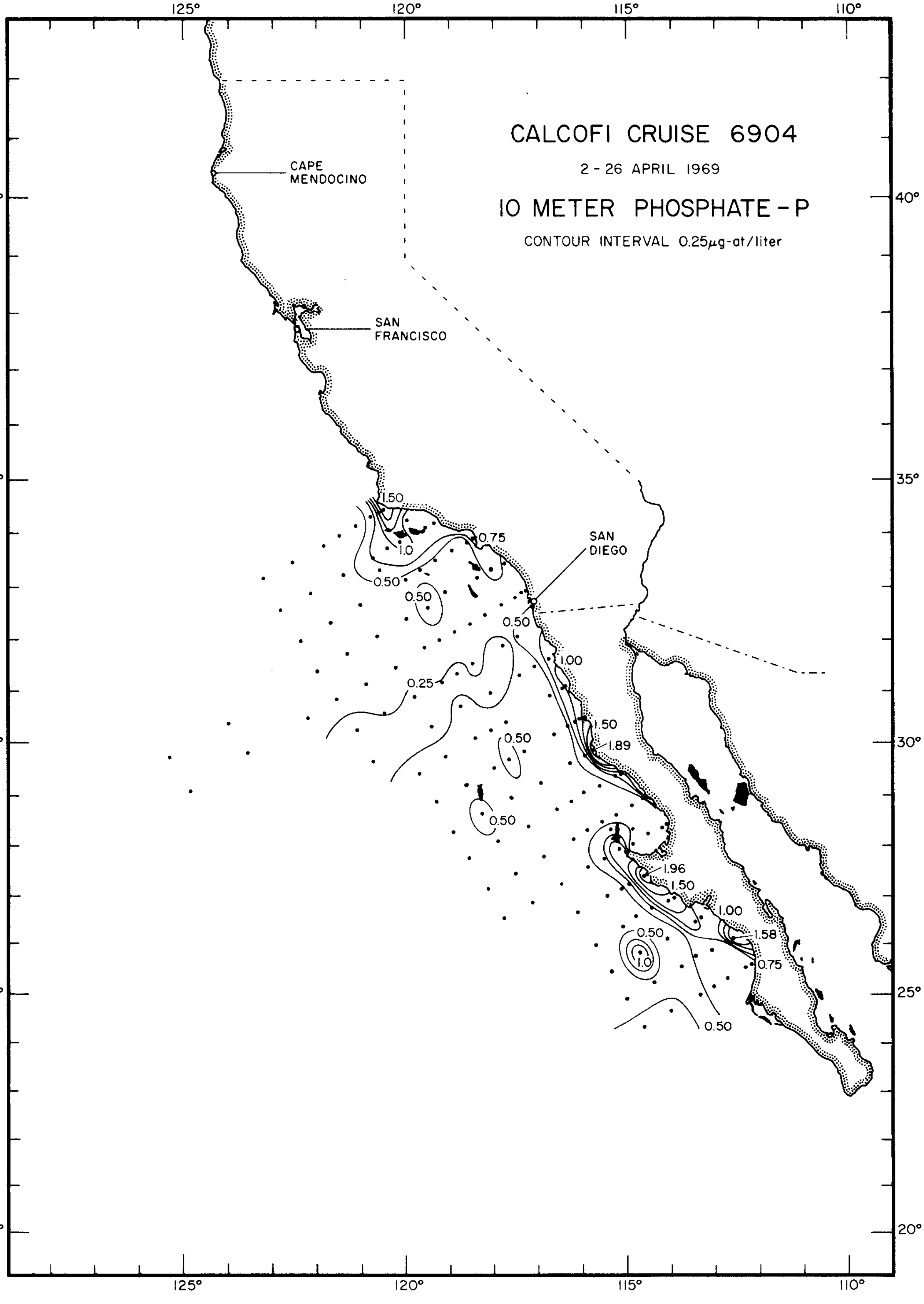

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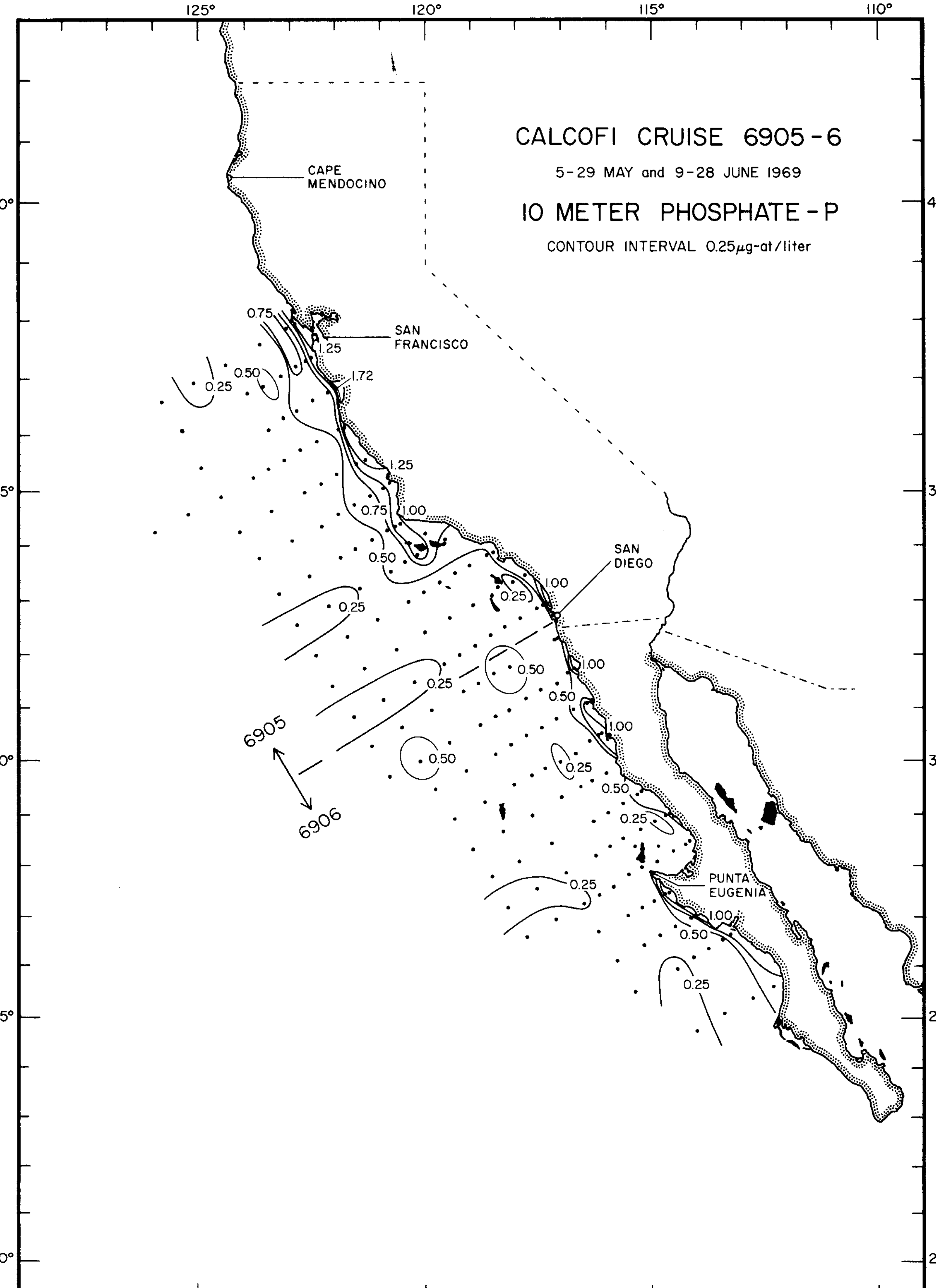

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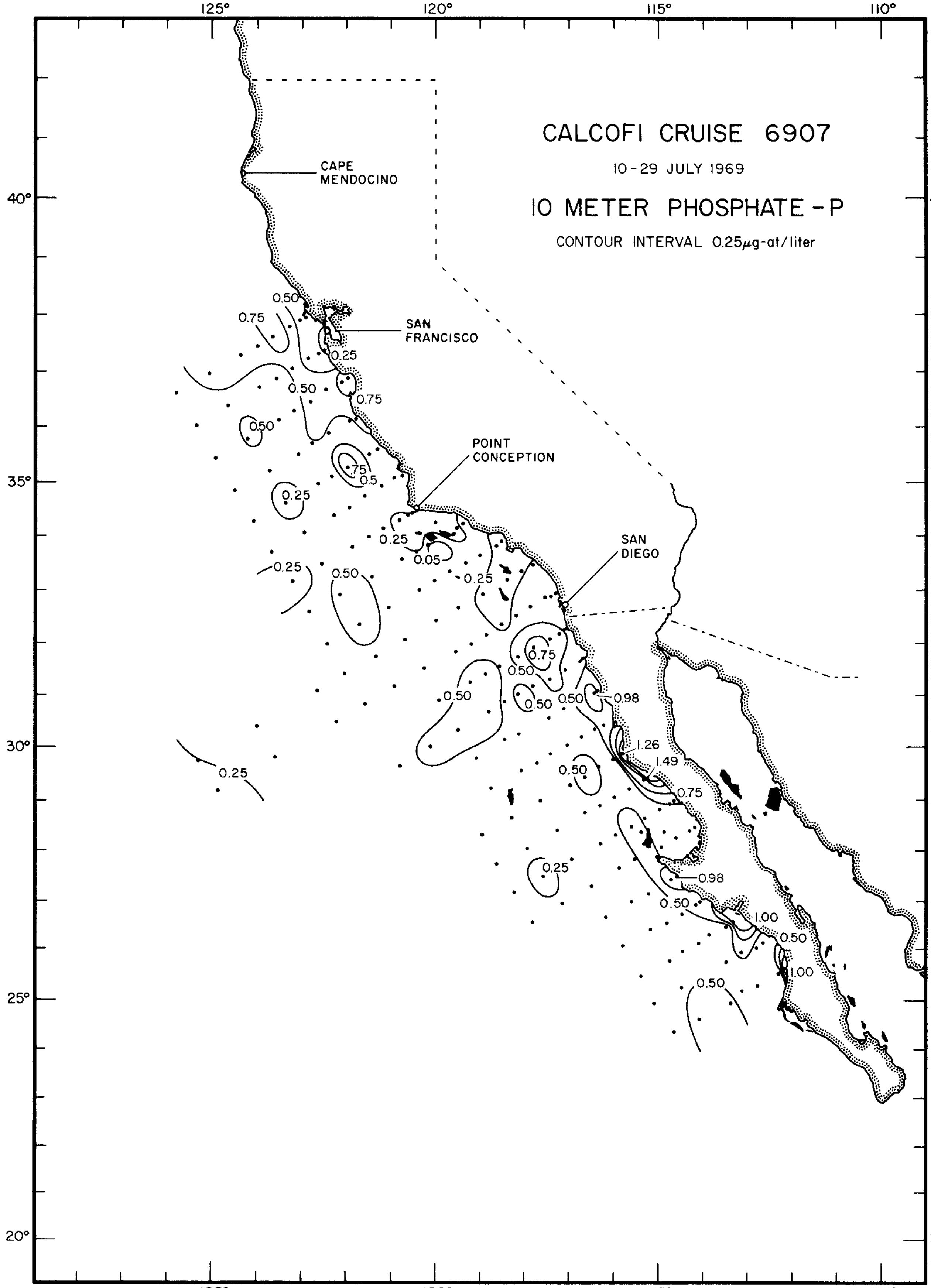

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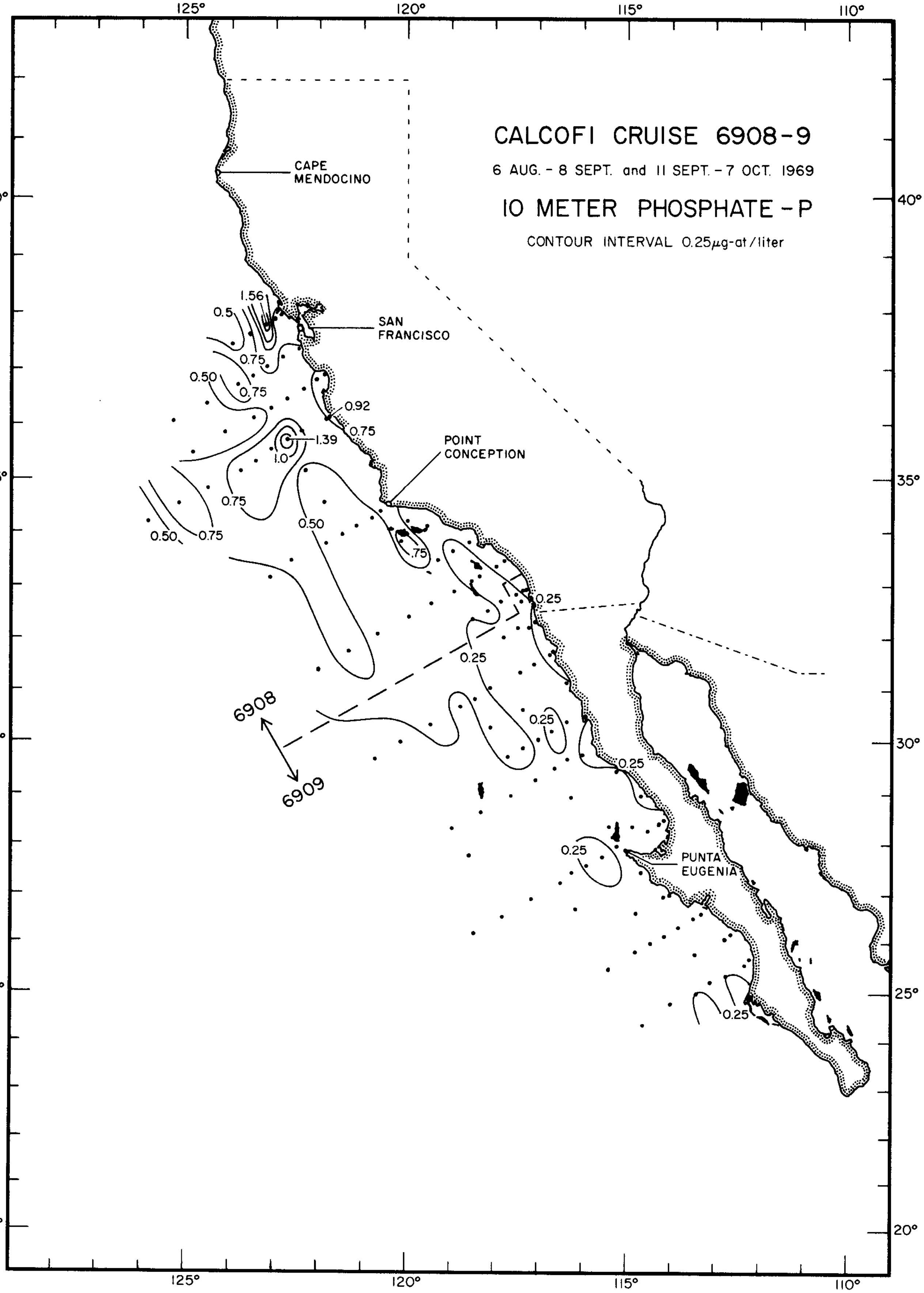
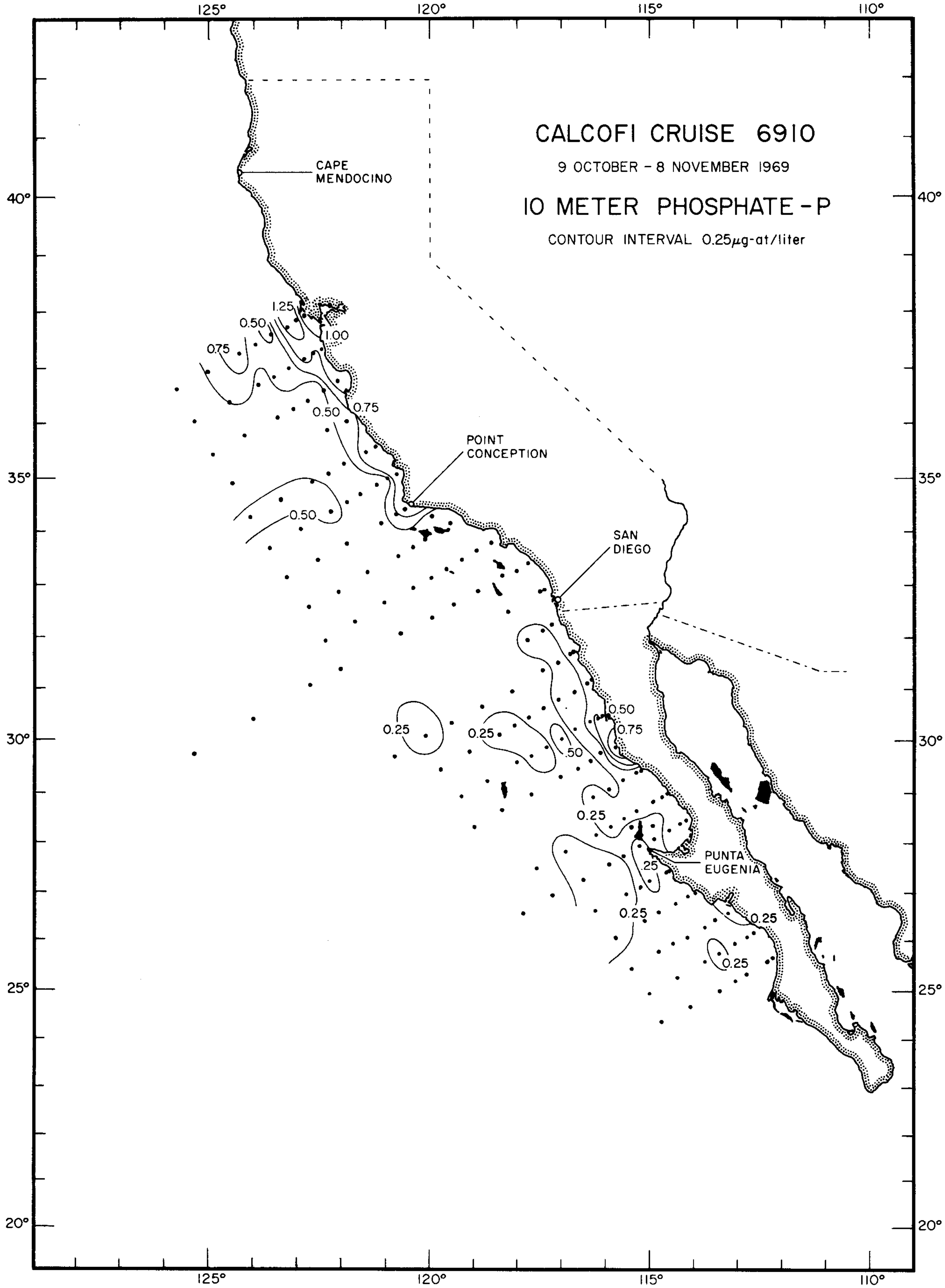


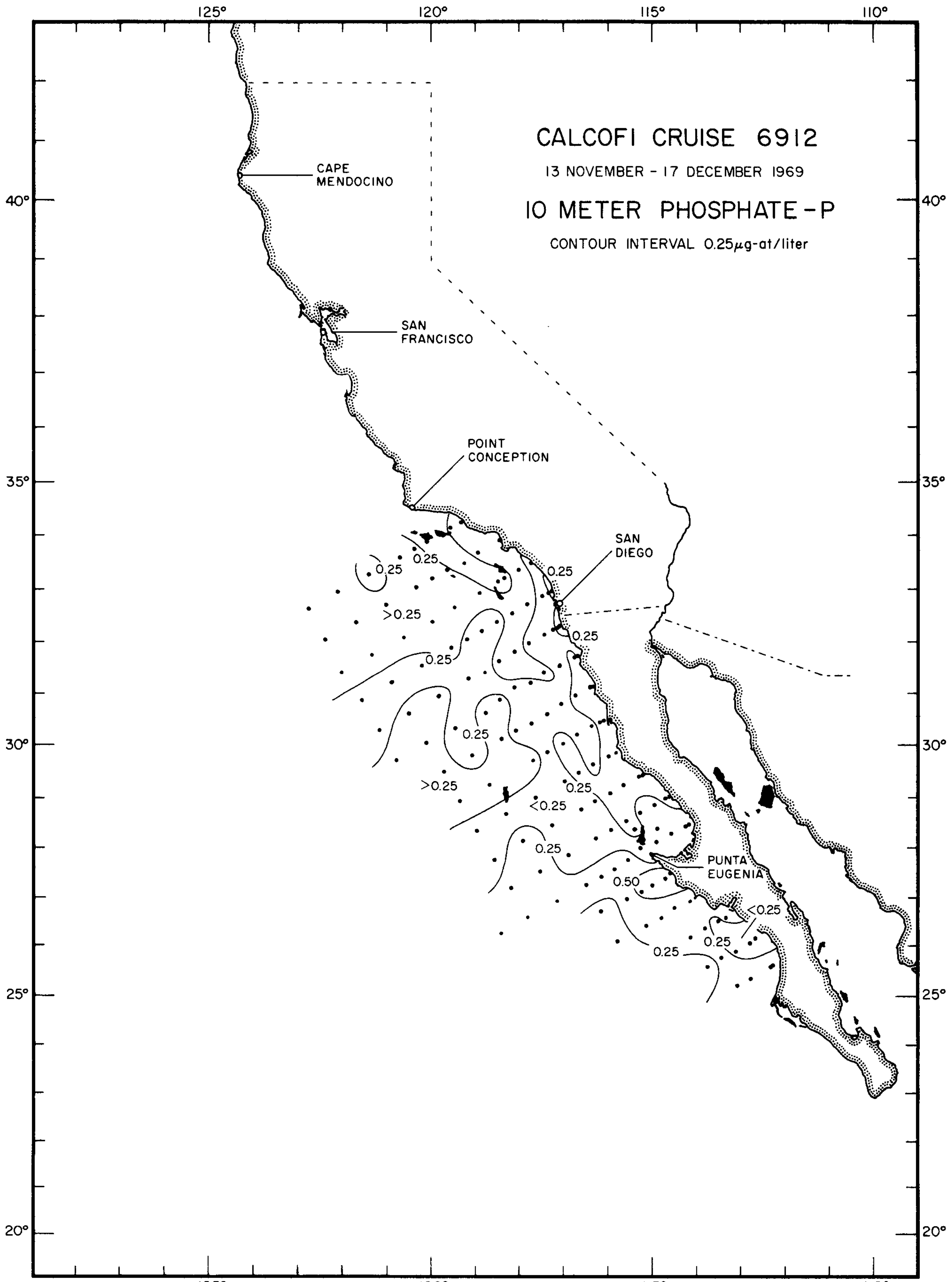
10m PHOSPHATE-P

6908-9



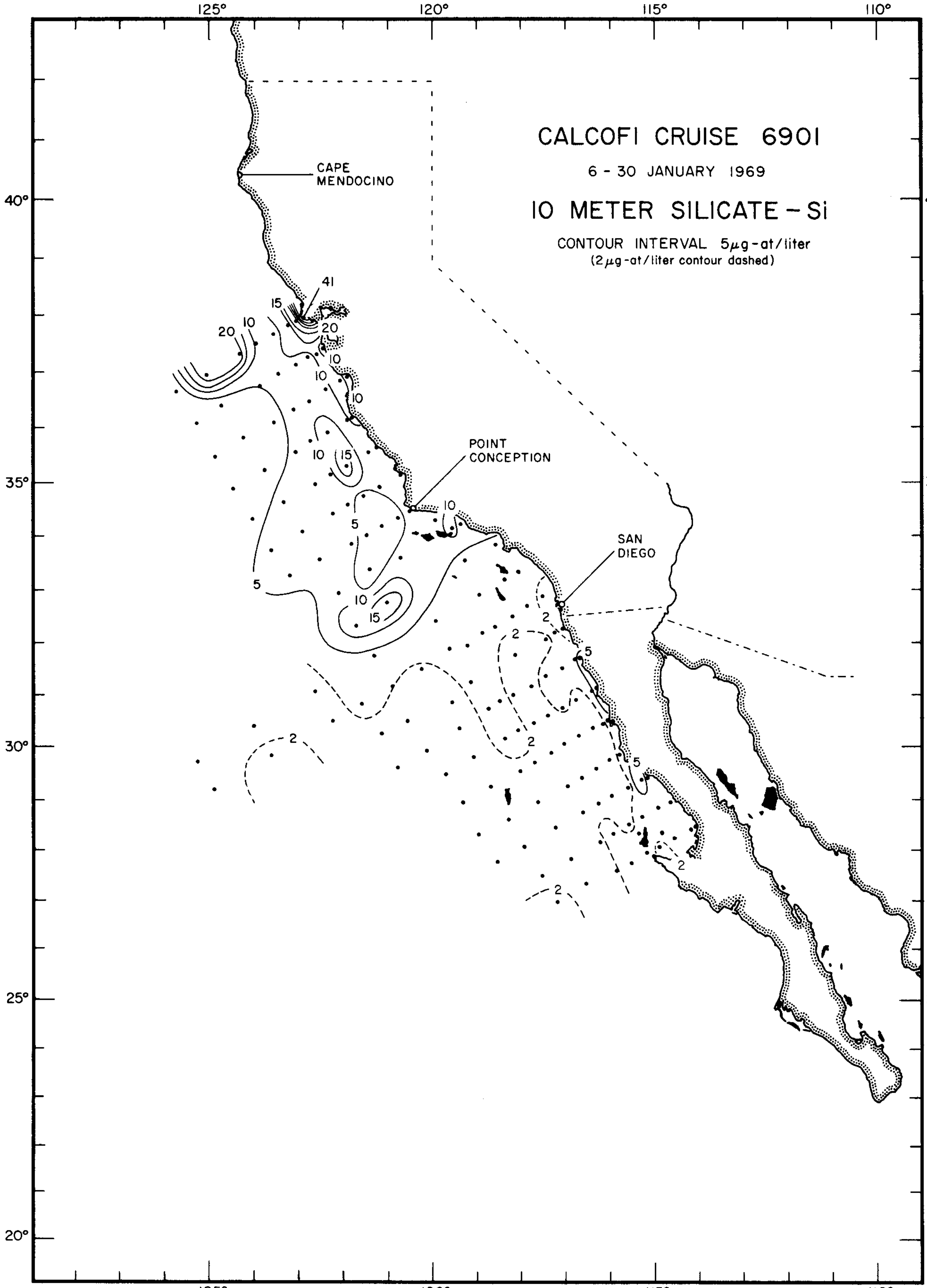
10m PHOSPHATE-P

6910



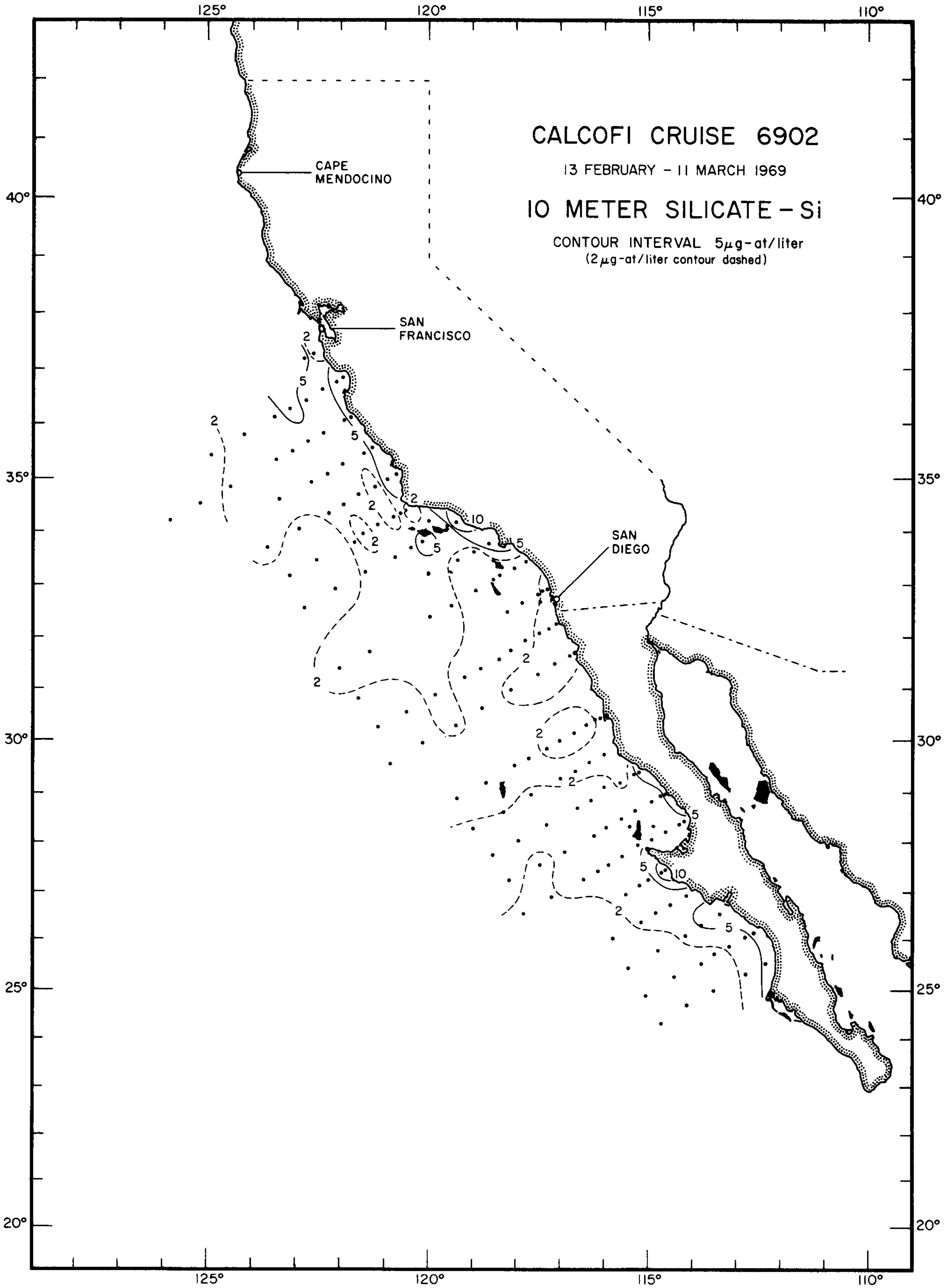
10m PHOSPHATE-P

6912



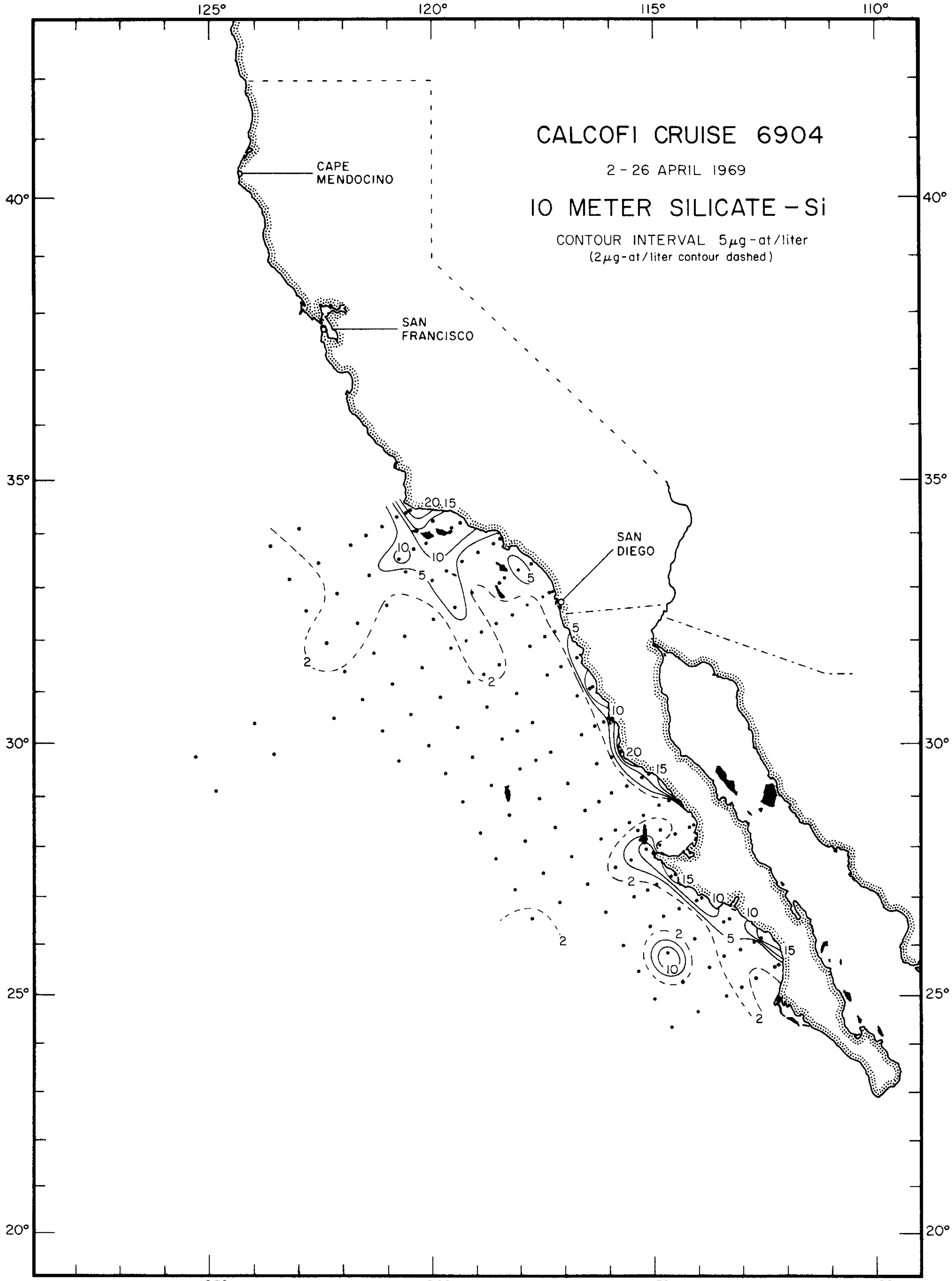
10m SILICATE-Si

6901

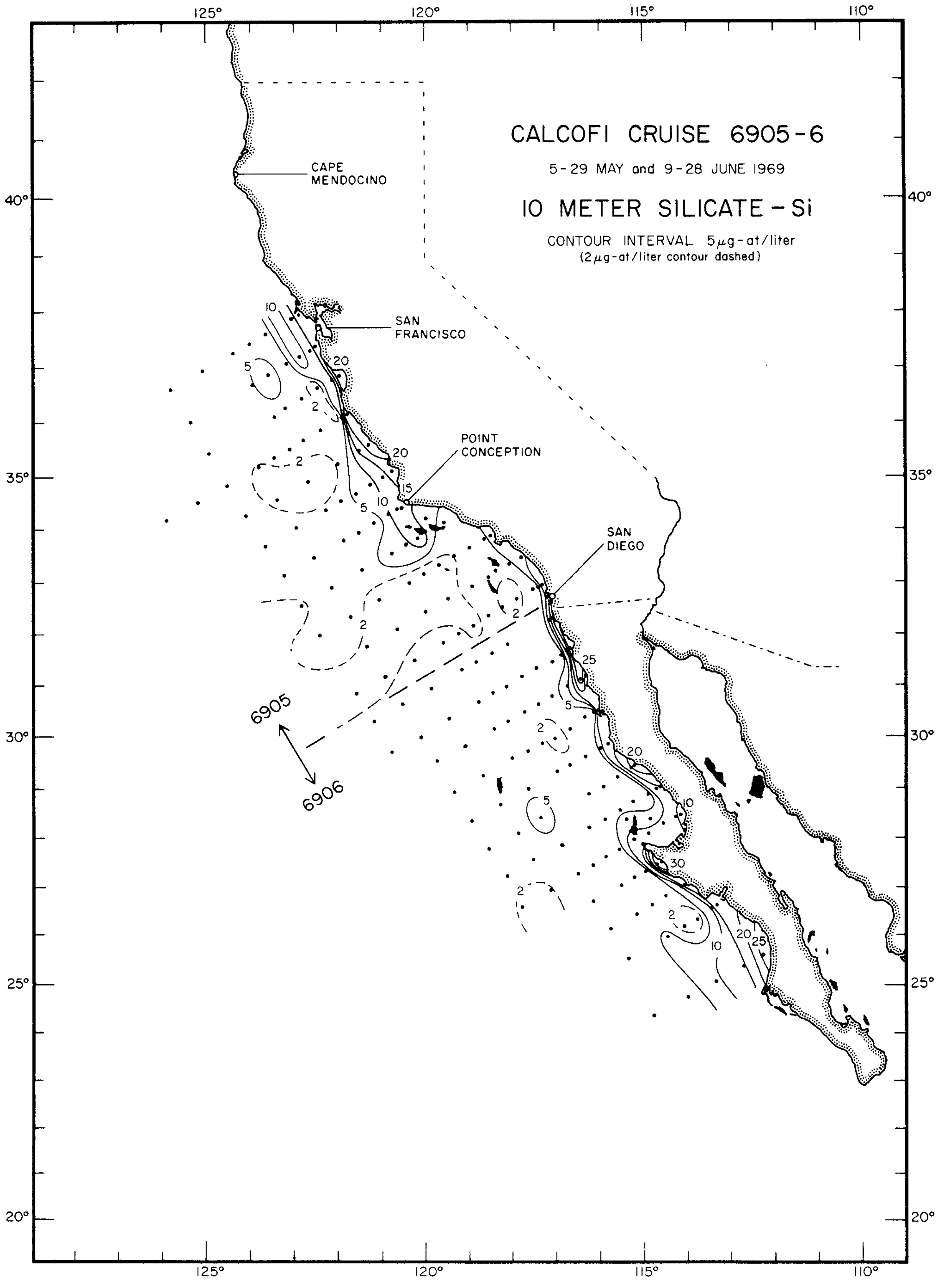


10m SILICATE-Si

6902

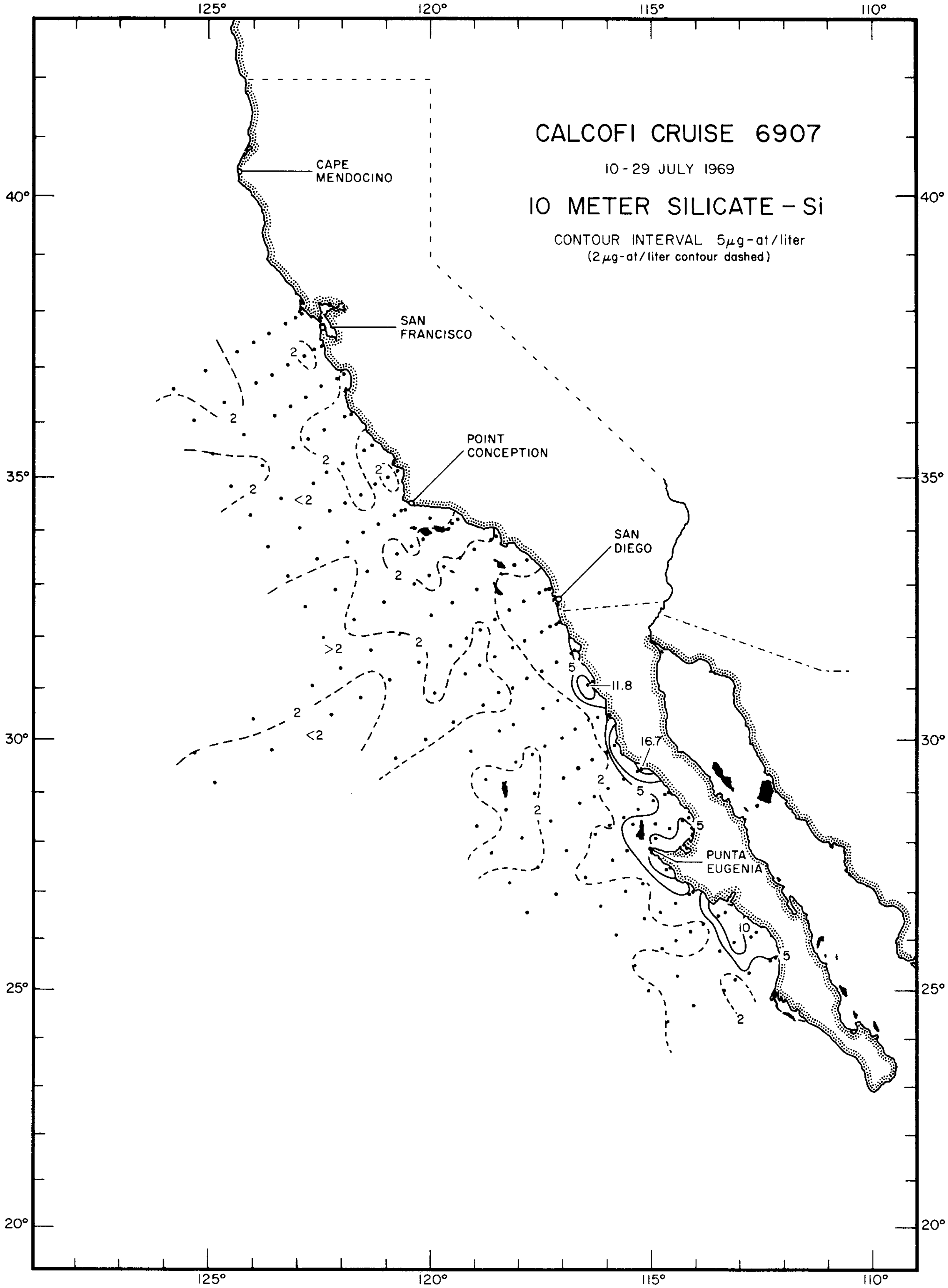


10m SILICATE-Si



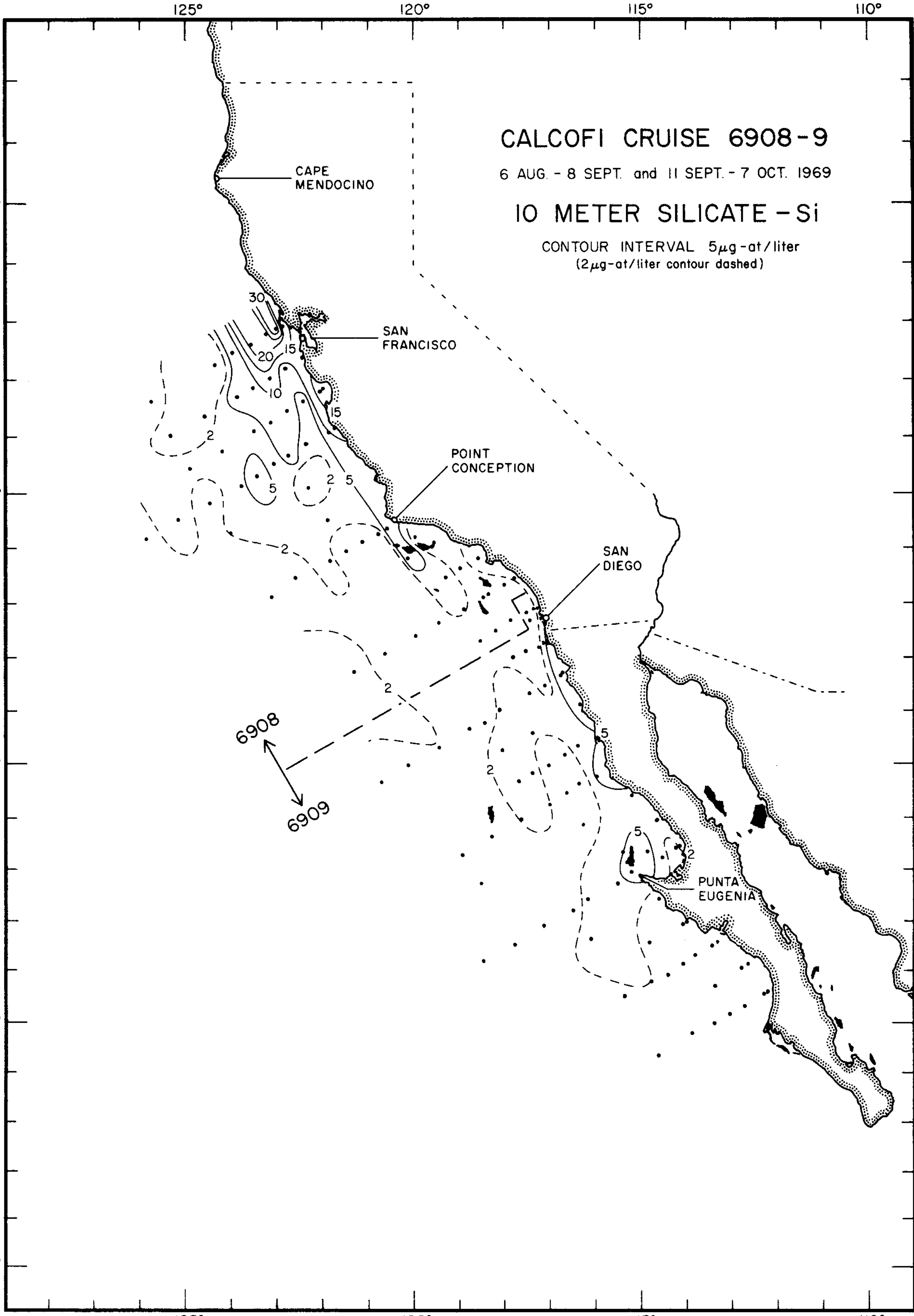
10m SILICATE-Si

6905-6



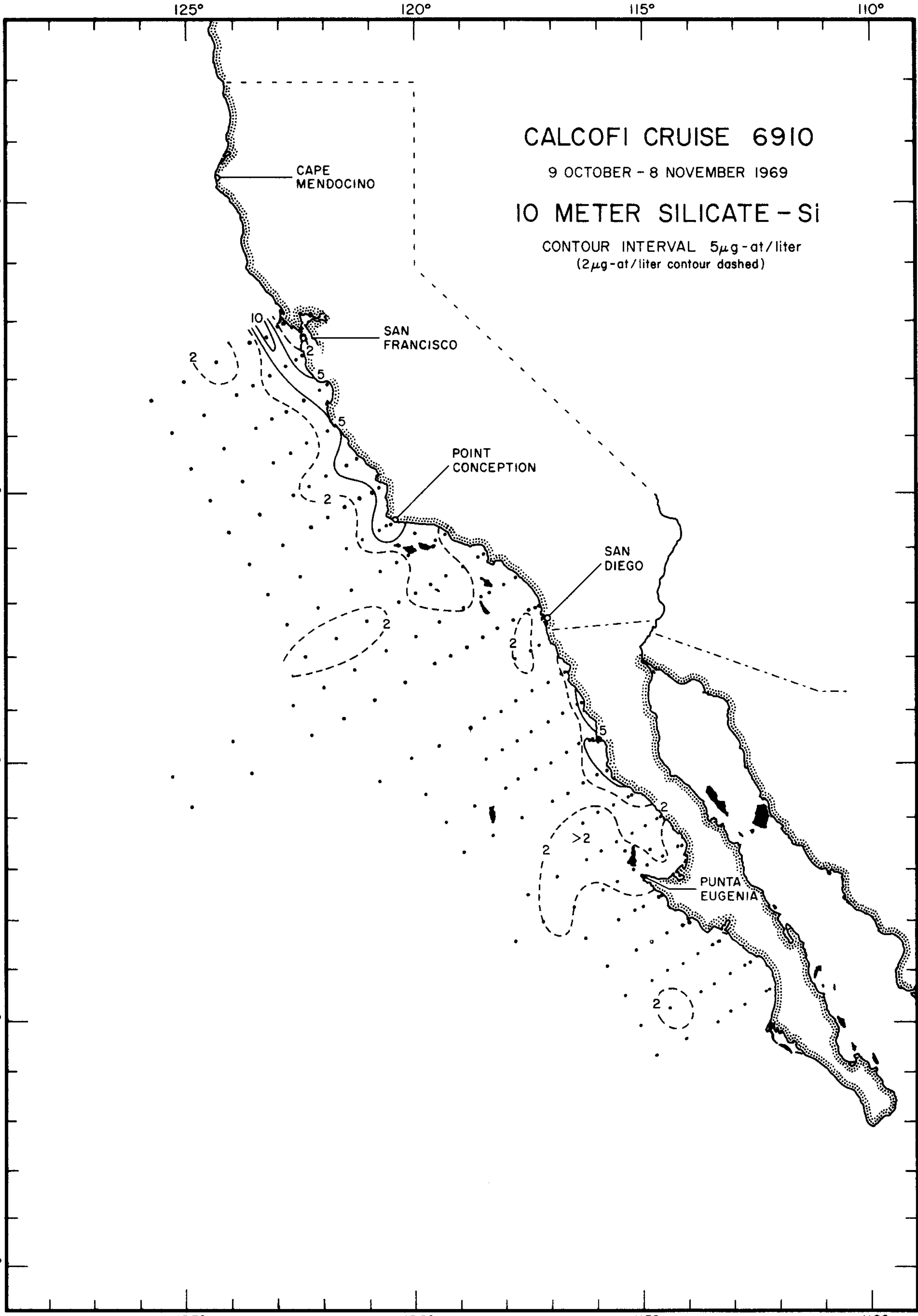
10m SILICATE-Si

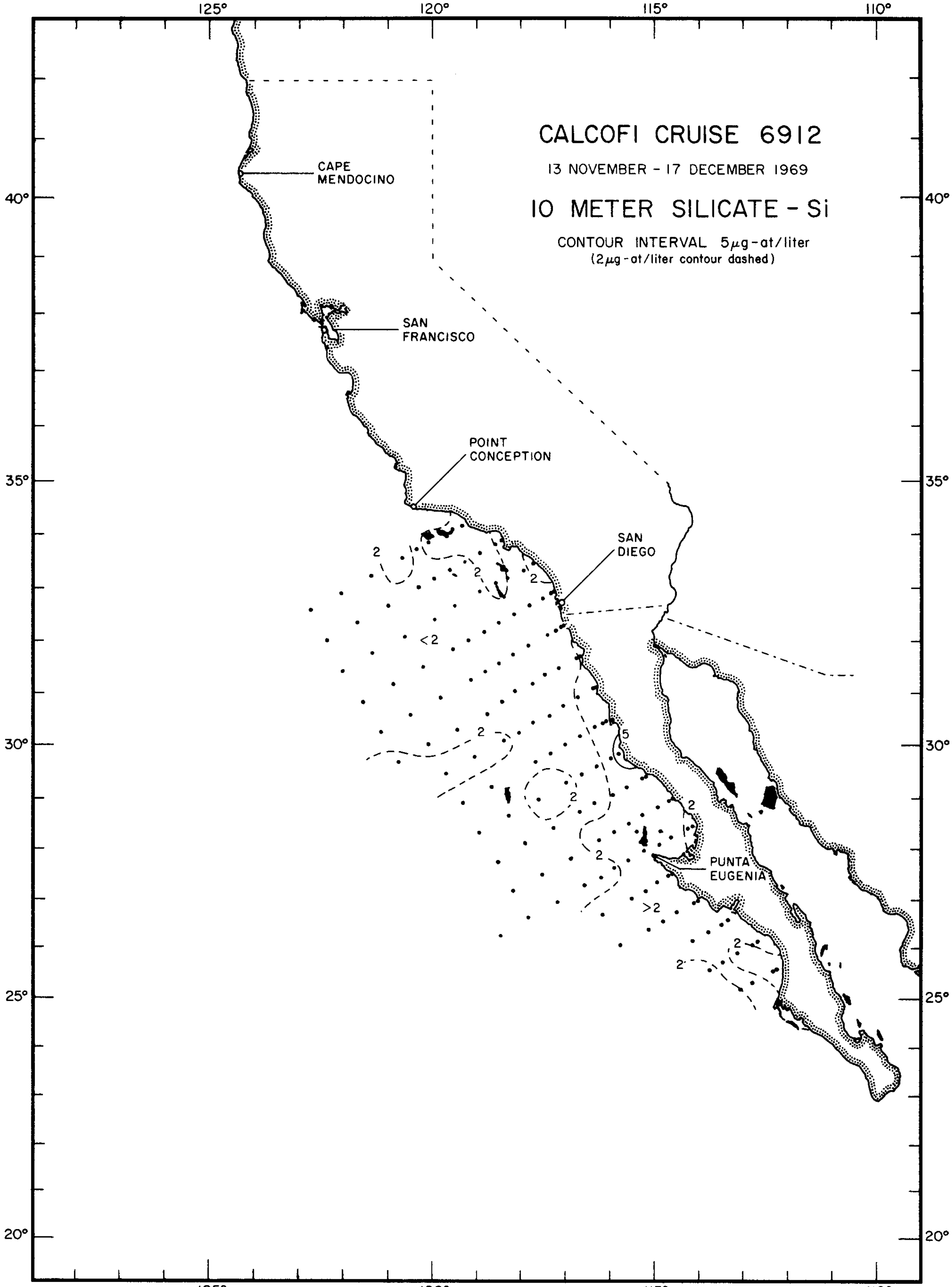
6907



10m SILICATE-Si

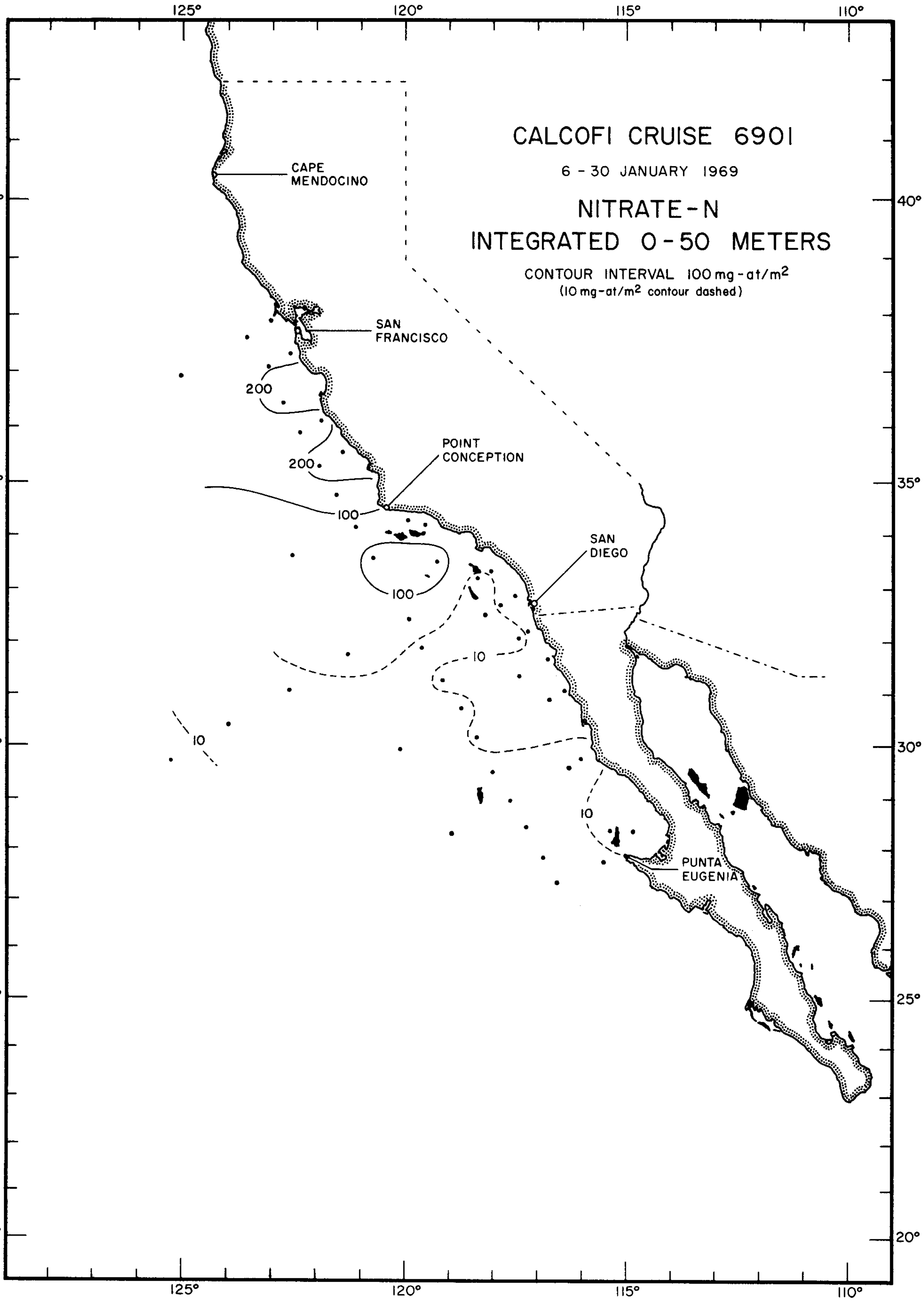
6908-9


CALCOFI CRUISE 6910
9 OCTOBER - 8 NOVEMBER 1969
10 METER SILICATE - Si
CONTOUR INTERVAL 5μg-at/liter
(2μg-at/liter contour dashed)
CAPE MENDOCINO
SAN FRANCISCO
POINT CONCEPTION
SAN DIEGO
PUNTA EUGENIA
125°
120°
115°
110°
40°
35°
30°
25°
20°
10
5
2
>2



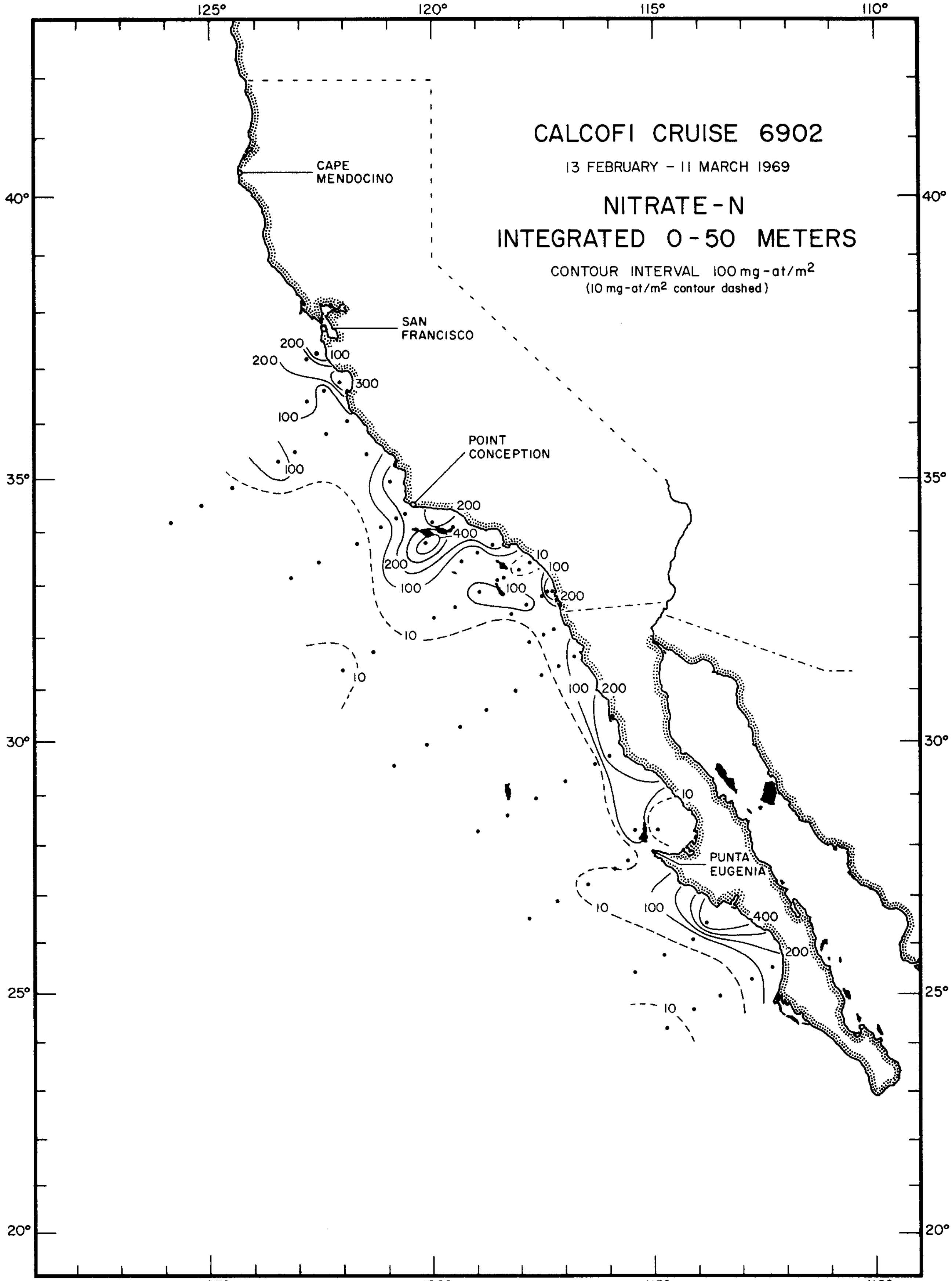
10m SILICATE-Si

6912



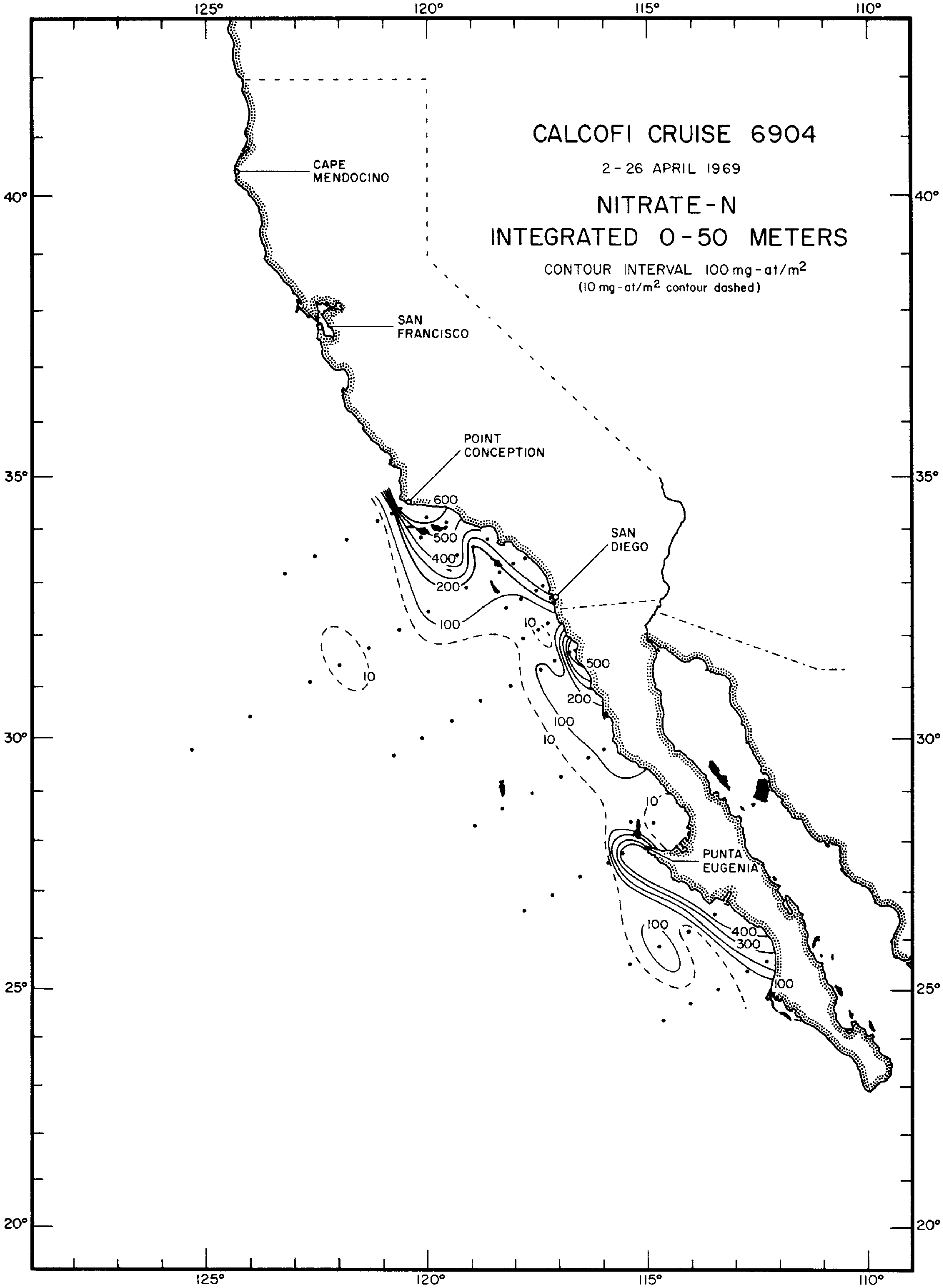
INTEGRATED NITRATE-N

6901

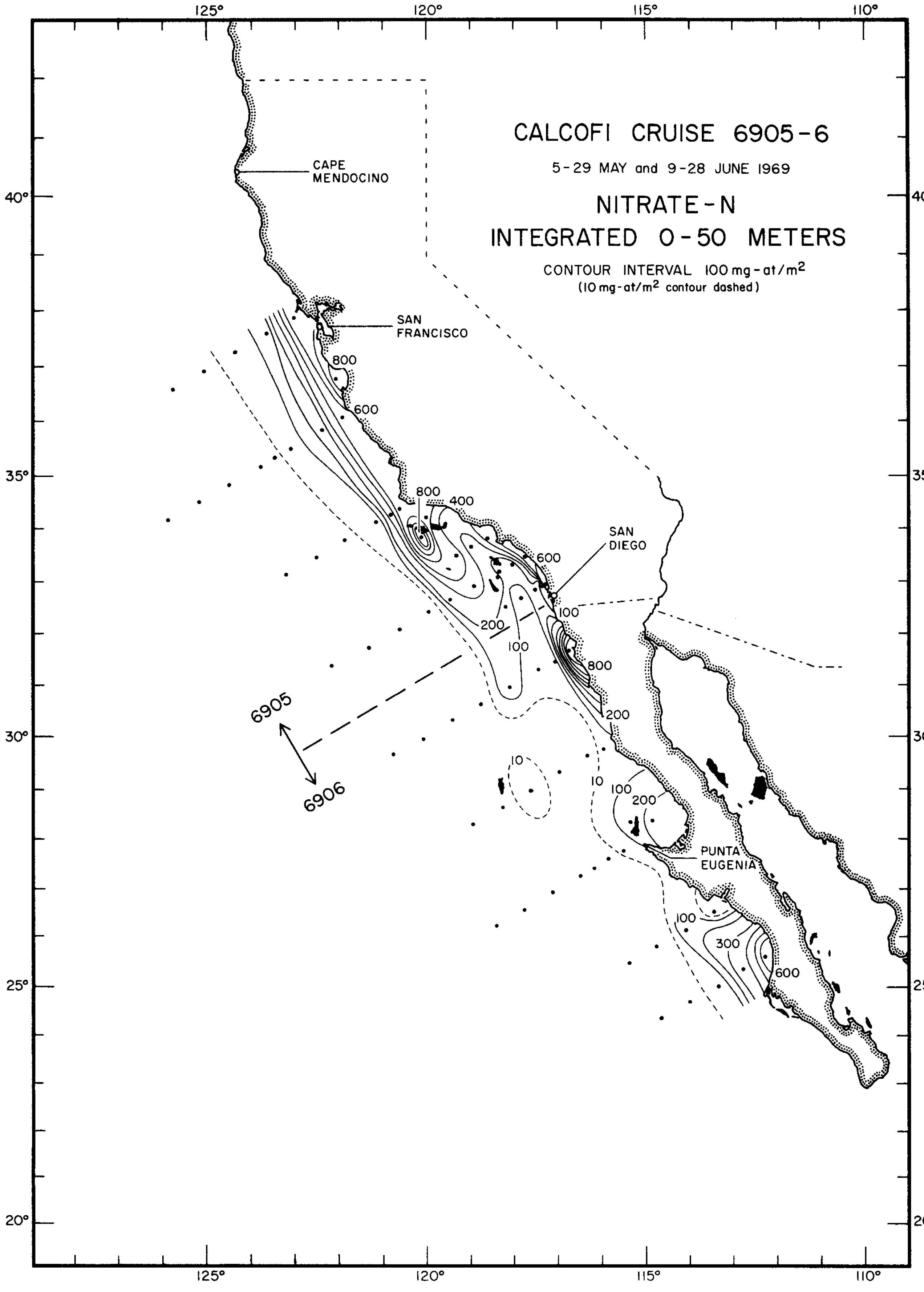


INTEGRATED NITRATE-N

6902

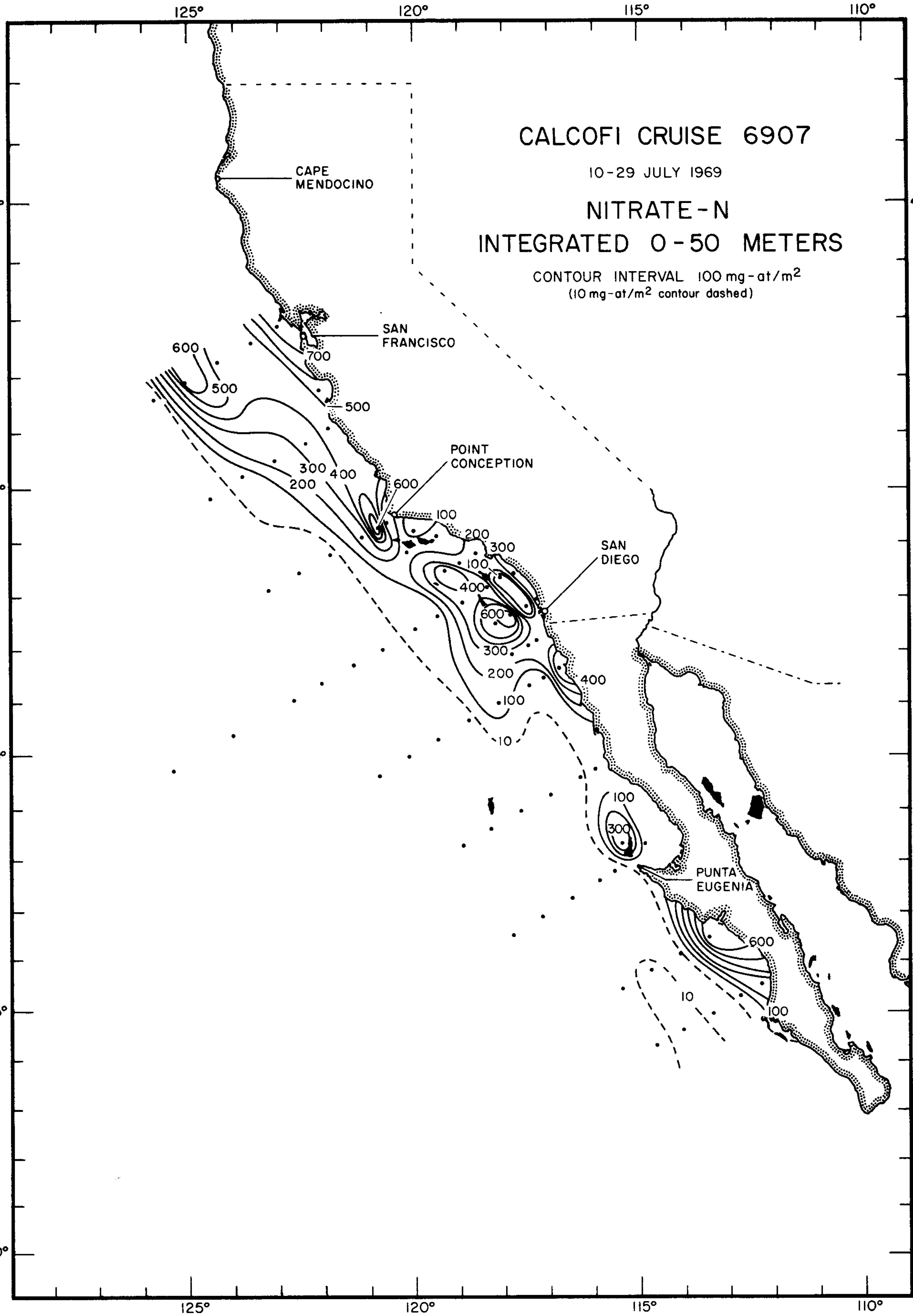


INTEGRATED NITRATE-N



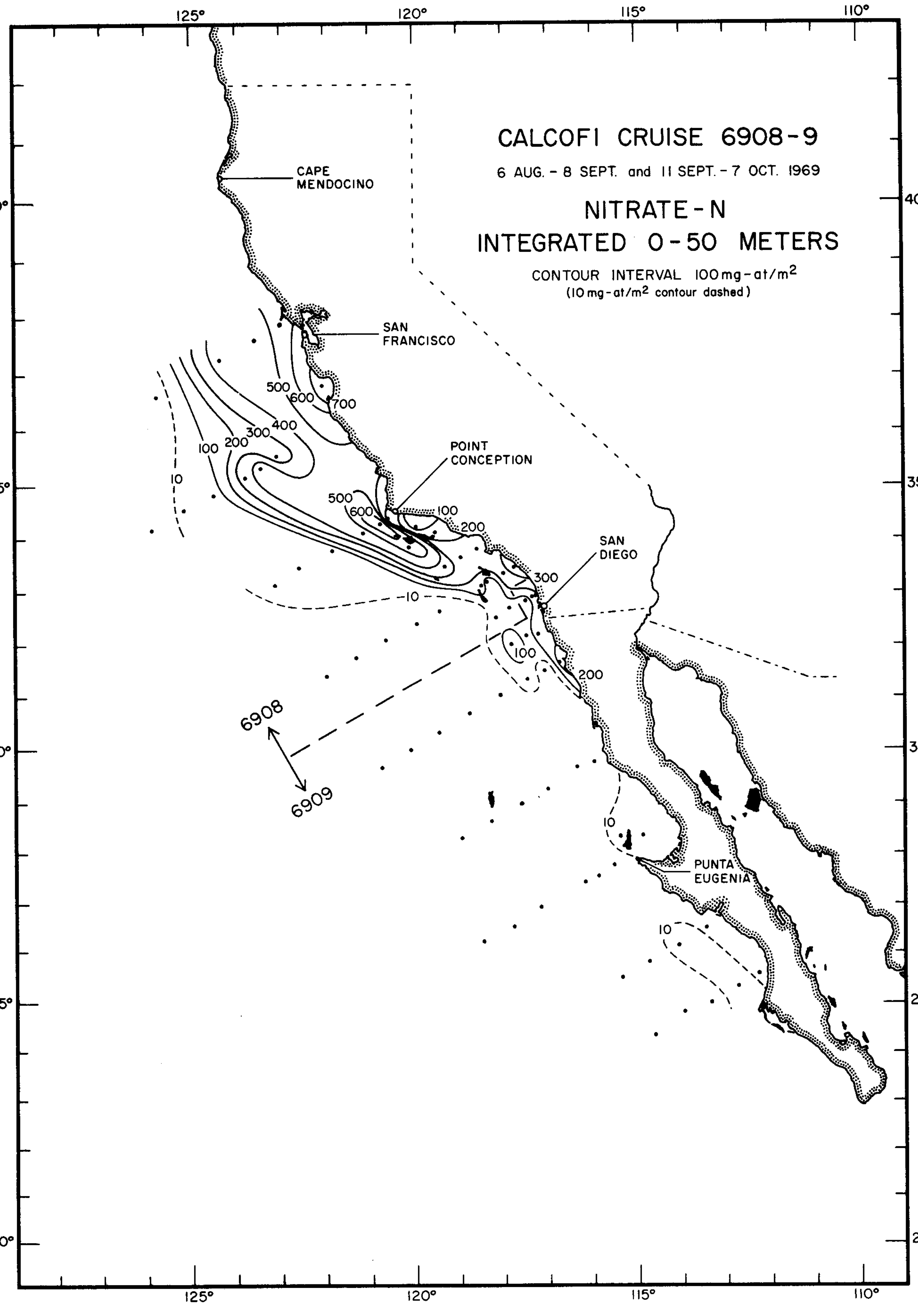
INTEGRATED NITRATE-N

6905-6



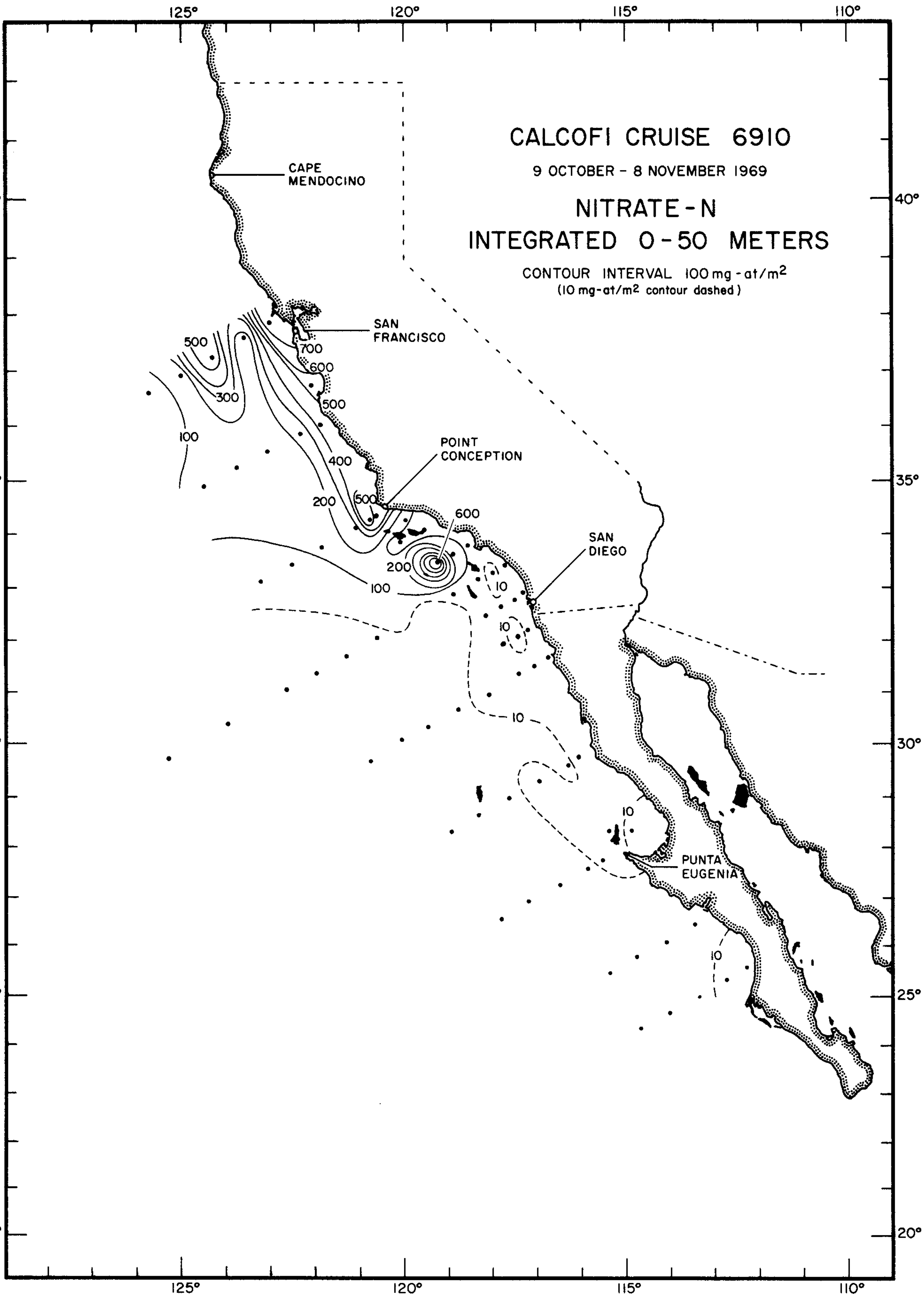
INTEGRATED NITRATE-N

6907

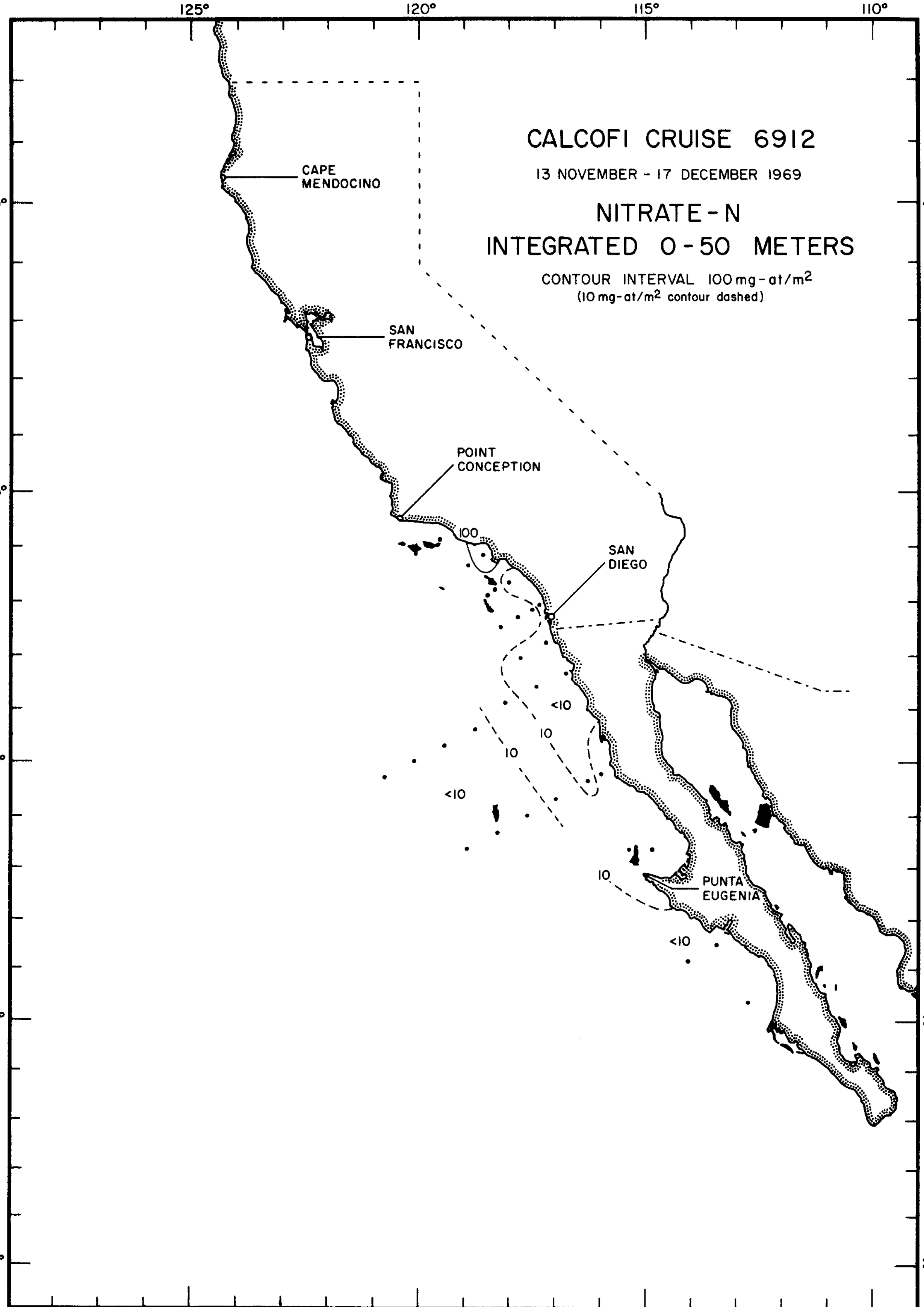


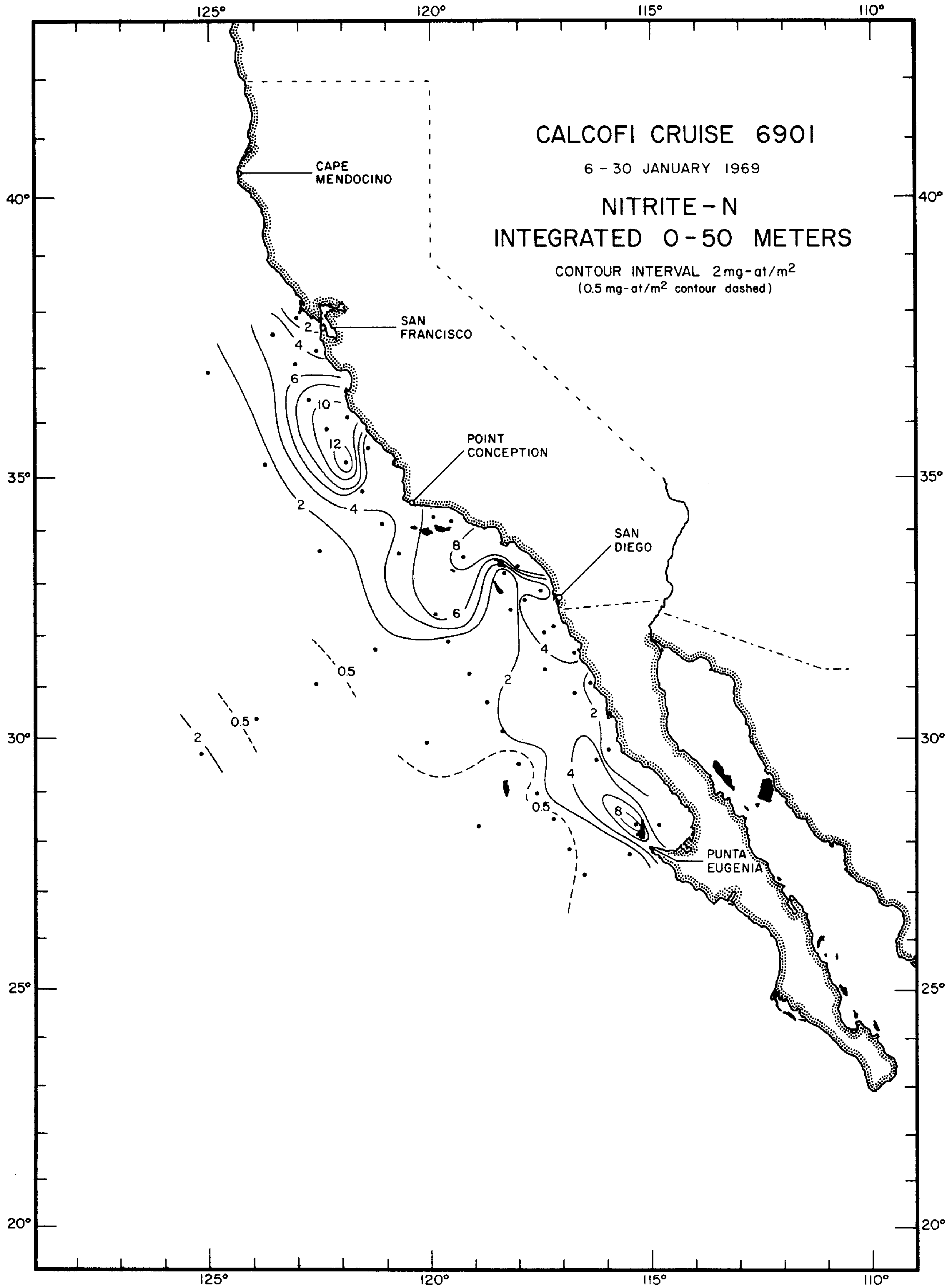
INTEGRATED NITRATE-N

6908-9

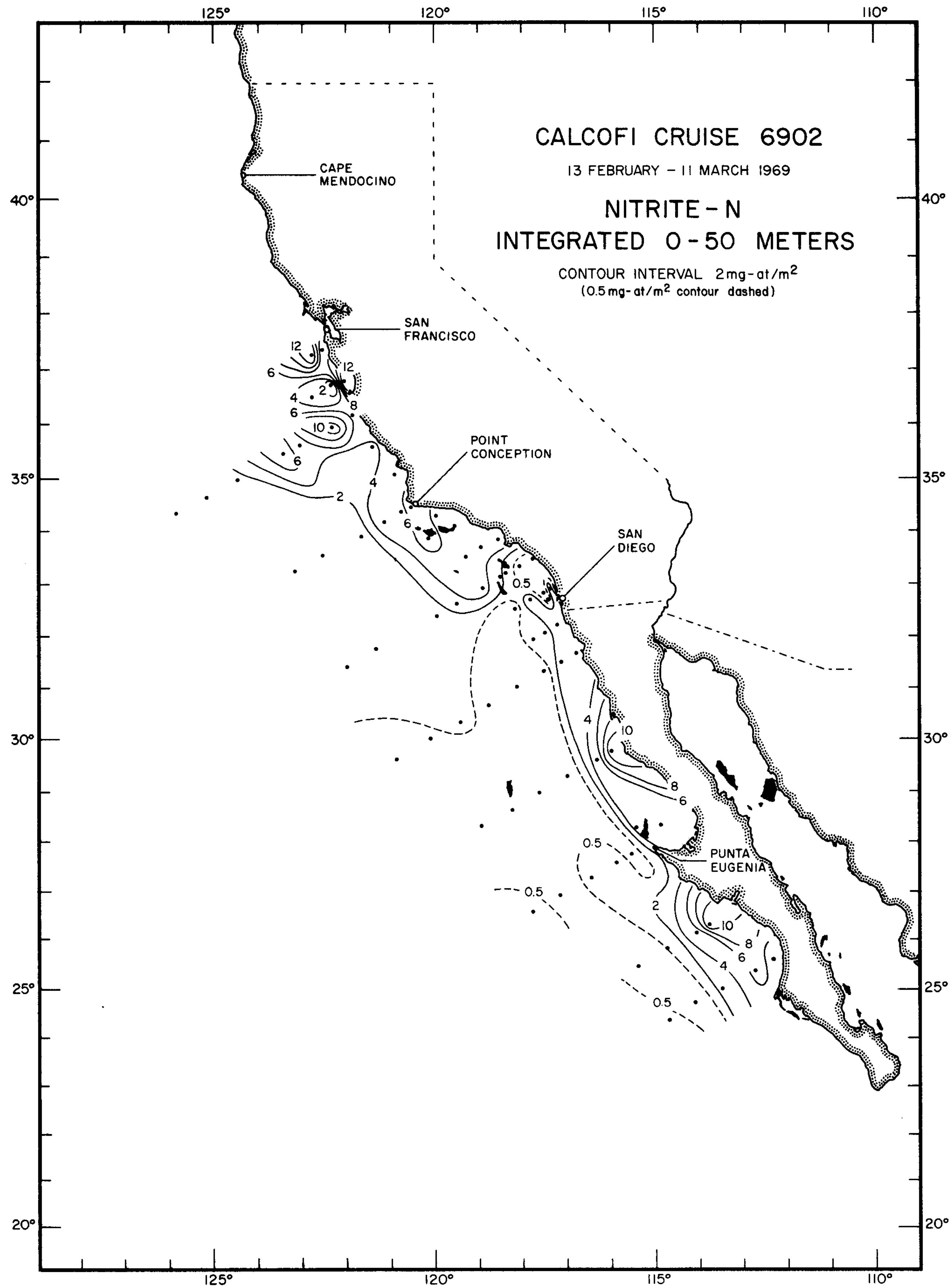


CALCOFI CRUISE 6910
9 OCTOBER - 8 NOVEMBER 1969
NITRATE-N
INTEGRATED 0-50 METERS
CONTOUR INTERVAL 100 mg-at/m2
(10 mg-at/m2 contour dashed)
CAPE MENDOCINO
SAN FRANCISCO
POINT CONCEPTION
SAN DIEGO
PUNTA EUGENIA
125°
120°
115°
110°
40°
35°
30°
25°
20°
700
600
500
400
300
200
100
10


CALCOFI CRUISE 6912
13 NOVEMBER - 17 DECEMBER 1969
NITRATE-N
INTEGRATED 0-50 METERS
CONTOUR INTERVAL 100 mg-at/m2
(10 mg-at/m2 contour dashed)
CAPE MENDOCINO
SAN FRANCISCO
POINT CONCEPTION
SAN DIEGO
PUNTA EUGENIA
100
<10
10
125°
120°
115°
110°
40°
35°
30°
25°
20°

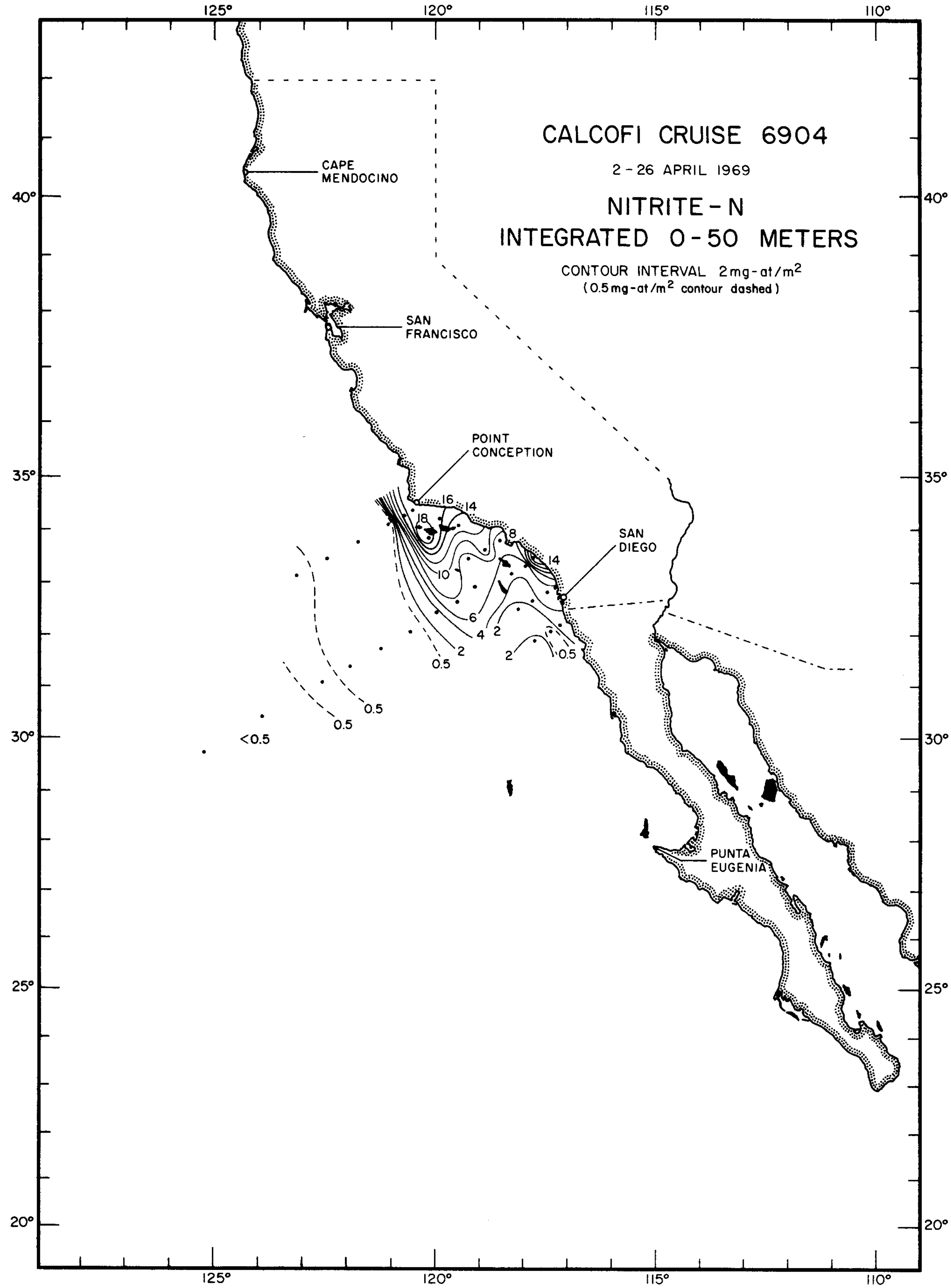


INTEGRATED NITRITE-N

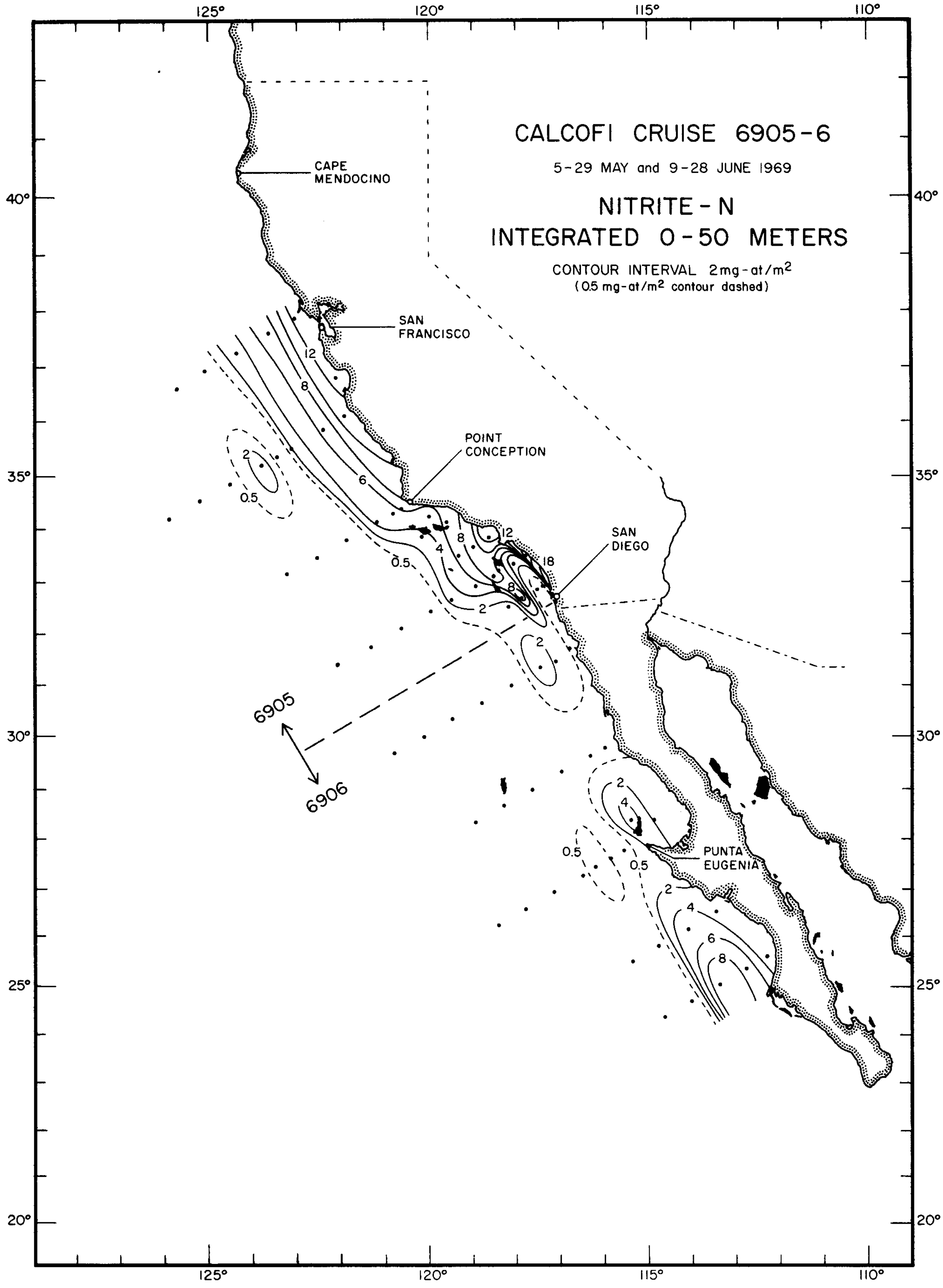


INTEGRATED NITRITE-N

6902

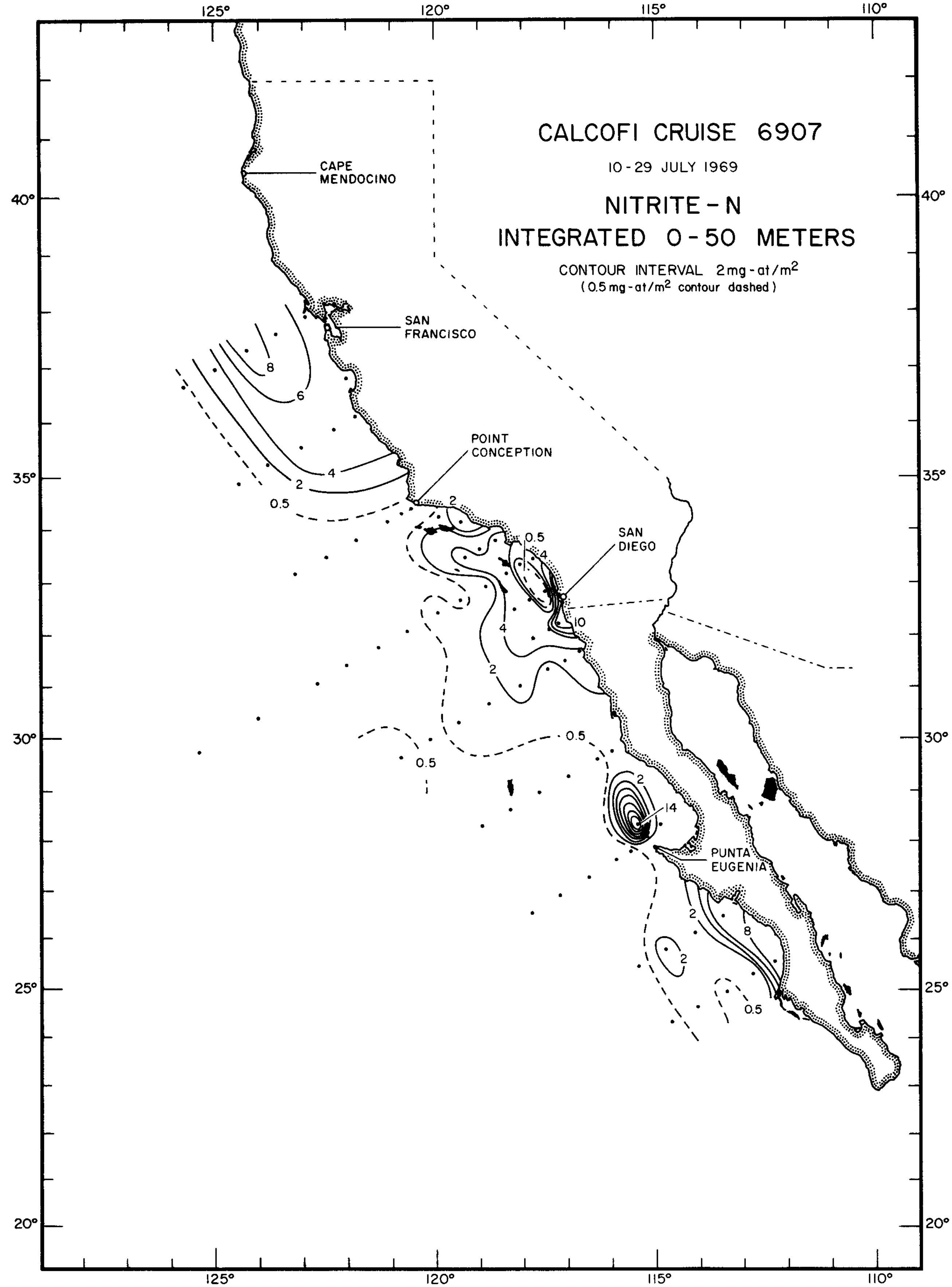


INTEGRATED NITRITE-N



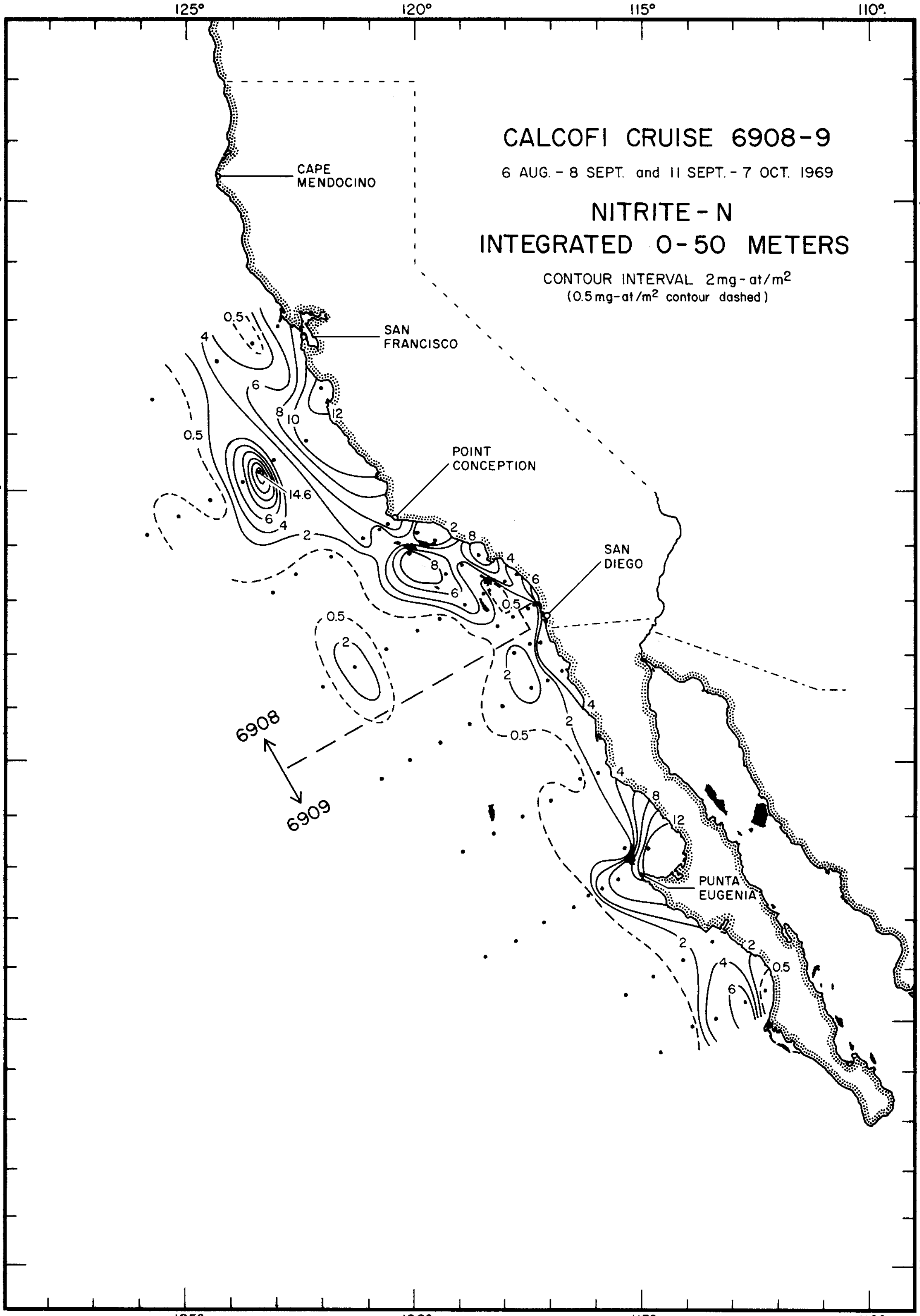
INTEGRATED NITRITE-N

6905-6



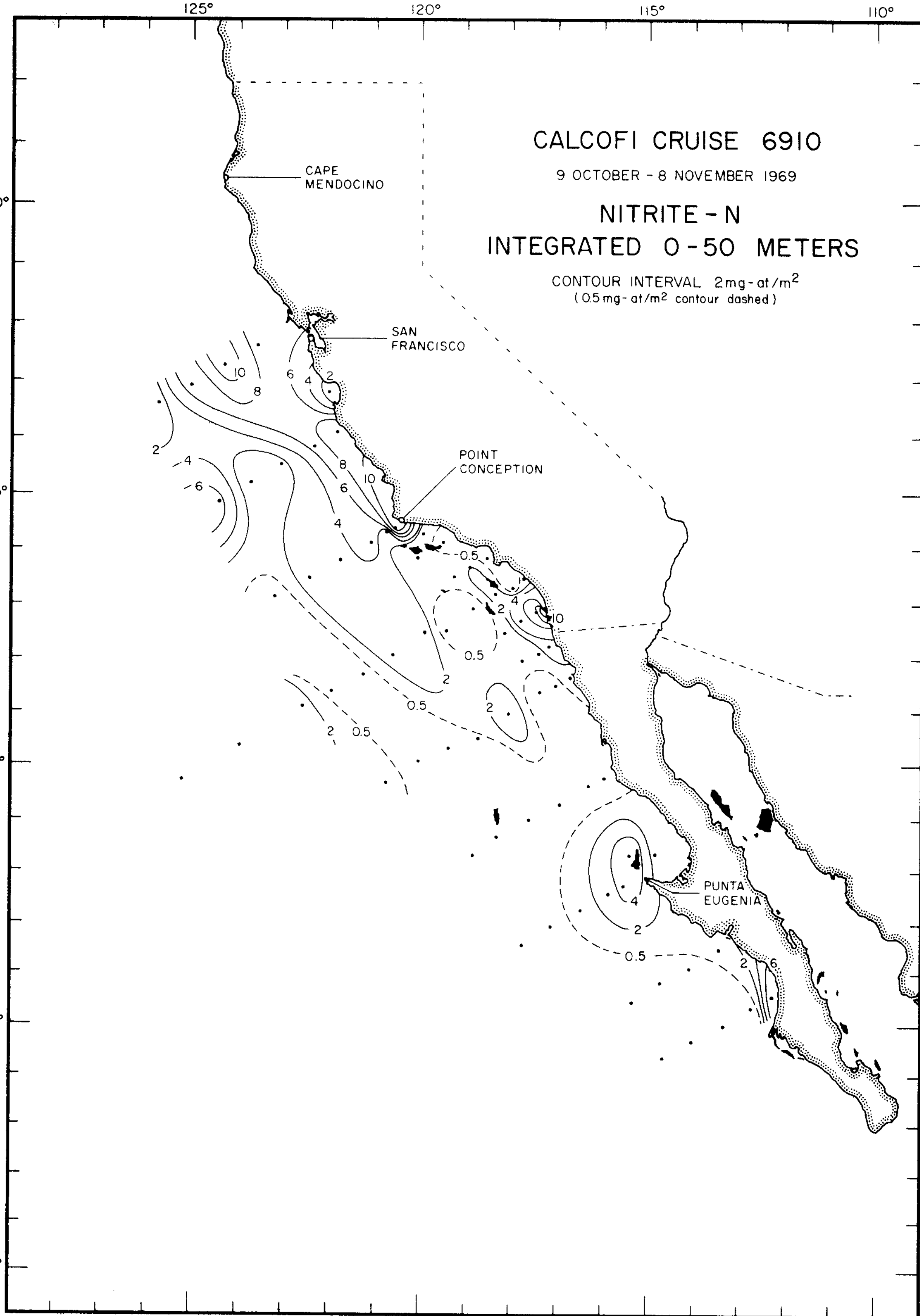
INTEGRATED NITRITE-N

6907



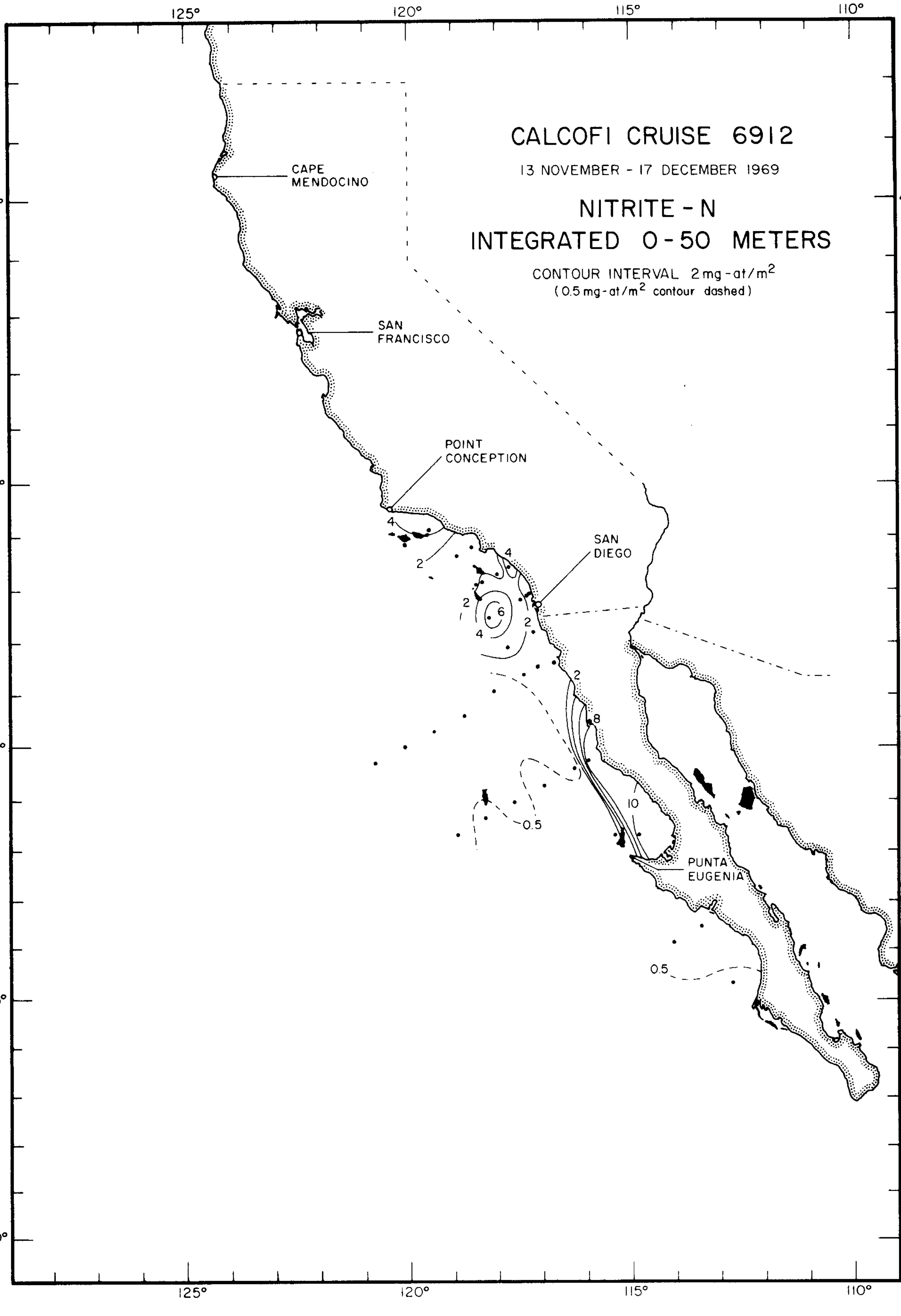
INTEGRATED NITRITE-N

6908-9

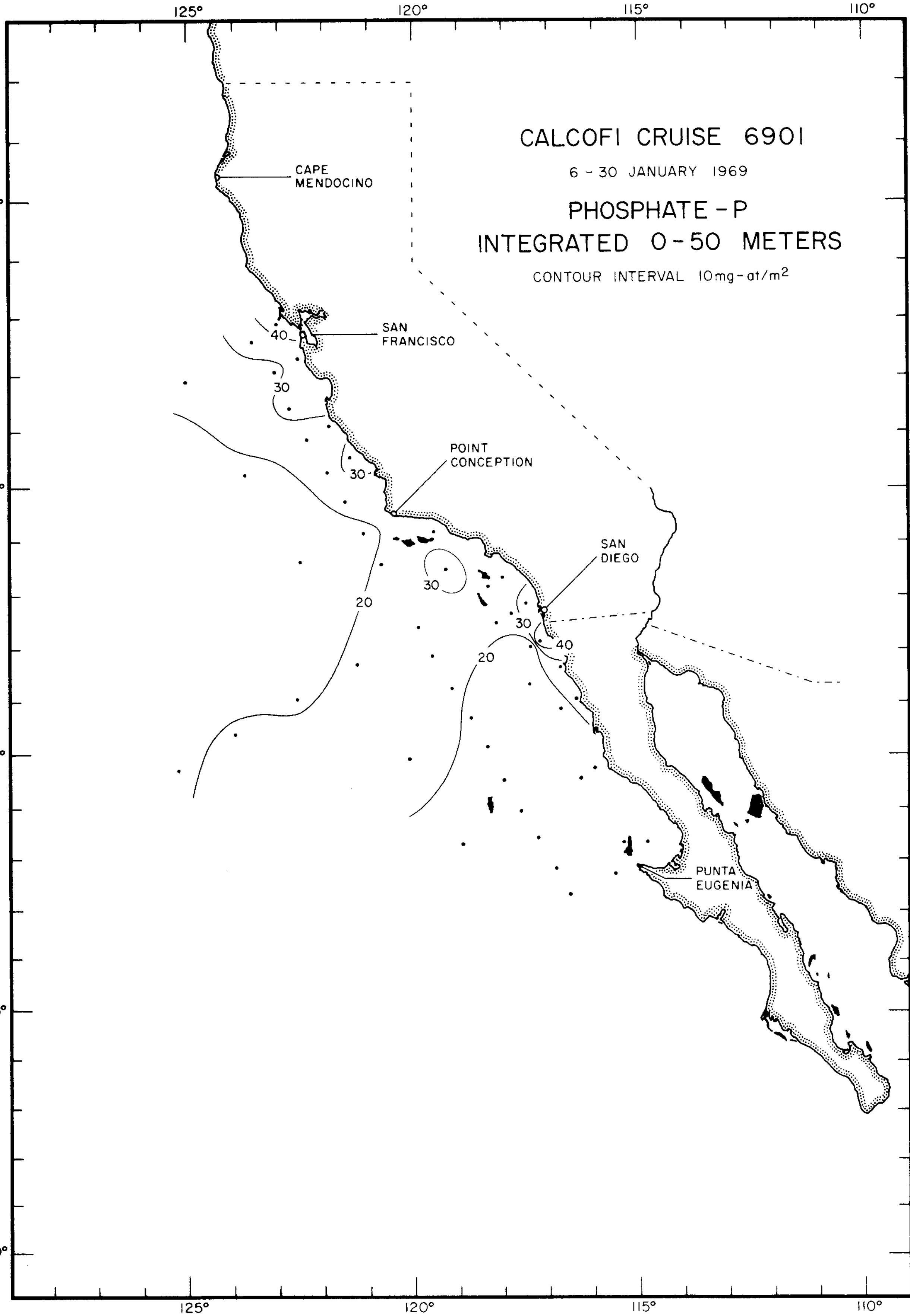


INTEGRATED NITRITE-N

6910

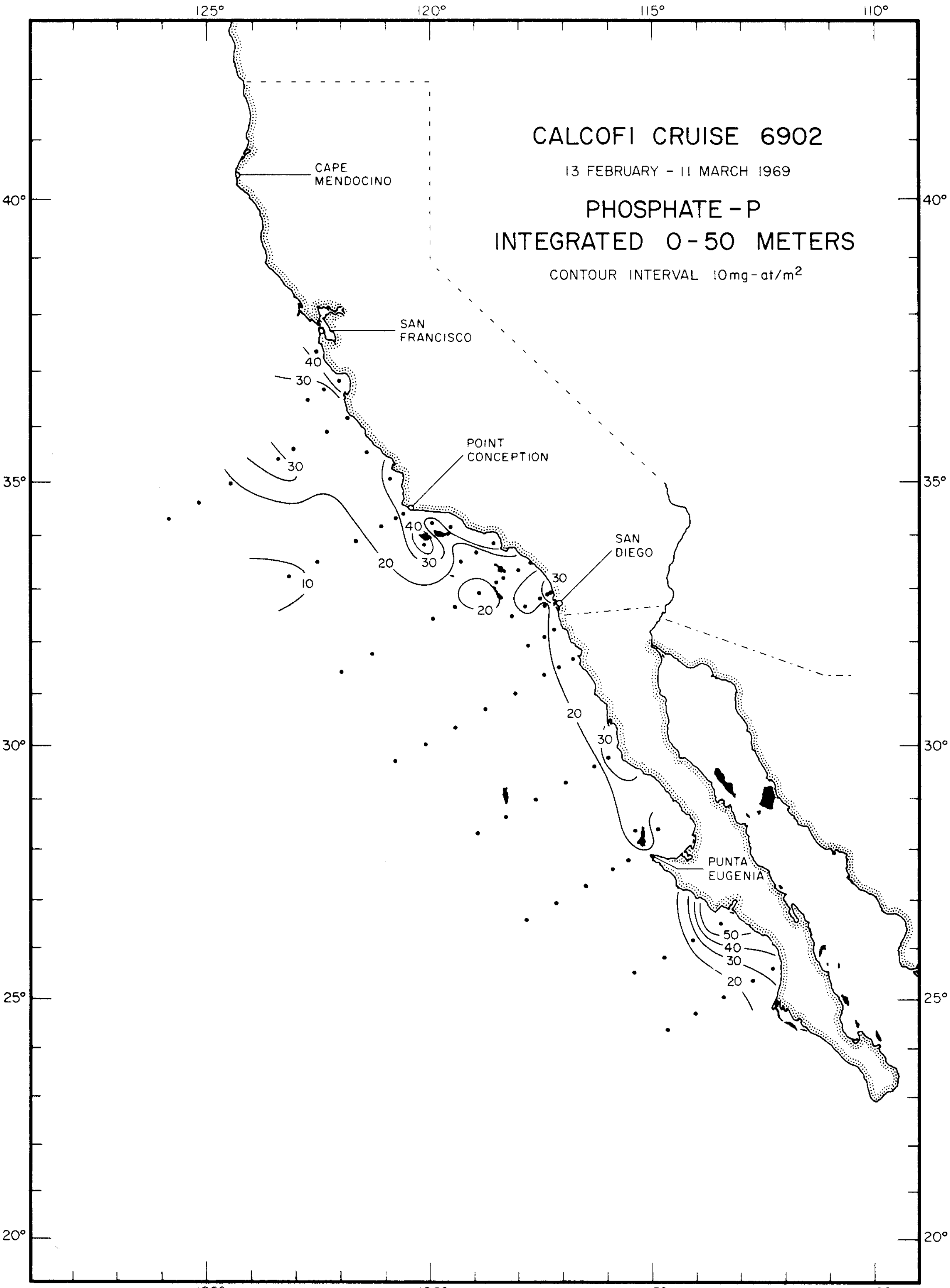


CALCOFI CRUISE 6912
13 NOVEMBER - 17 DECEMBER 1969
NITRITE - N
INTEGRATED 0-50 METERS
CONTOUR INTERVAL 2 mg-at/m²
(0.5 mg-at/m² contour dashed)
CAPE MENDOCINO
SAN FRANCISCO
POINT CONCEPTION
SAN DIEGO
PUNTA EUGENIA
125°
120°
115°
110°
40°
35°
30°
25°
20°
4
2
6
8
10
0.5



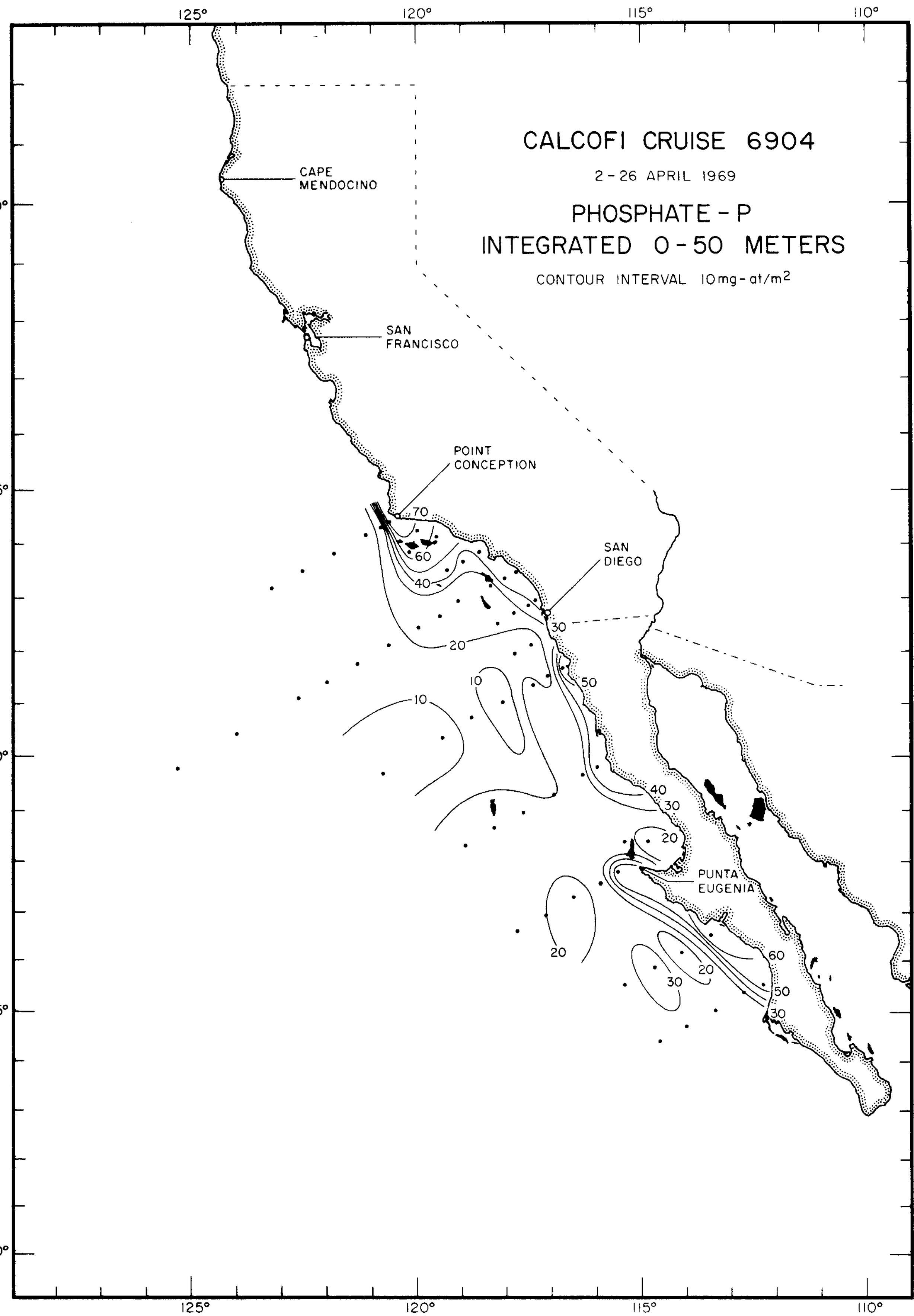
INTEGRATED PHOSPHATE - P

6901



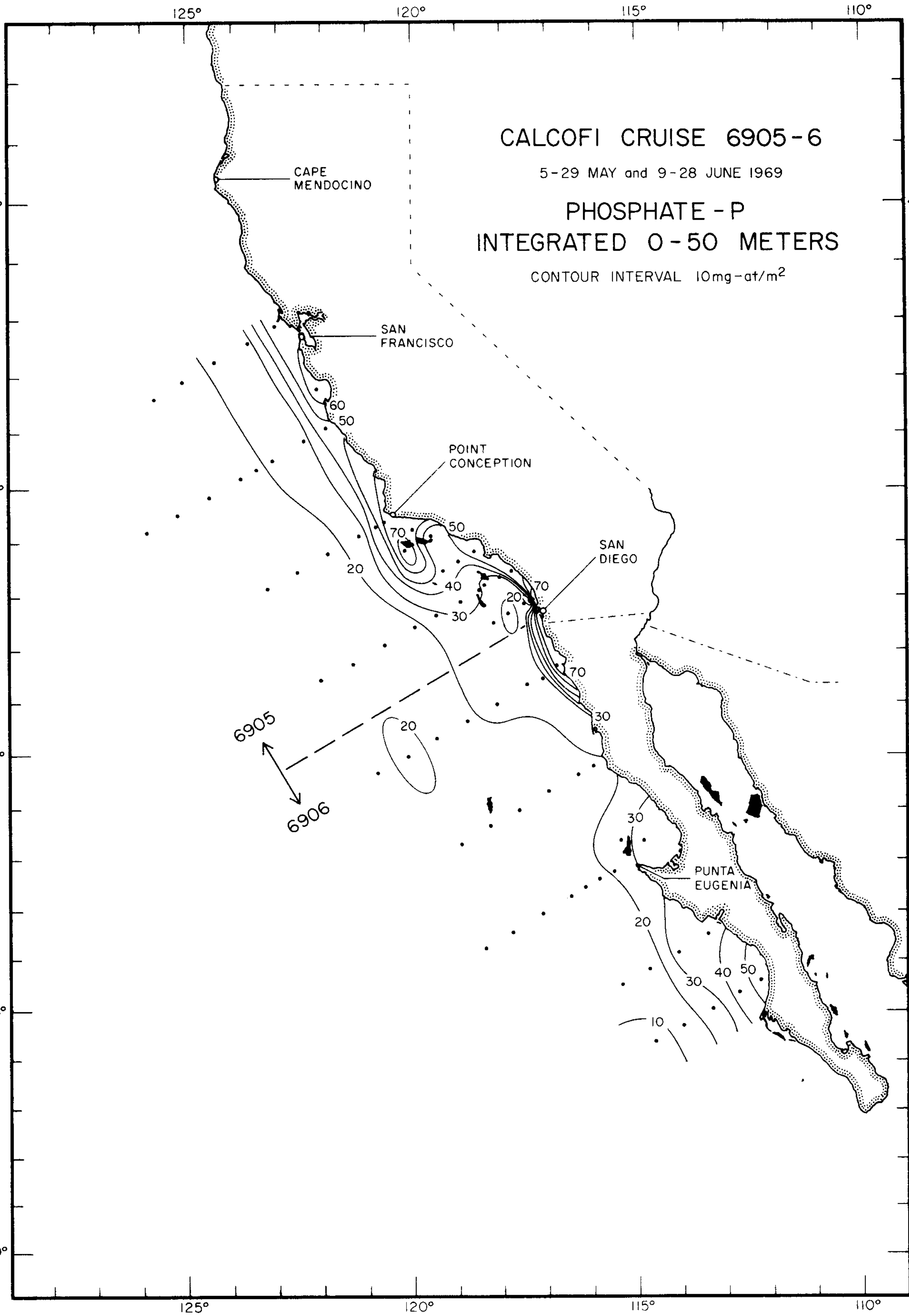
INTEGRATED PHOSPHATE-P

6902



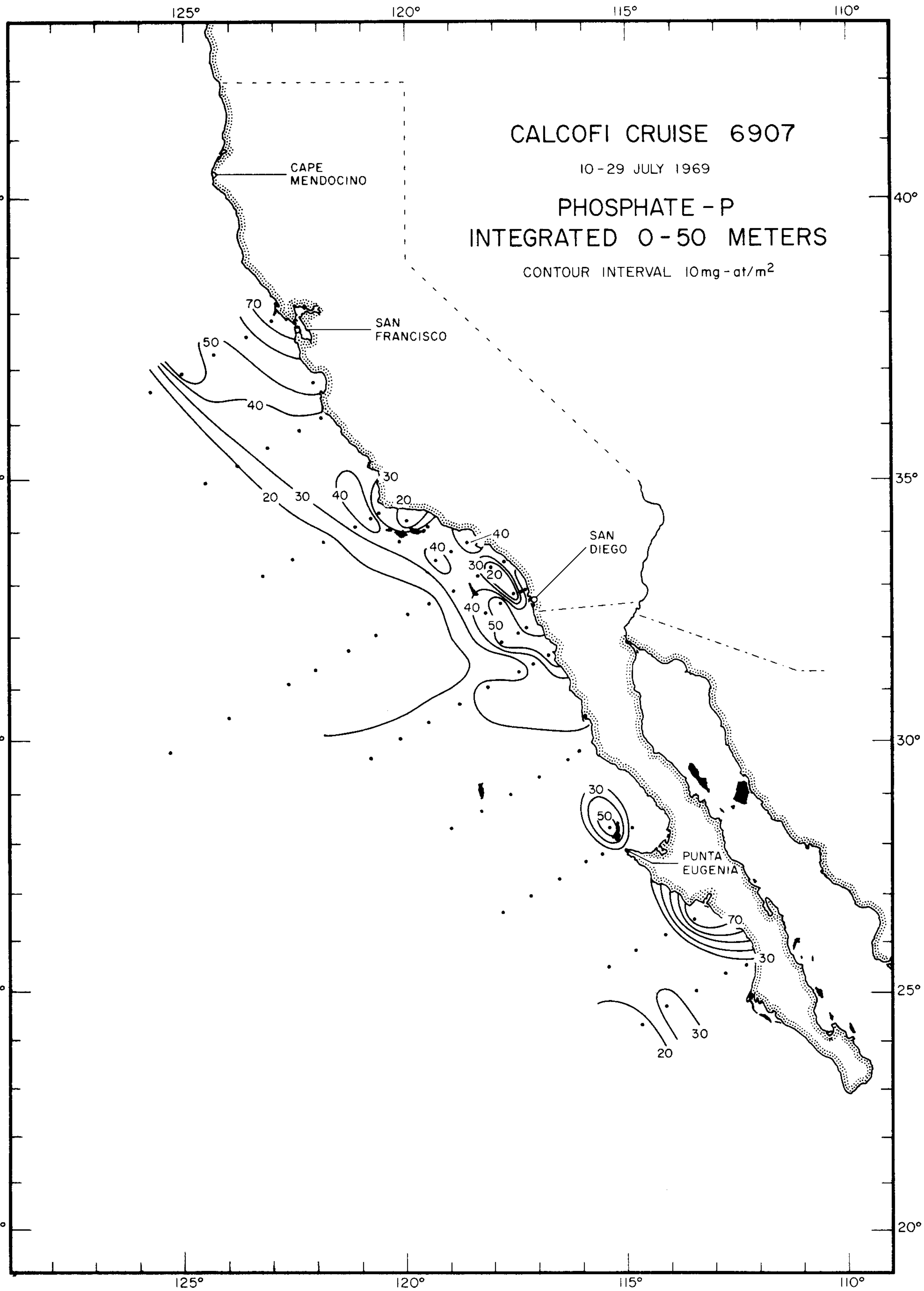
INTEGRATED PHOSPHATE-P

6904



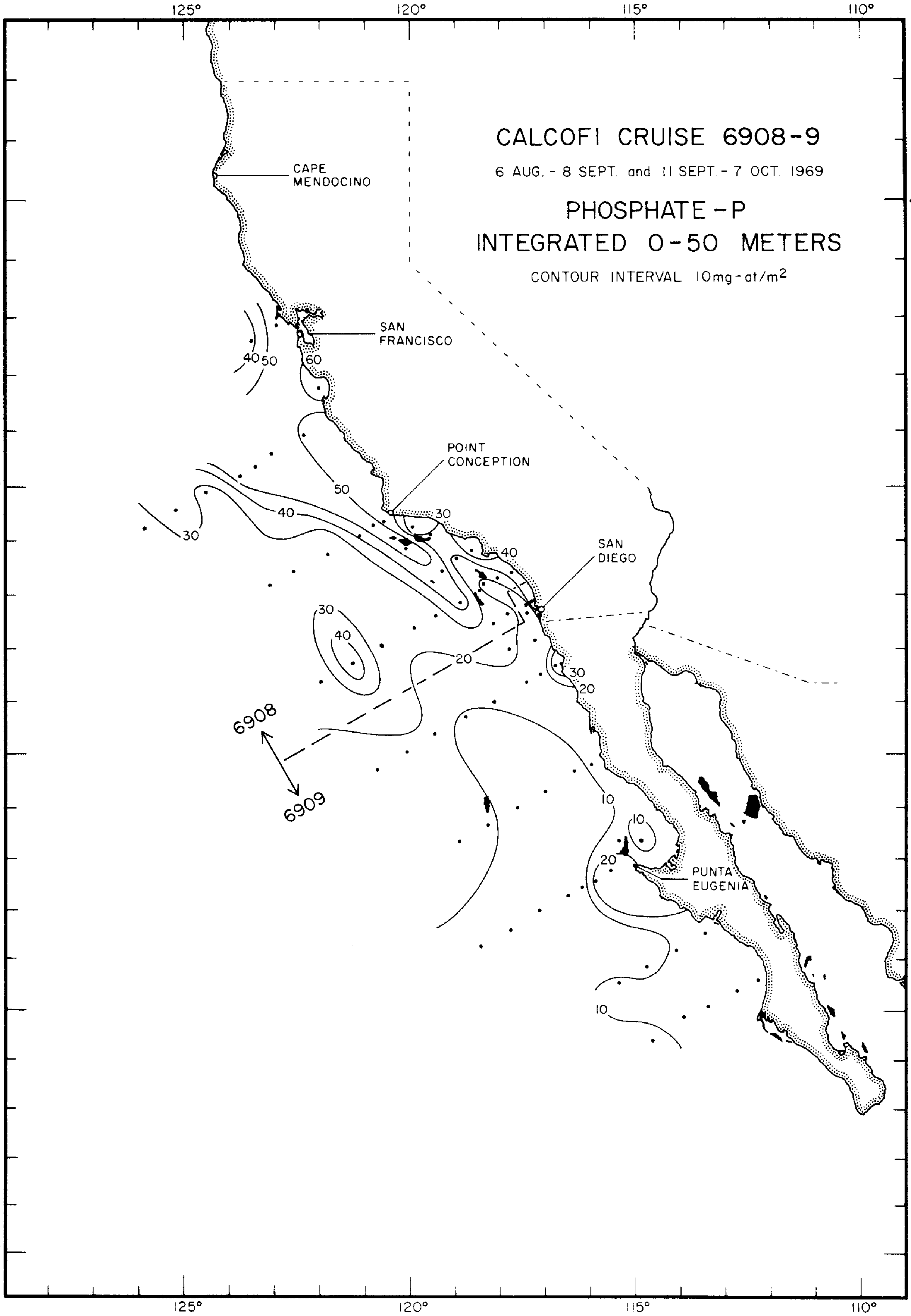
INTEGRATED PHOSPHATE-P

6905-6



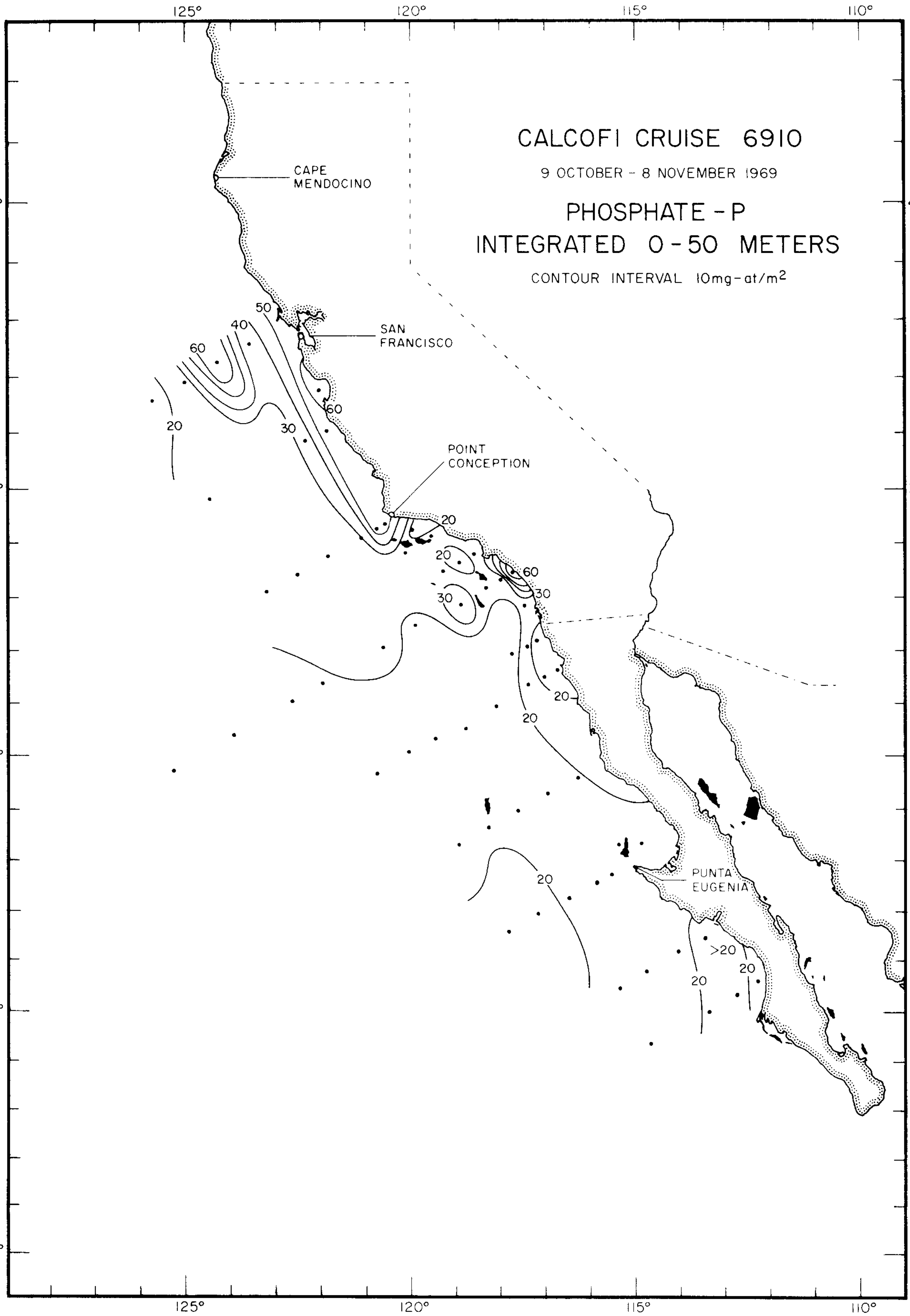
INTEGRATED PHOSPHATE-P

6907



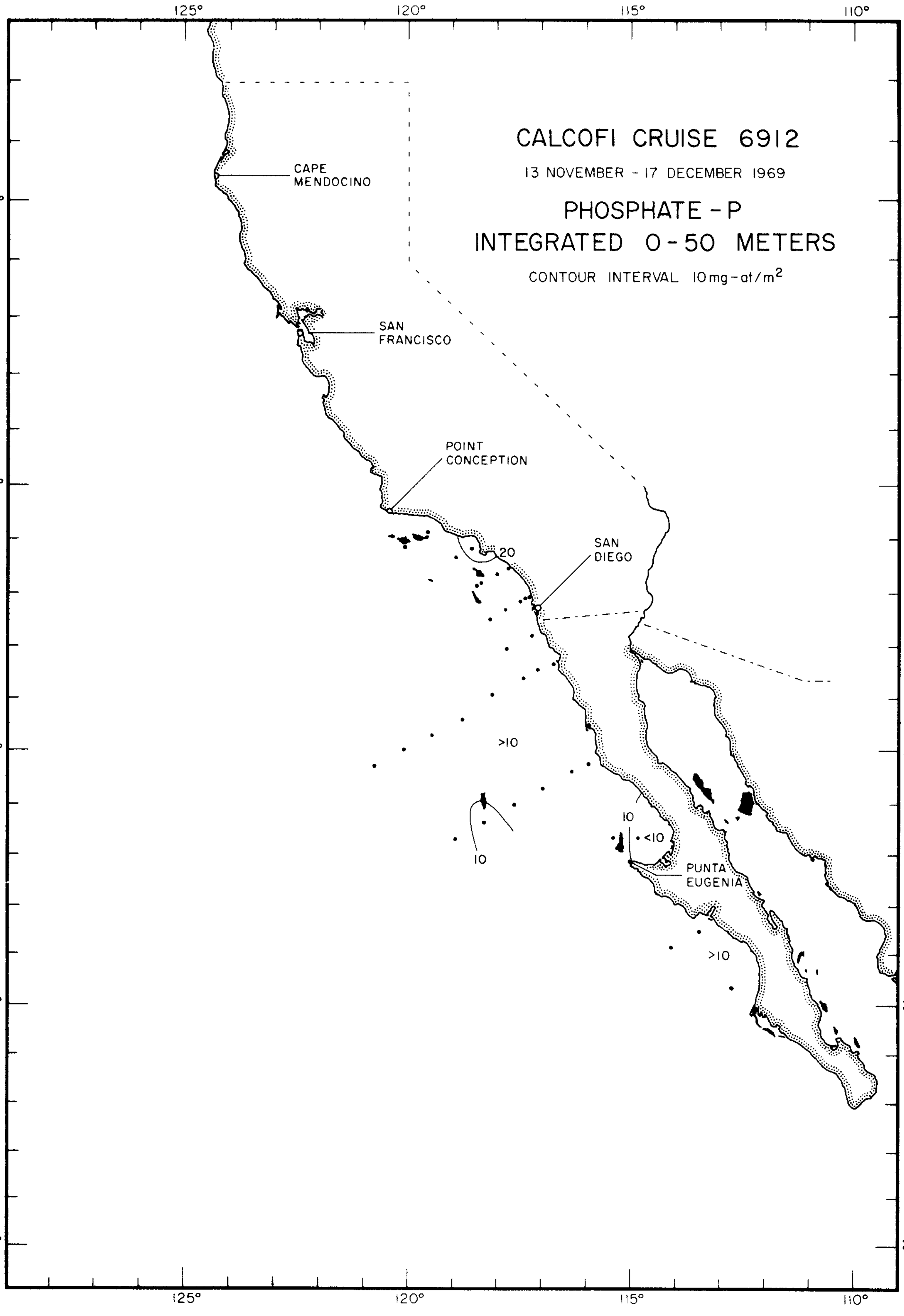
INTEGRATED PHOSPHATE-P

6908-9



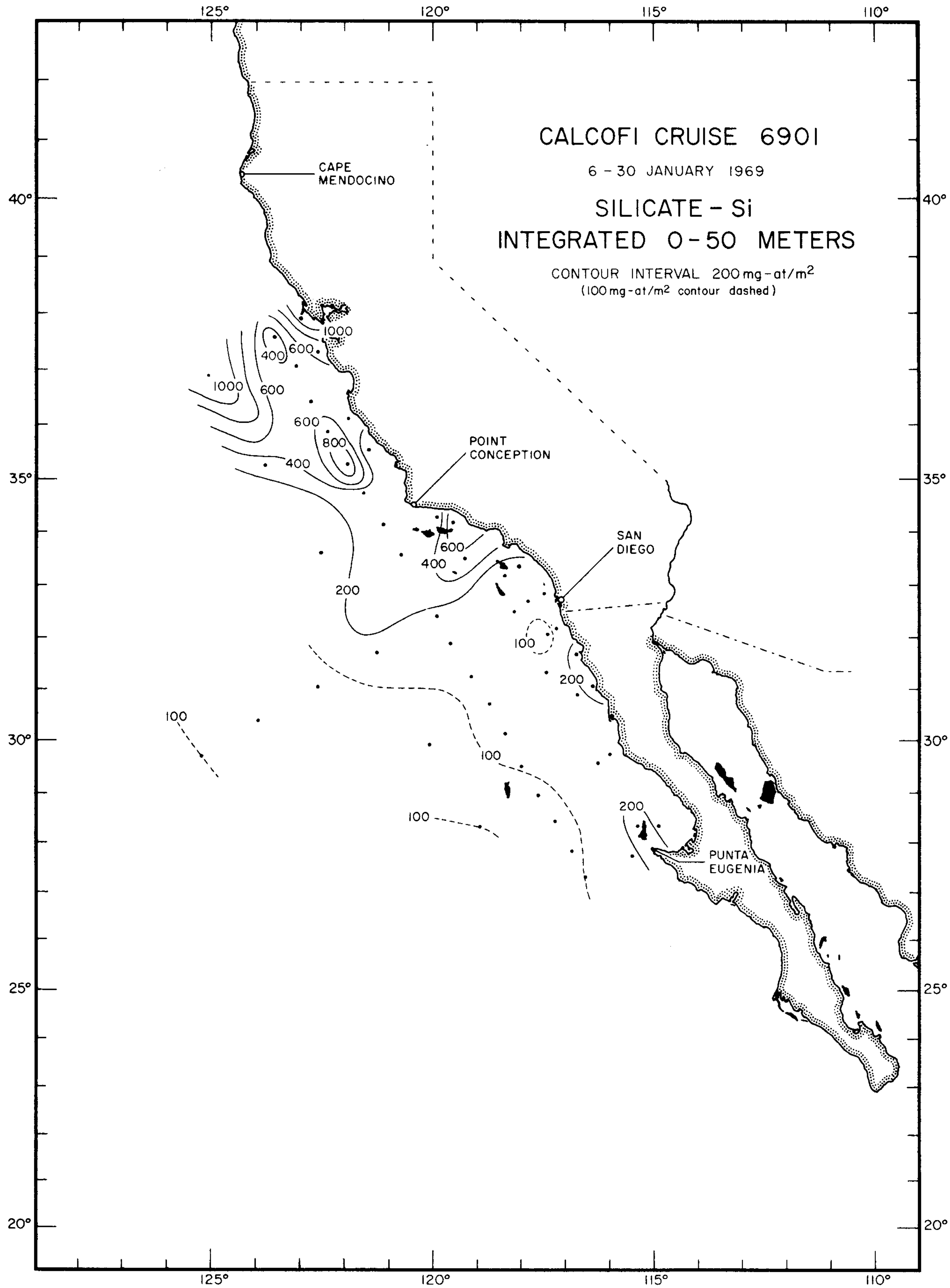
INTEGRATED PHOSPHATE-P

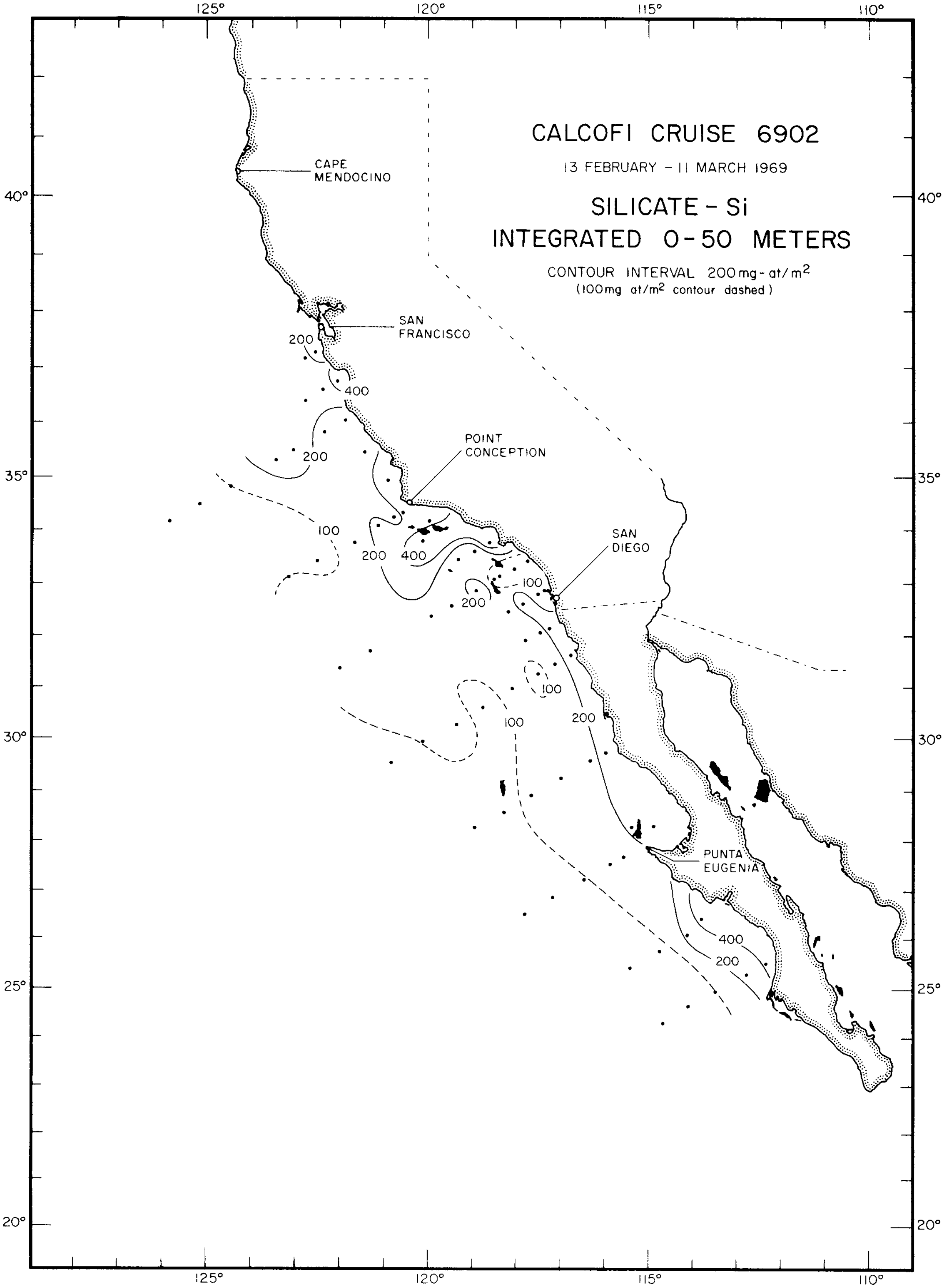
6910



INTEGRATED PHOSPHATE-P

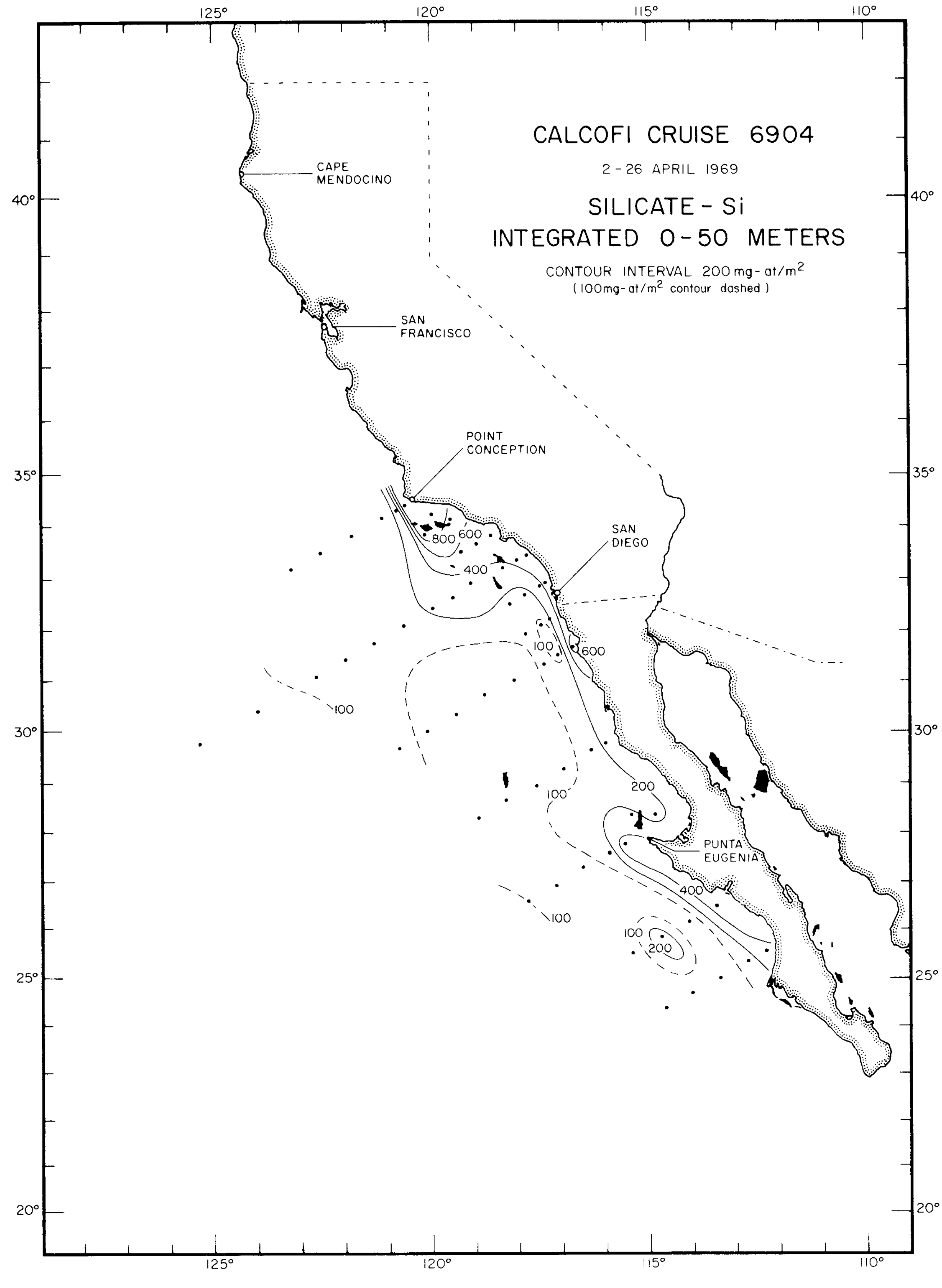
6912


125°
120°
115°
110°
40°
35°
30°
25°
20°
CALCOFI CRUISE 6901
6 - 30 JANUARY 1969
SILICATE - Si
INTEGRATED 0-50 METERS
CONTOUR INTERVAL 200 mg-at/m²
(100 mg-at/m² contour dashed)
CAPE MENDOCINO
POINT CONCEPTION
SAN DIEGO
PUNTA EUGENIA
1000
600
400
800
200
100



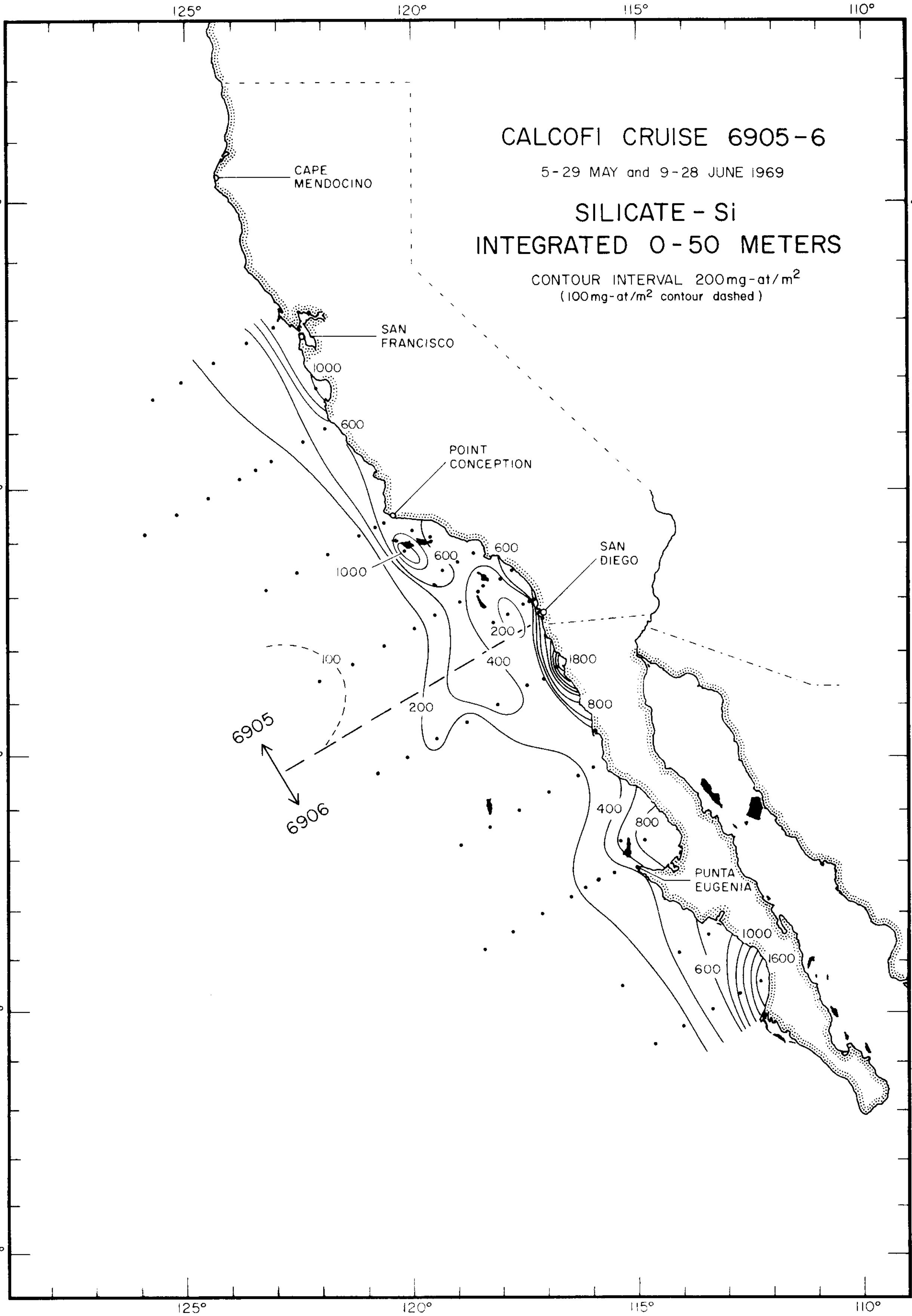
INTEGRATED SILICATE-Si

6902



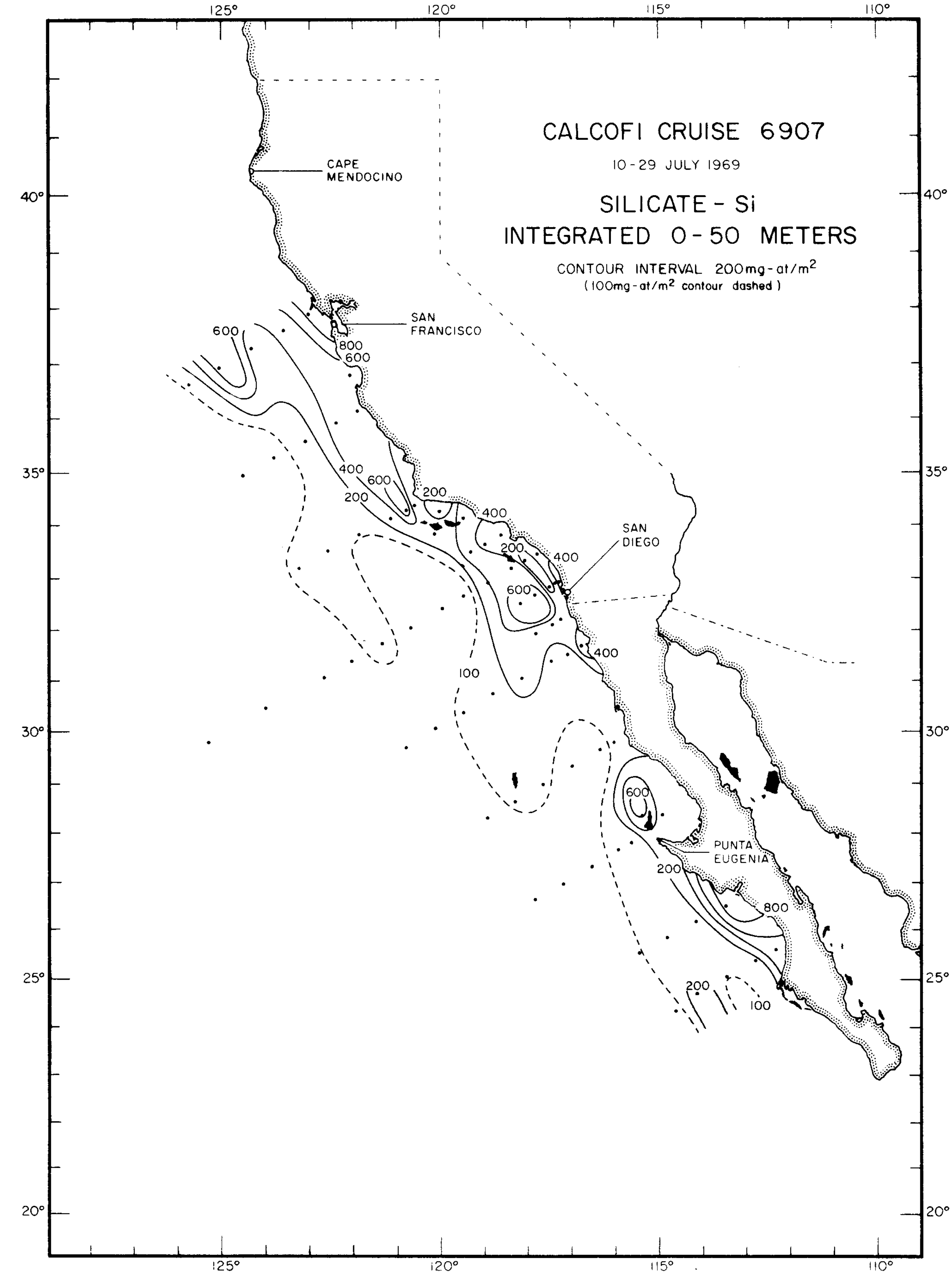
INTEGRATED SILICATE-Si

6904



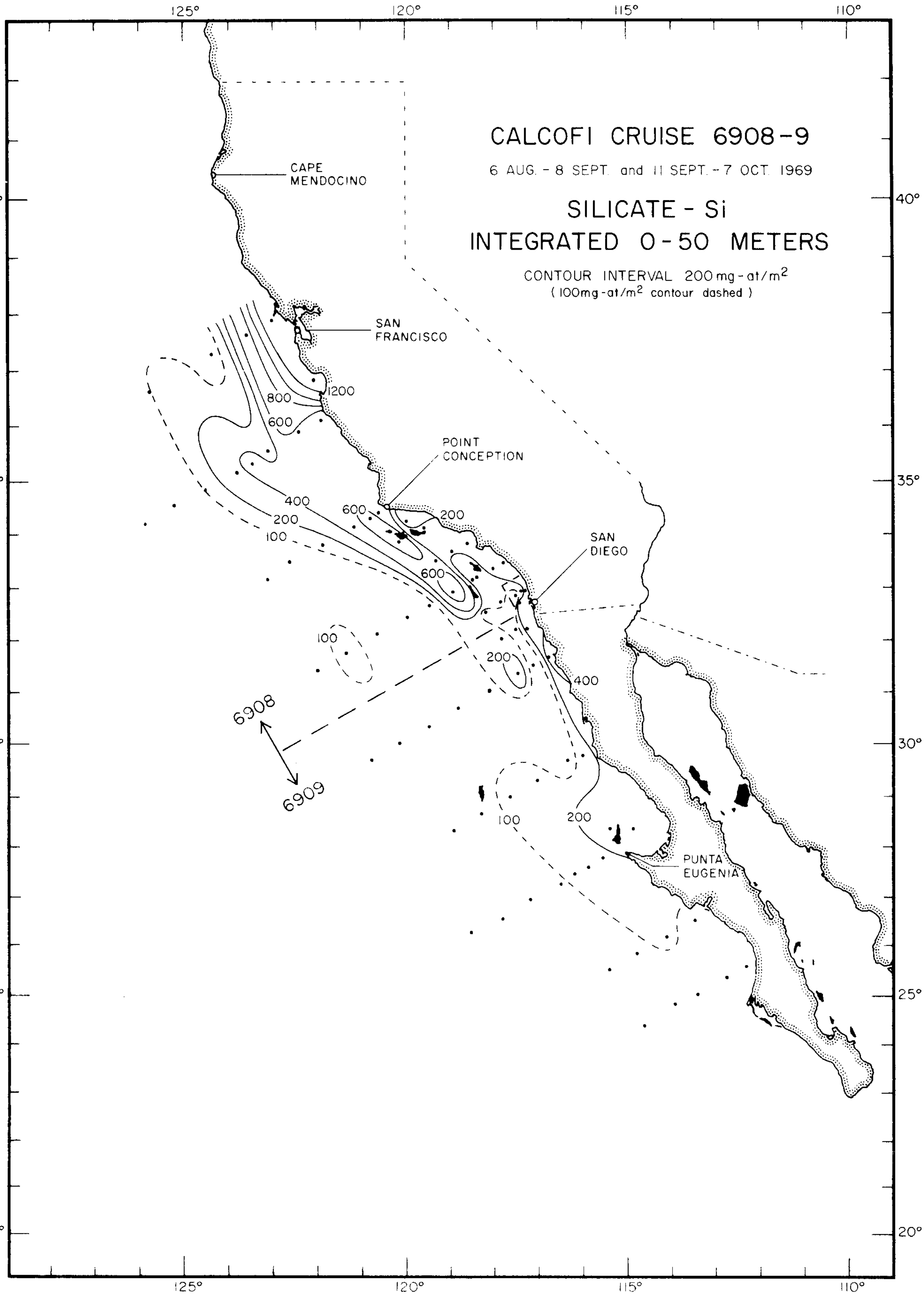
INTEGRATED SILICATE-Si

6905-6



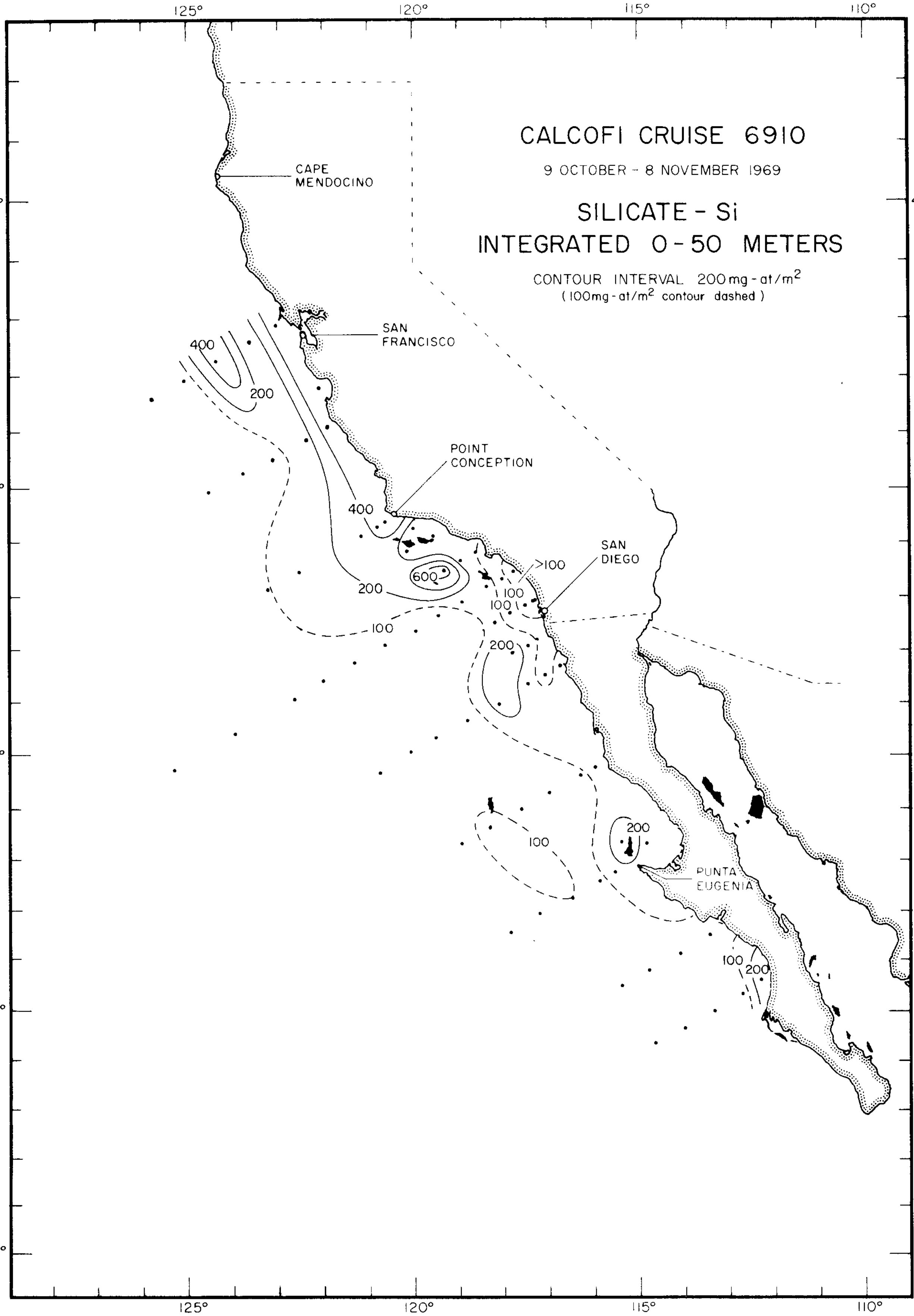
INTEGRATED SILICATE-Si

6907



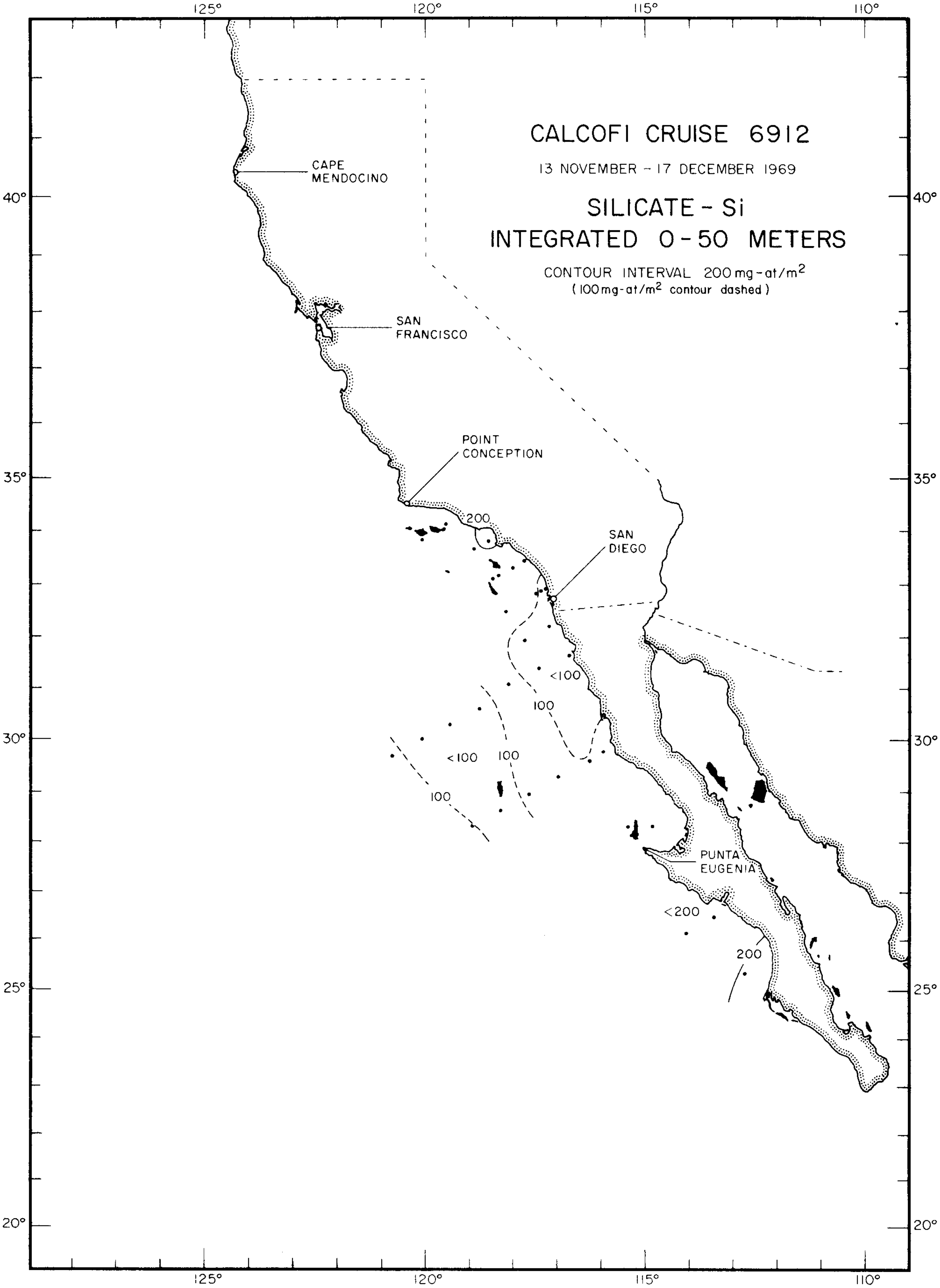
INTEGRATED SILICATE-Si

6908-9



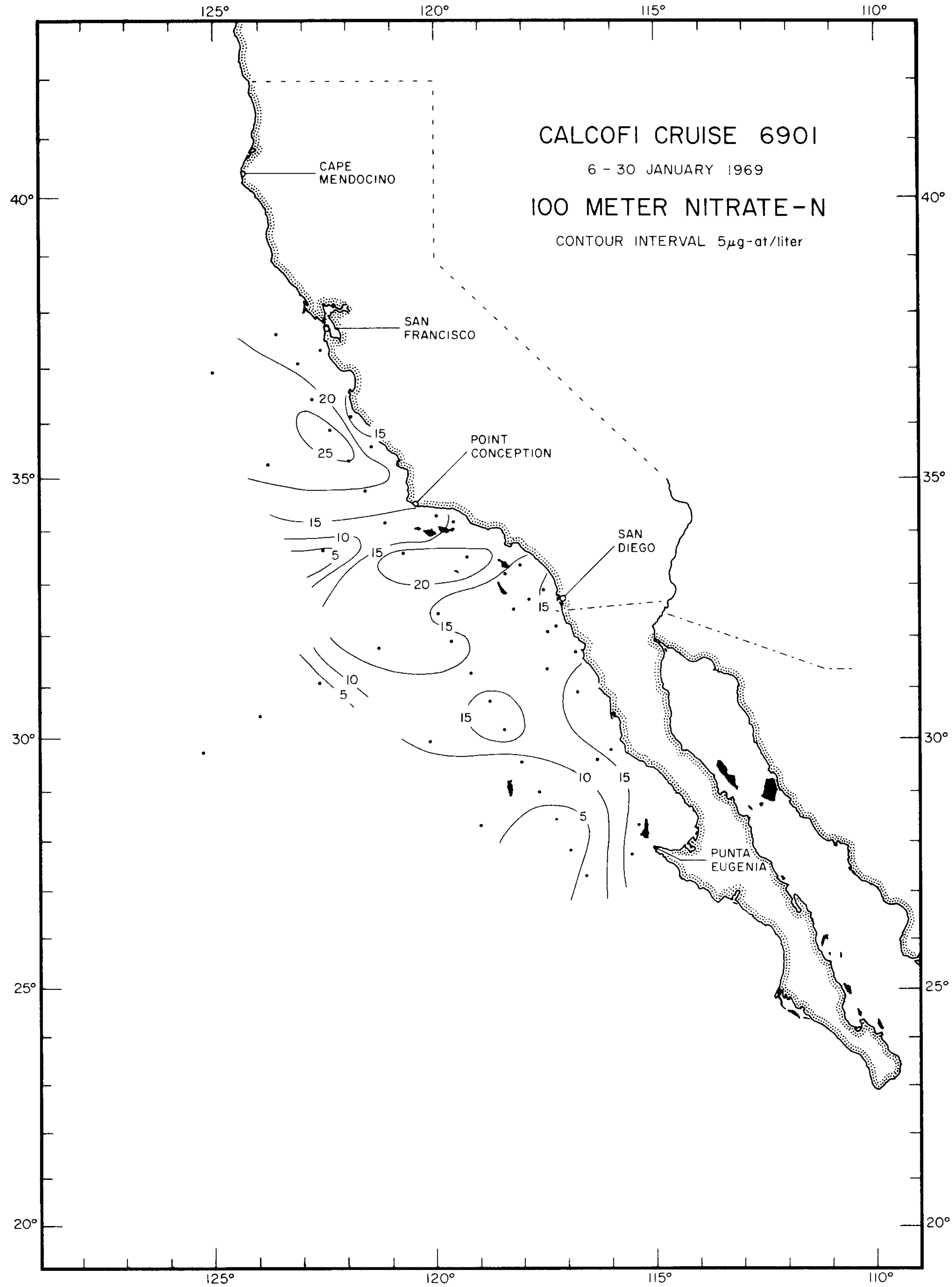
INTEGRATED SILICATE-Si

6910



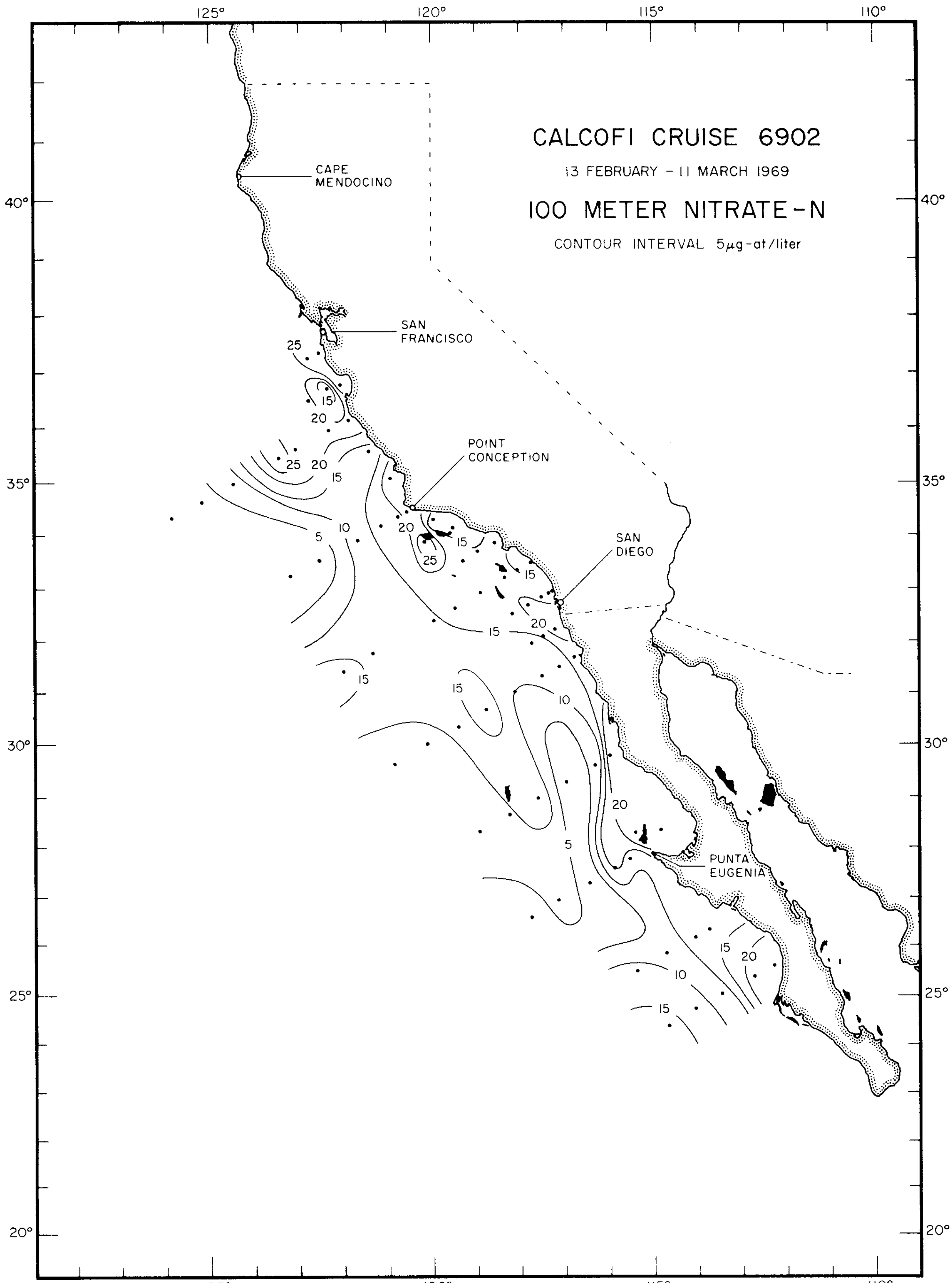
INTEGRATED SILICATE-Si

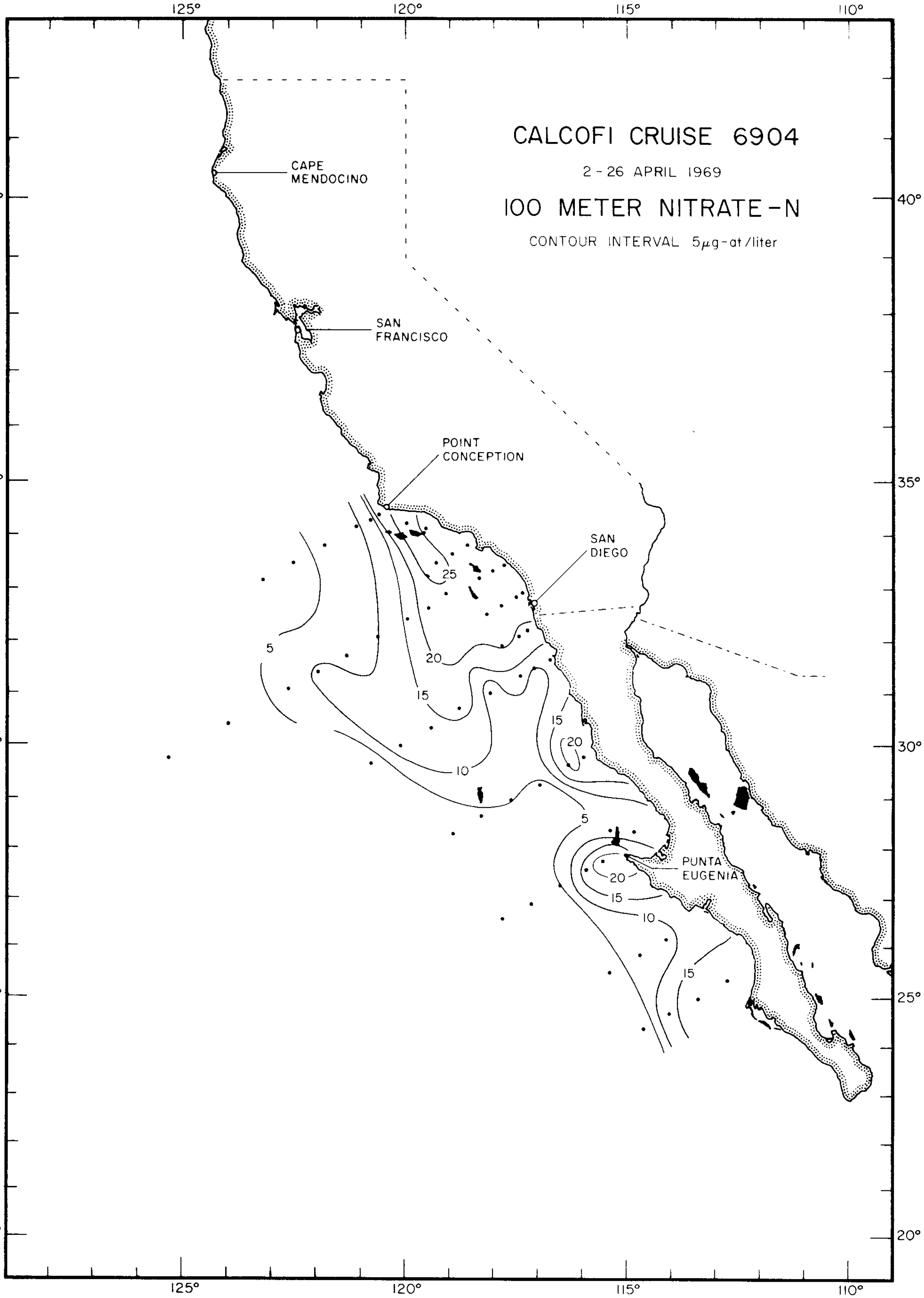
6912

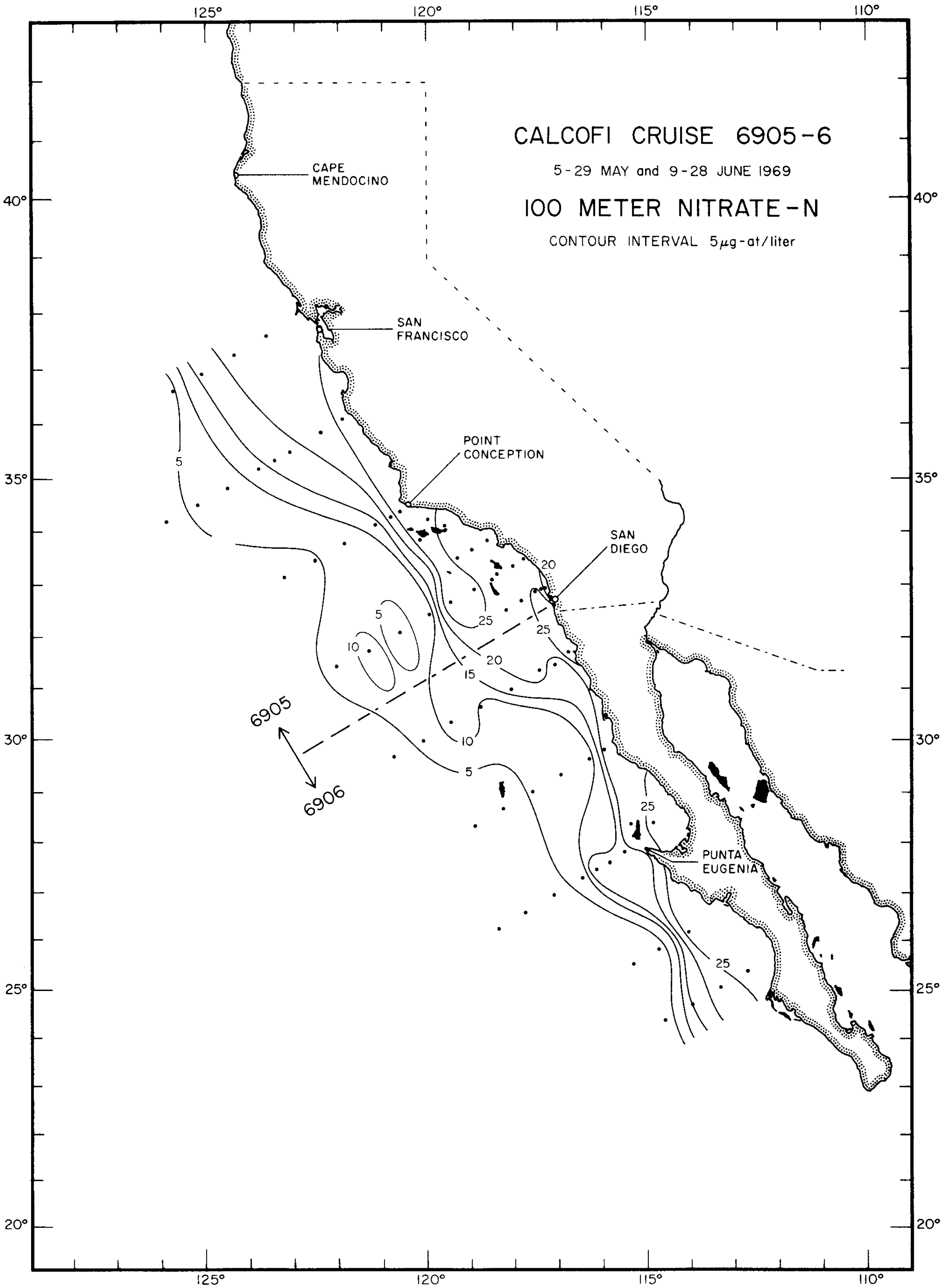


100m NITRATE-N

6901

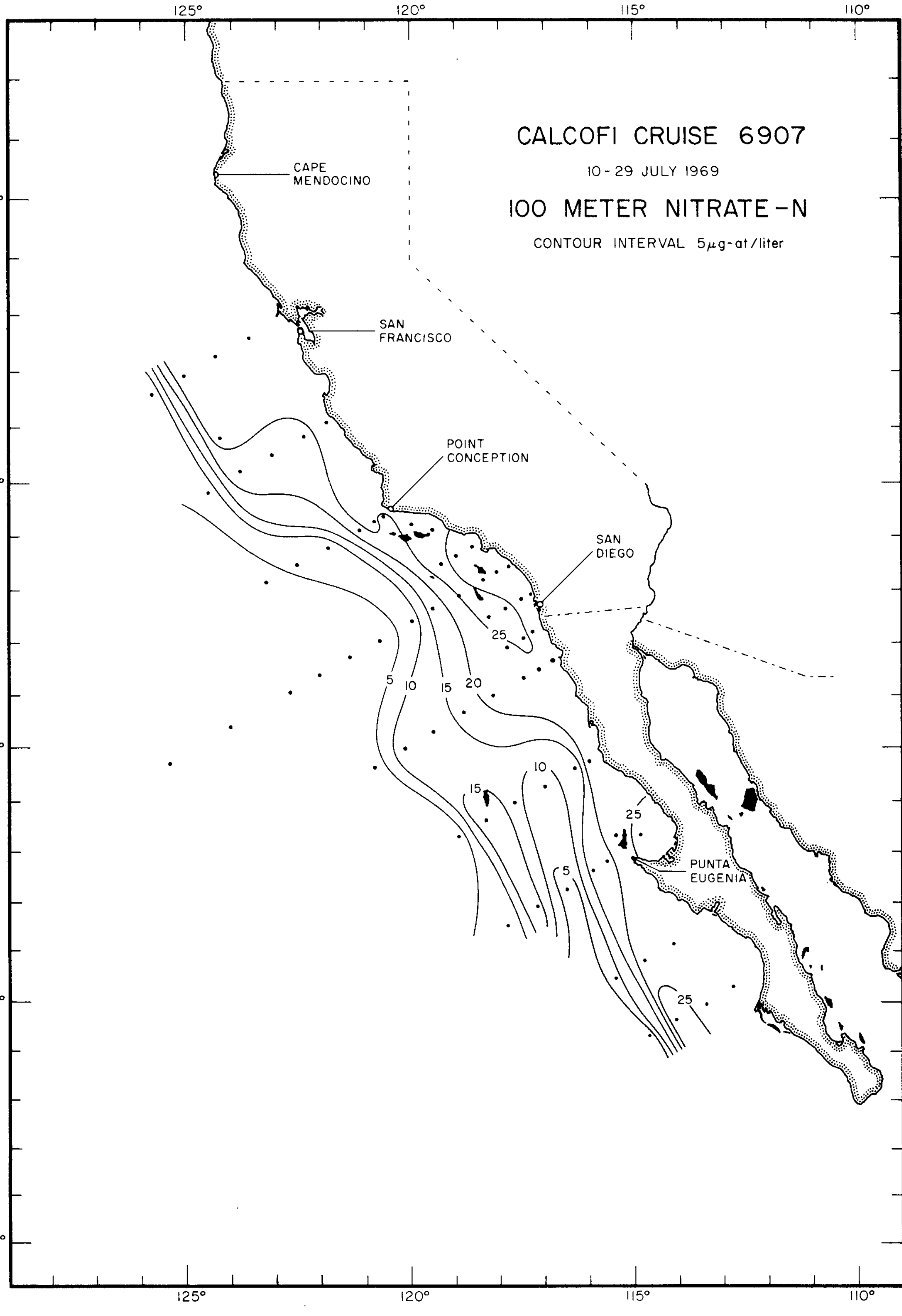

CALCOFI CRUISE 6902
13 FEBRUARY - 11 MARCH 1969
100 METER NITRATE-N
CONTOUR INTERVAL 5μg-at/liter
CAPE MENDOCINO
SAN FRANCISCO
POINT CONCEPTION
SAN DIEGO
PUNTA EUGENIA
125°
120°
115°
110°
40°
35°
30°
25°
20°


CALCOFI CRUISE 6904
2 - 26 APRIL 1969
100 METER NITRATE-N
CONTOUR INTERVAL 5μg-at/liter
CAPE MENDOCINO
SAN FRANCISCO
POINT CONCEPTION
SAN DIEGO
PUNTA EUGENIA
125°
120°
115°
110°
40°
35°
30°
25°
20°
5
10
15
20
25



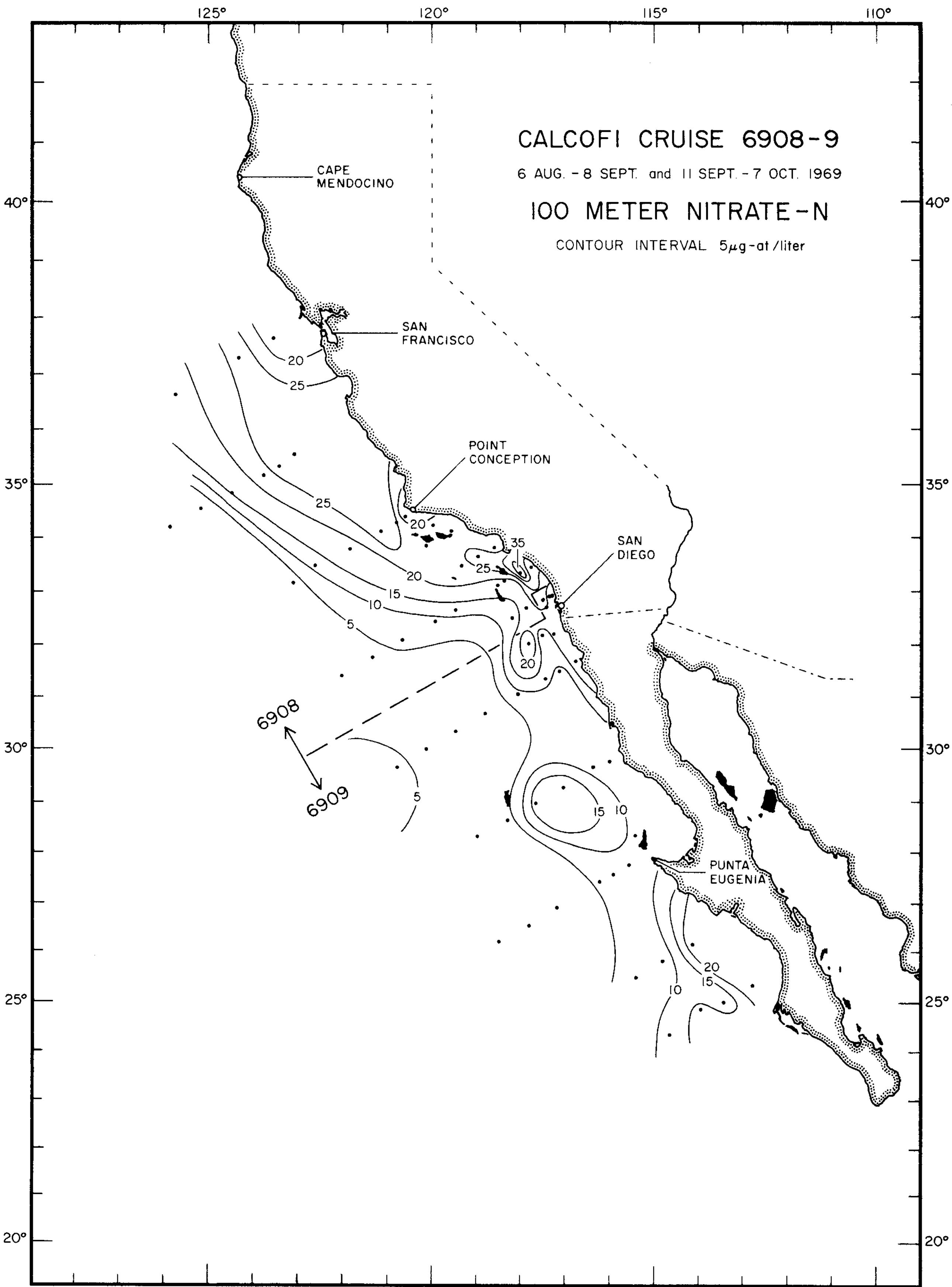
100m NITRATE-N

6905-6



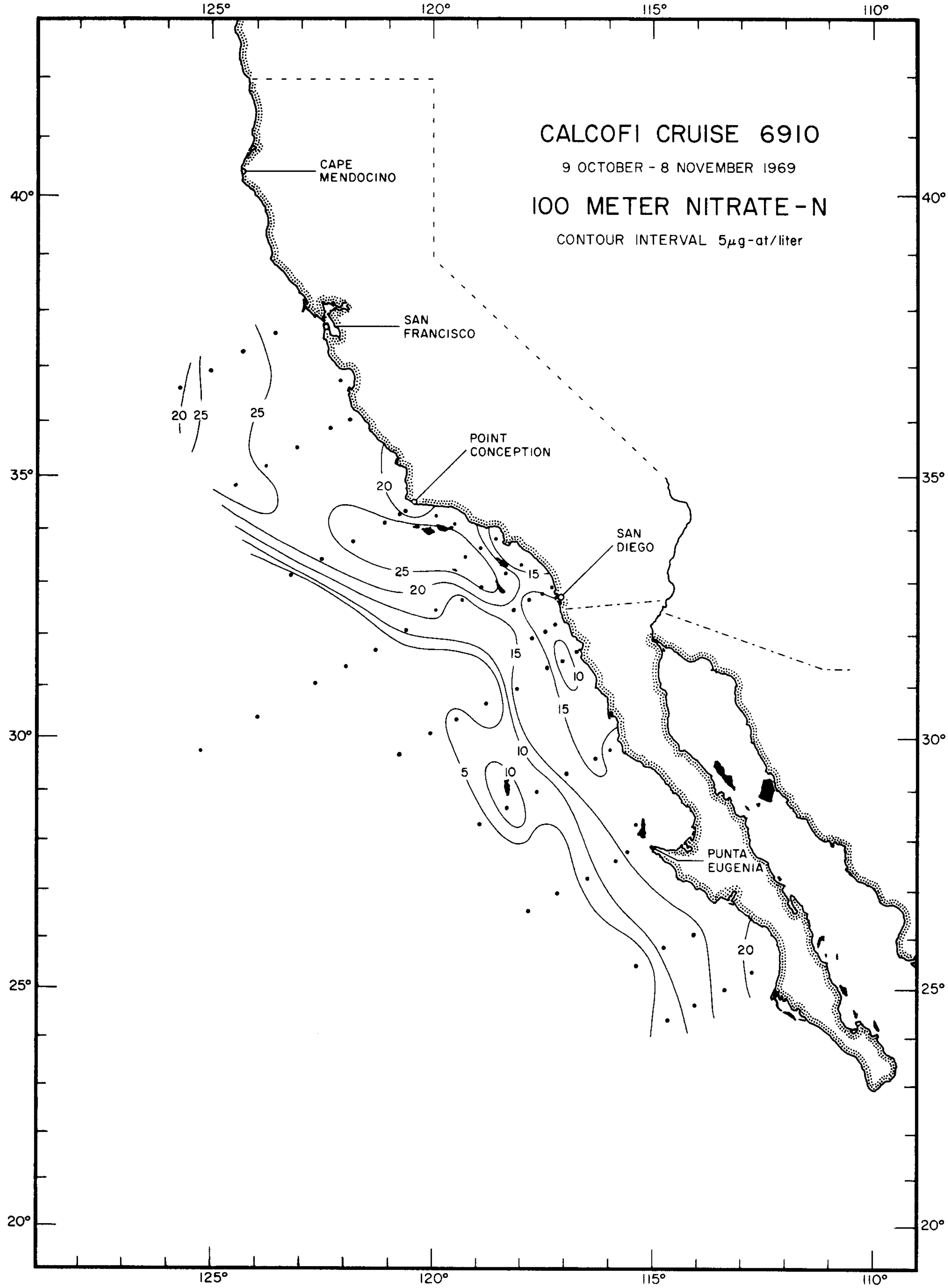
100m NITRATE-N

6907



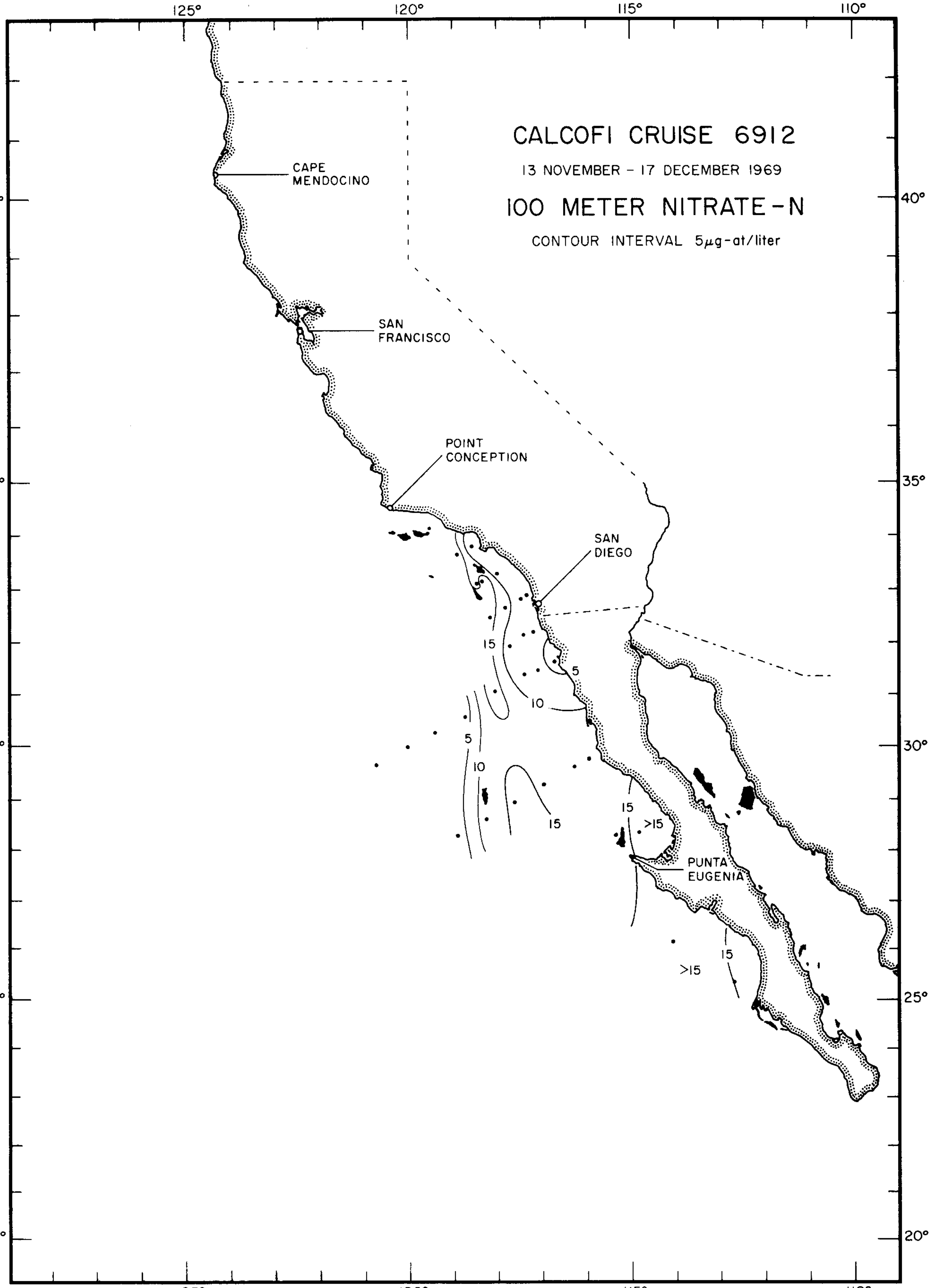
100m NITRATE-N

6908-9



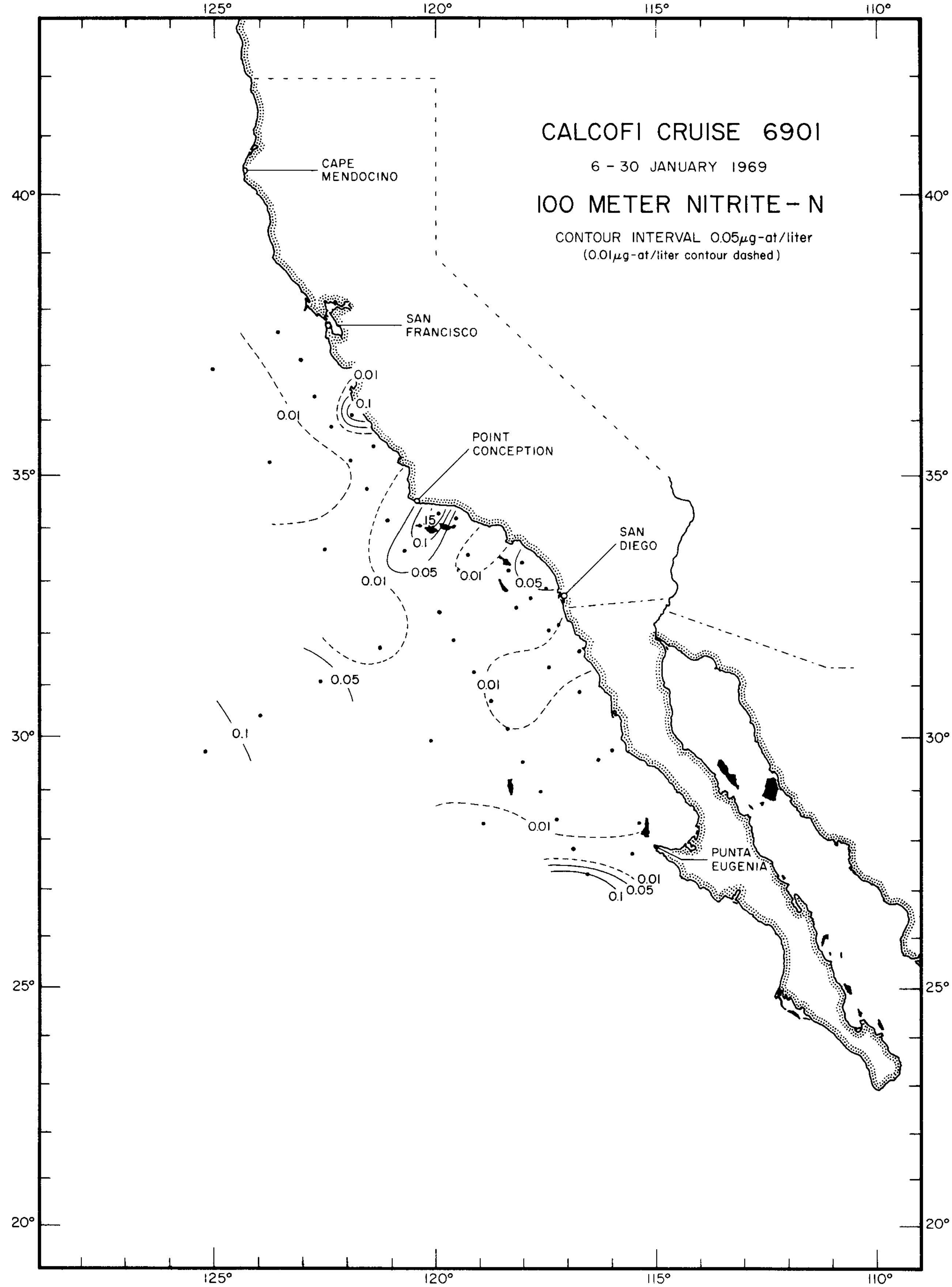
100m NITRATE-N

6910



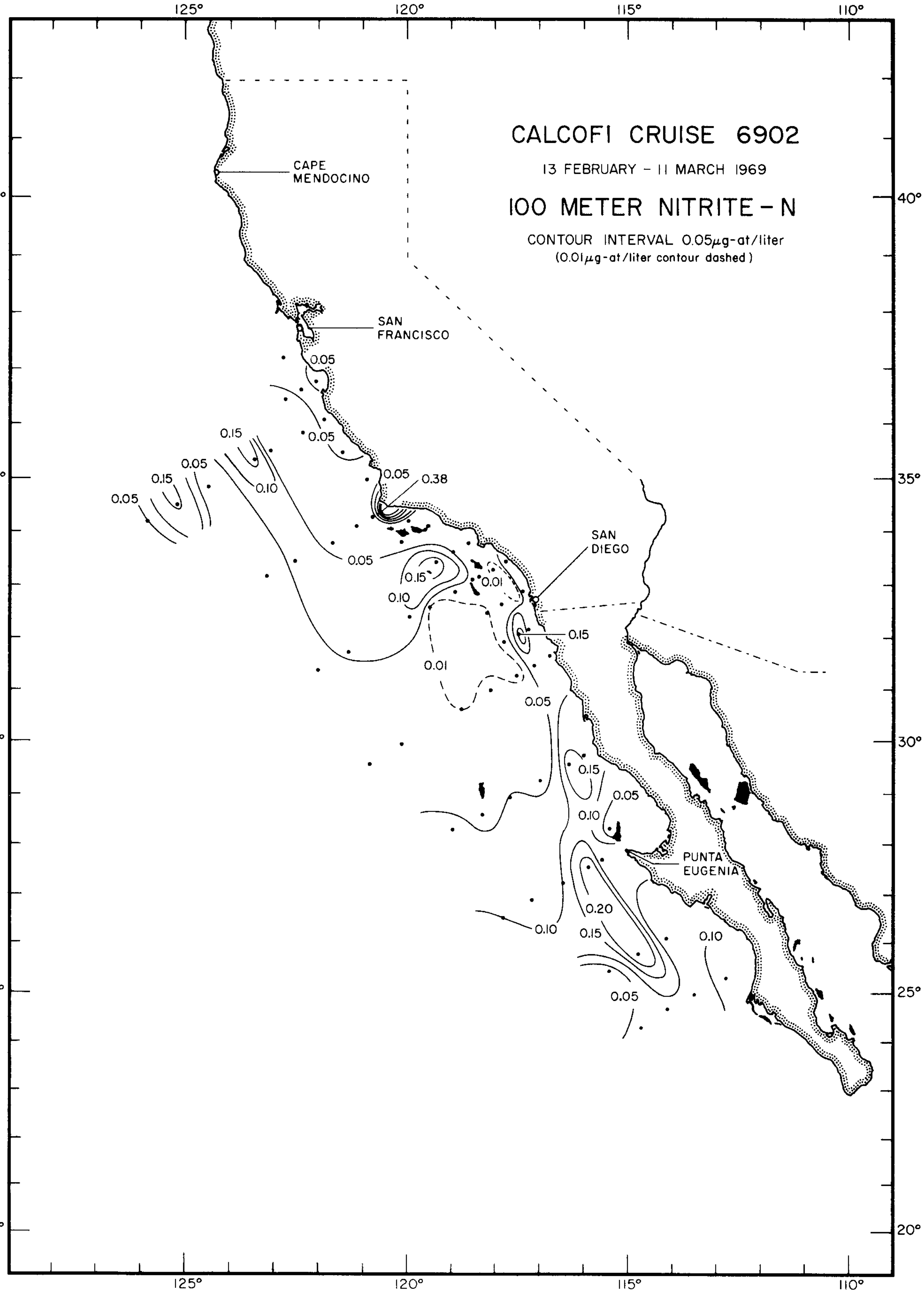
100m NITRATE-N

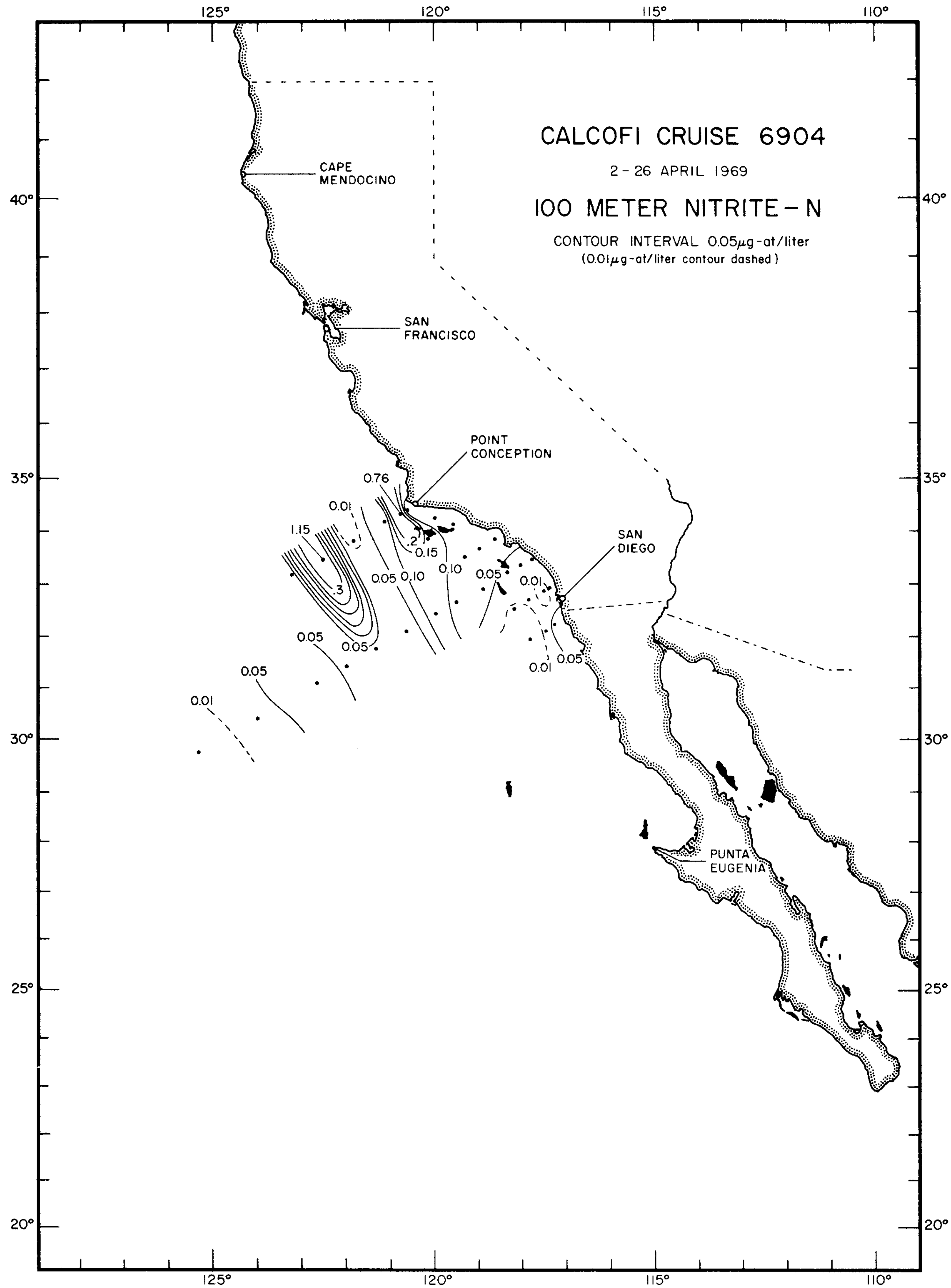
6912



100m NITRITE-N

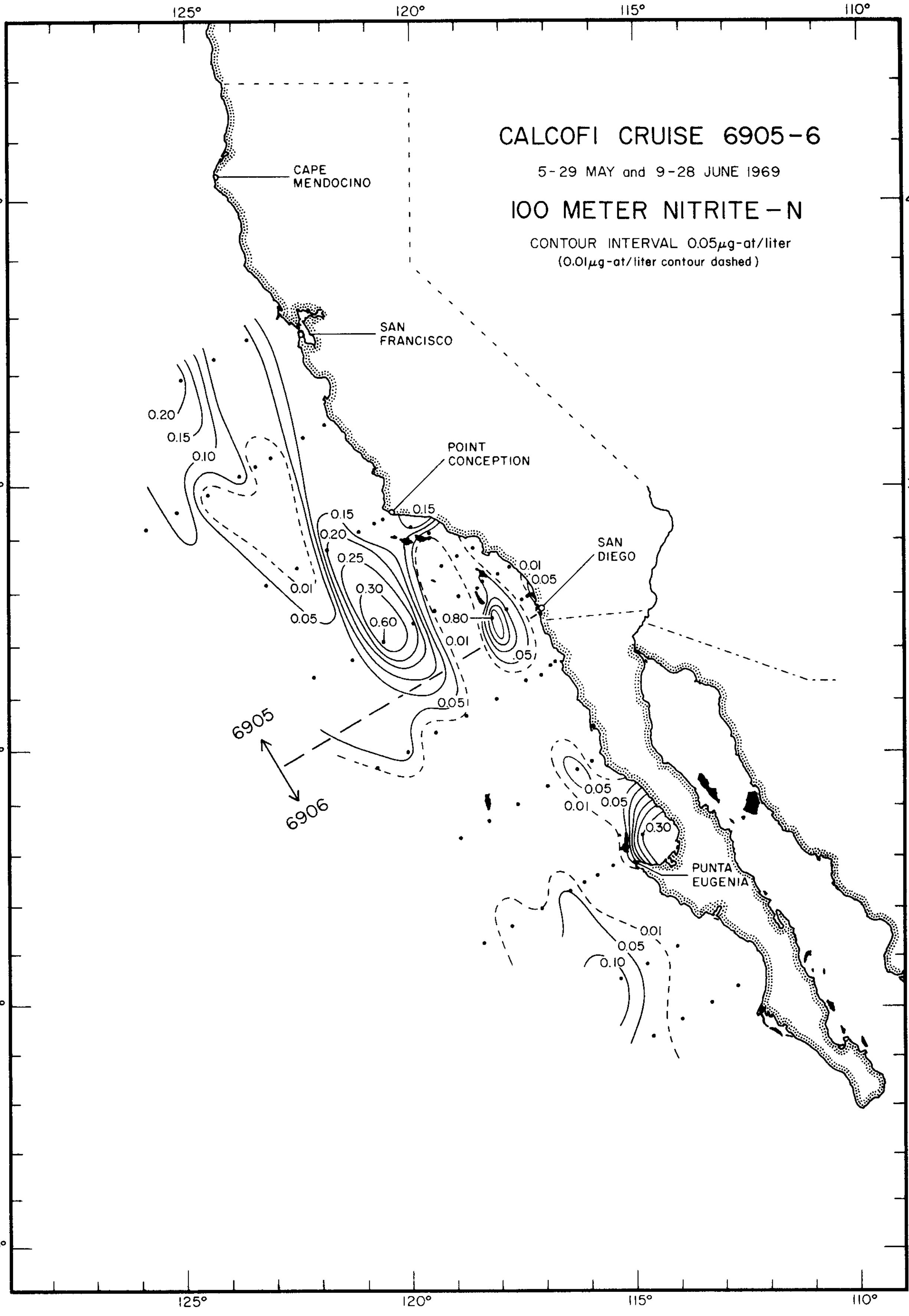
6901


CALCOFI CRUISE 6902
13 FEBRUARY - 11 MARCH 1969
100 METER NITRITE-N
CONTOUR INTERVAL 0.05μg-at/liter
(0.01μg-at/liter contour dashed)
CAPE MENDOCINO
SAN FRANCISCO
SAN DIEGO
PUNTA EUGENIA
125°
120°
115°
110°
40°
35°
30°
25°
20°
0.05
0.10
0.15
0.20
0.38
0.01



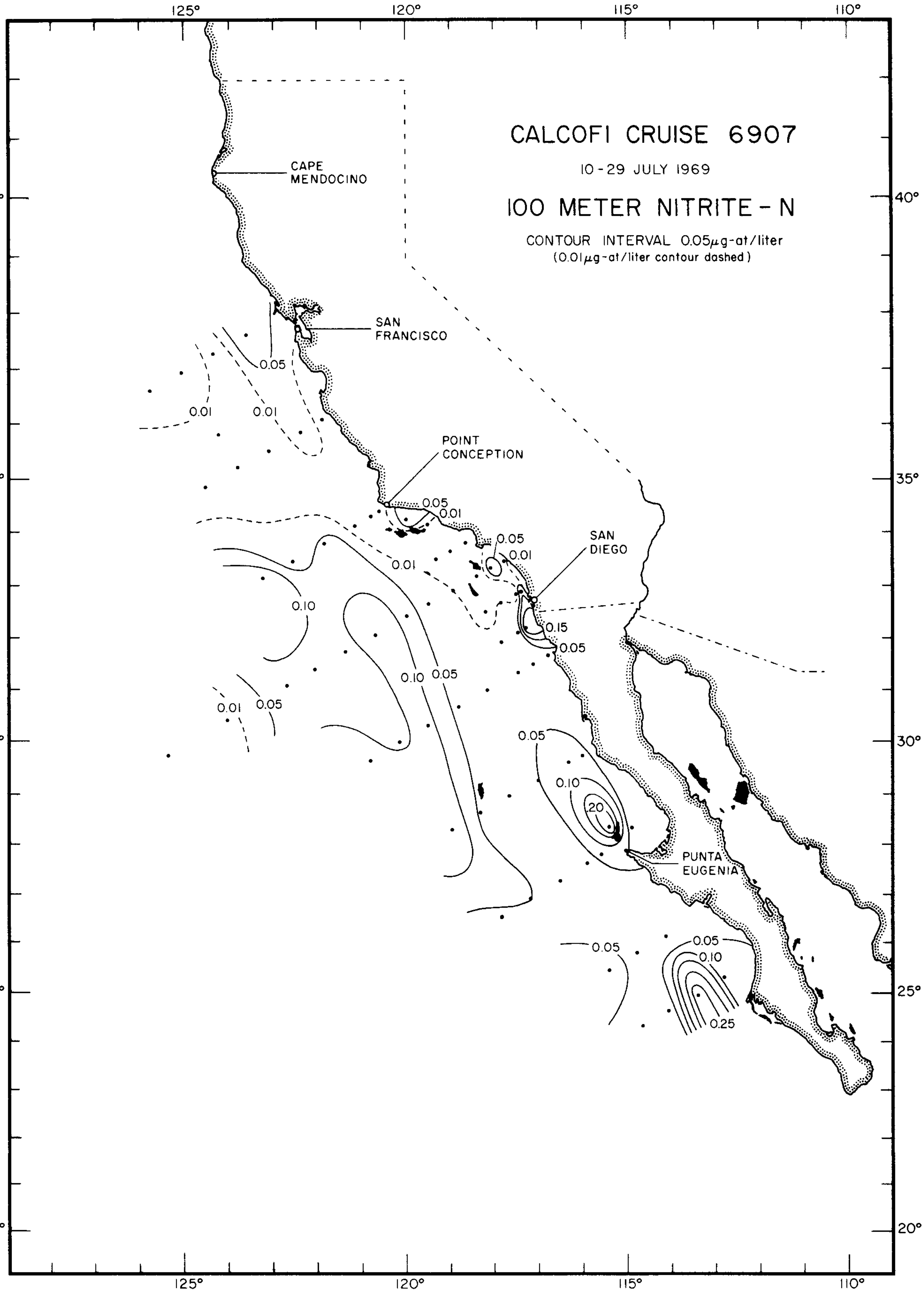
100m NITRITE-N

6904



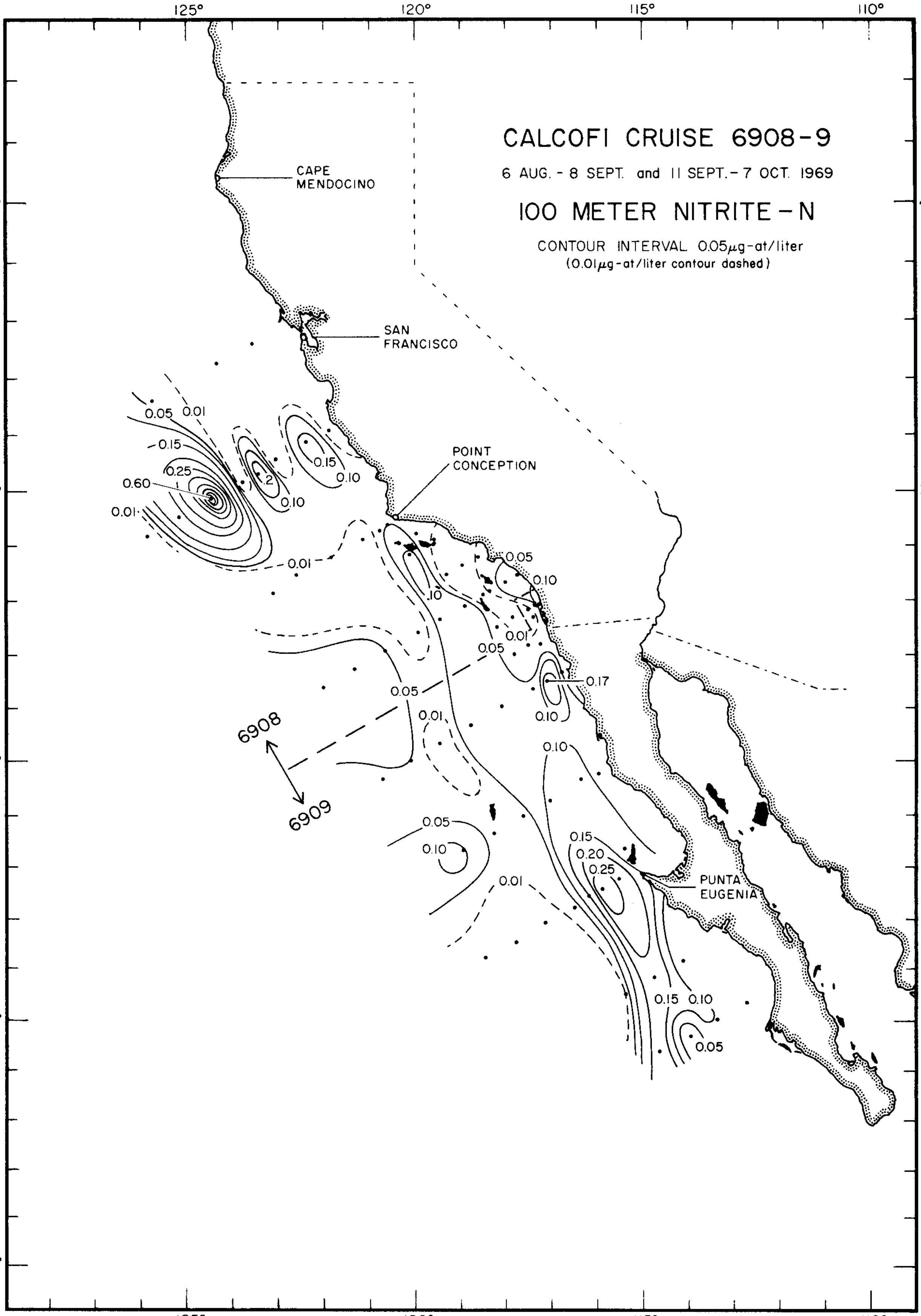
100m NITRITE-N

6905-6



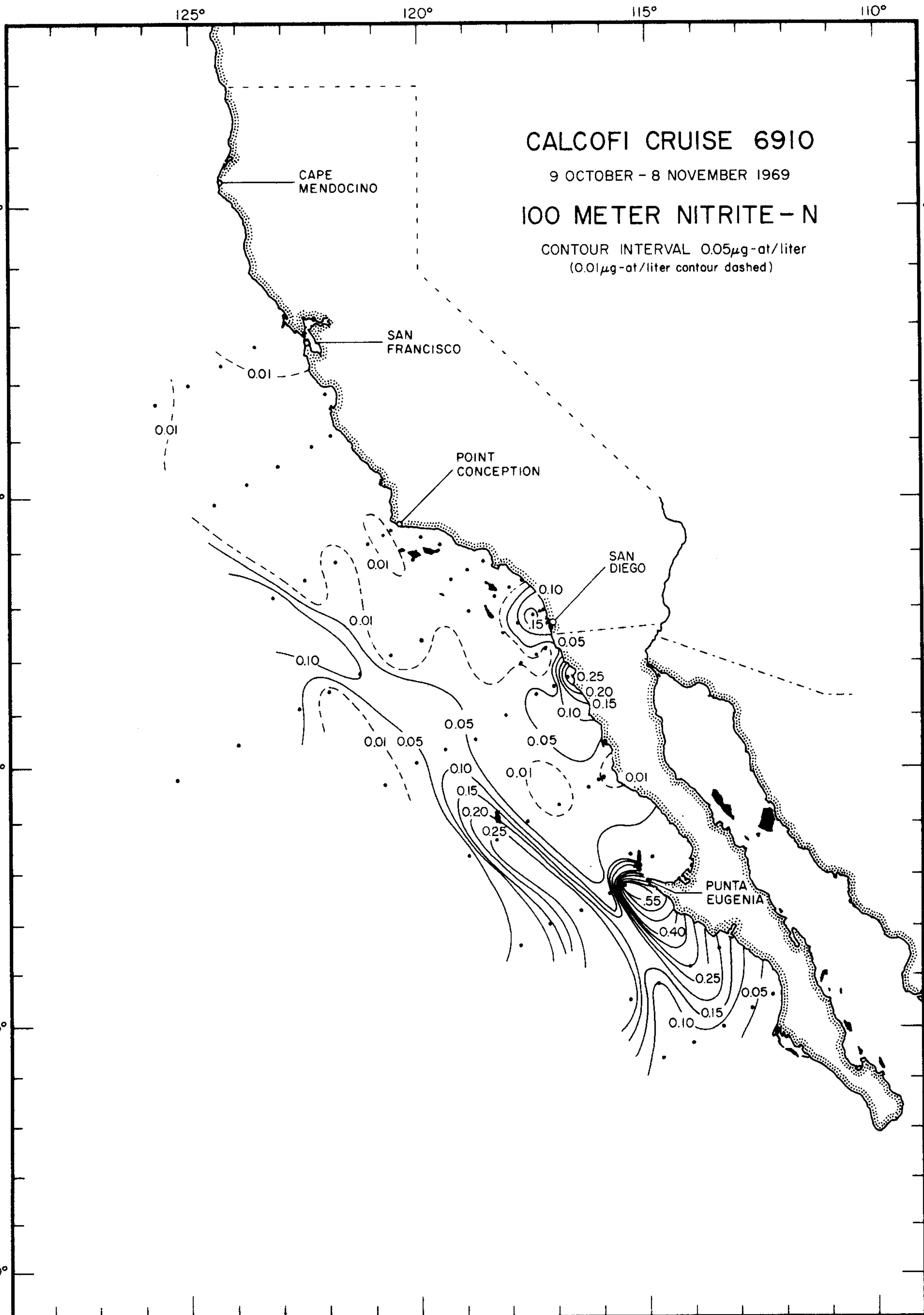
100m NITRITE-N

6907



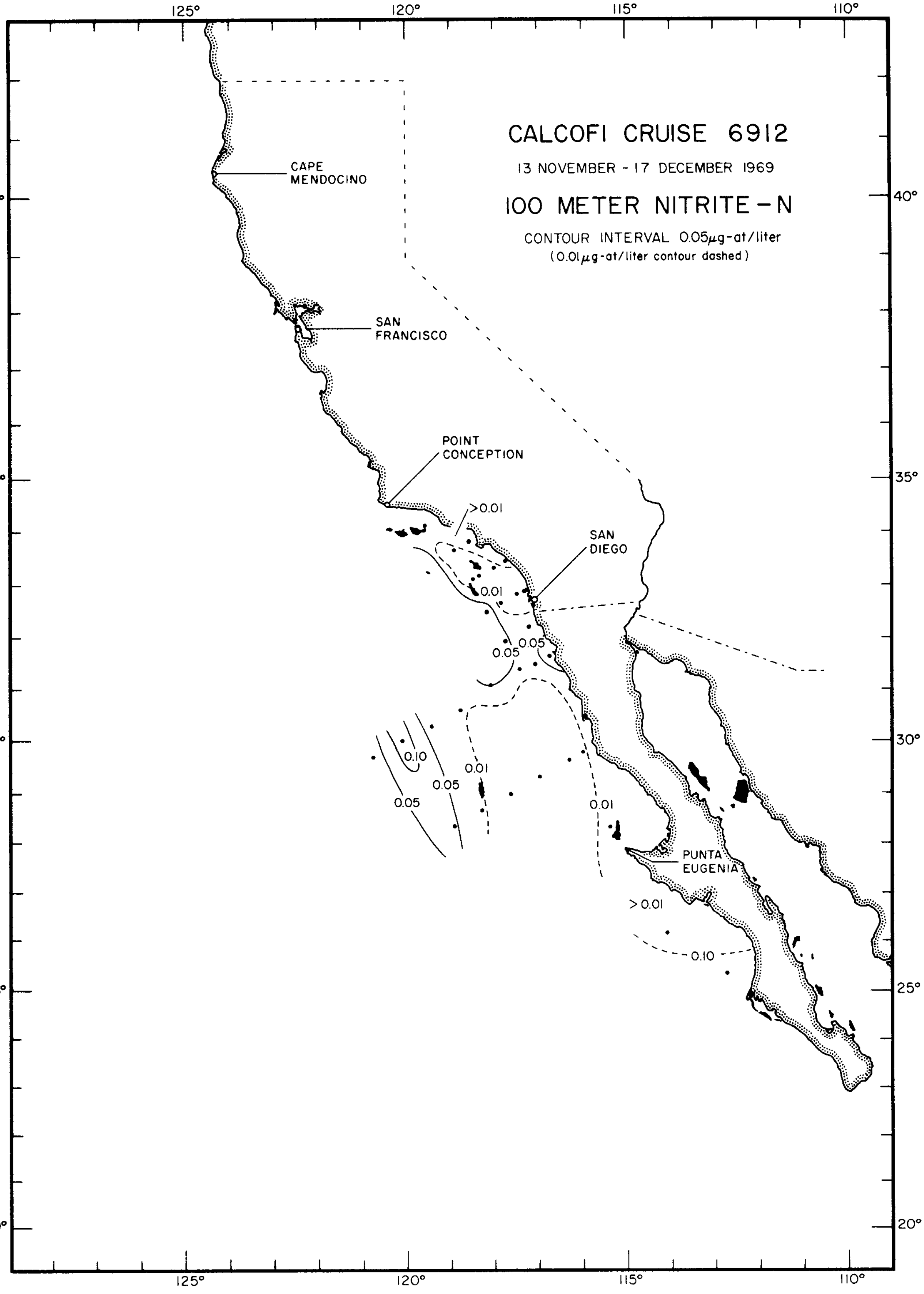
100m NITRITE-N

6908-9

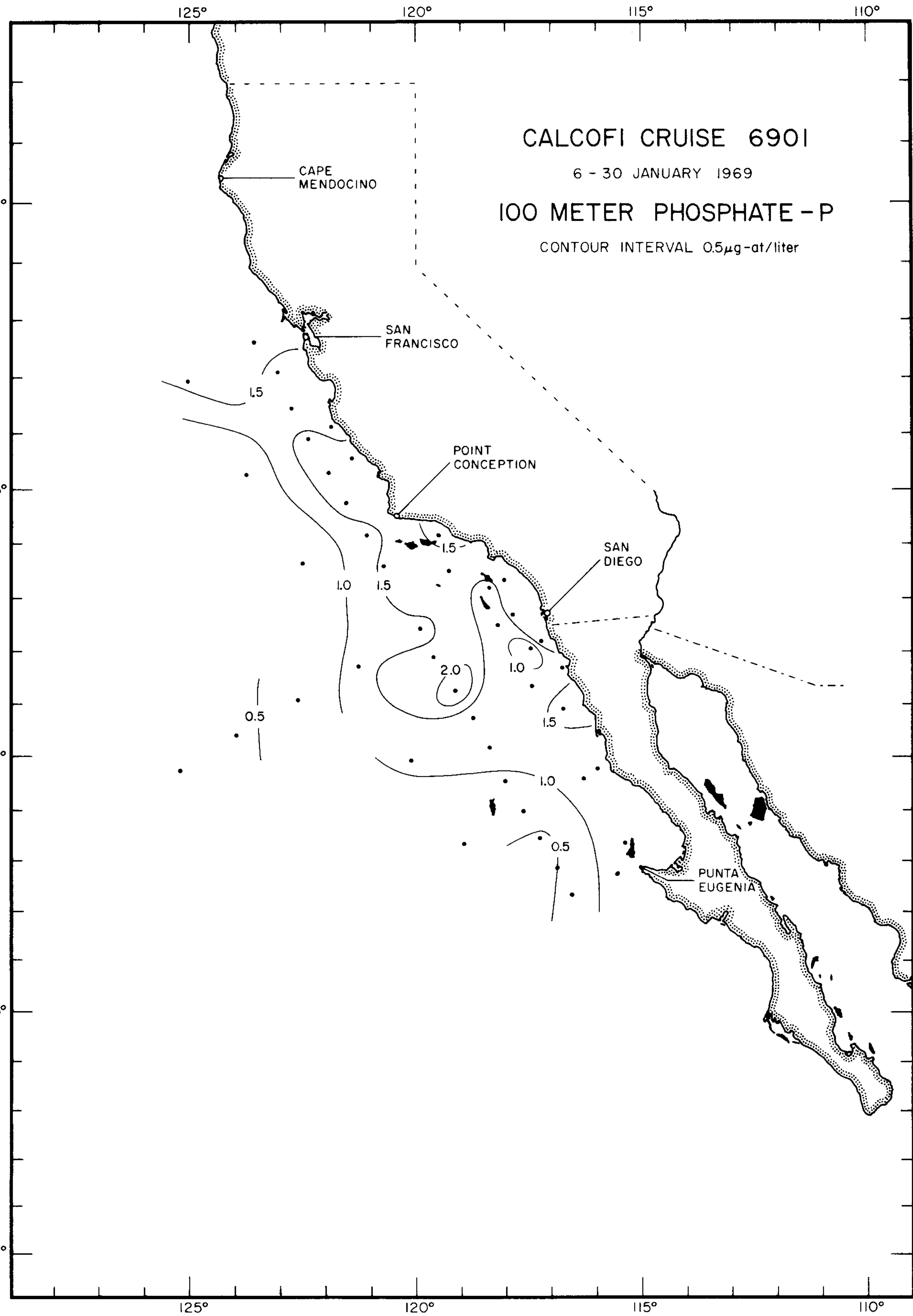


100m NITRITE-N

6910



CALCOFI CRUISE 6912
13 NOVEMBER - 17 DECEMBER 1969
100 METER NITRITE-N
CONTOUR INTERVAL 0.05μg-at/liter
(0.01μg-at/liter contour dashed)
125°
120°
115°
110°
40°
35°
30°
25°
20°
CAPE MENDOCINO
SAN FRANCISCO
POINT CONCEPTION
SAN DIEGO
PUNTA EUGENIA
>0.01
0.01
0.05
0.05
0.10
0.05
0.05
0.01
0.01
>0.01
0.10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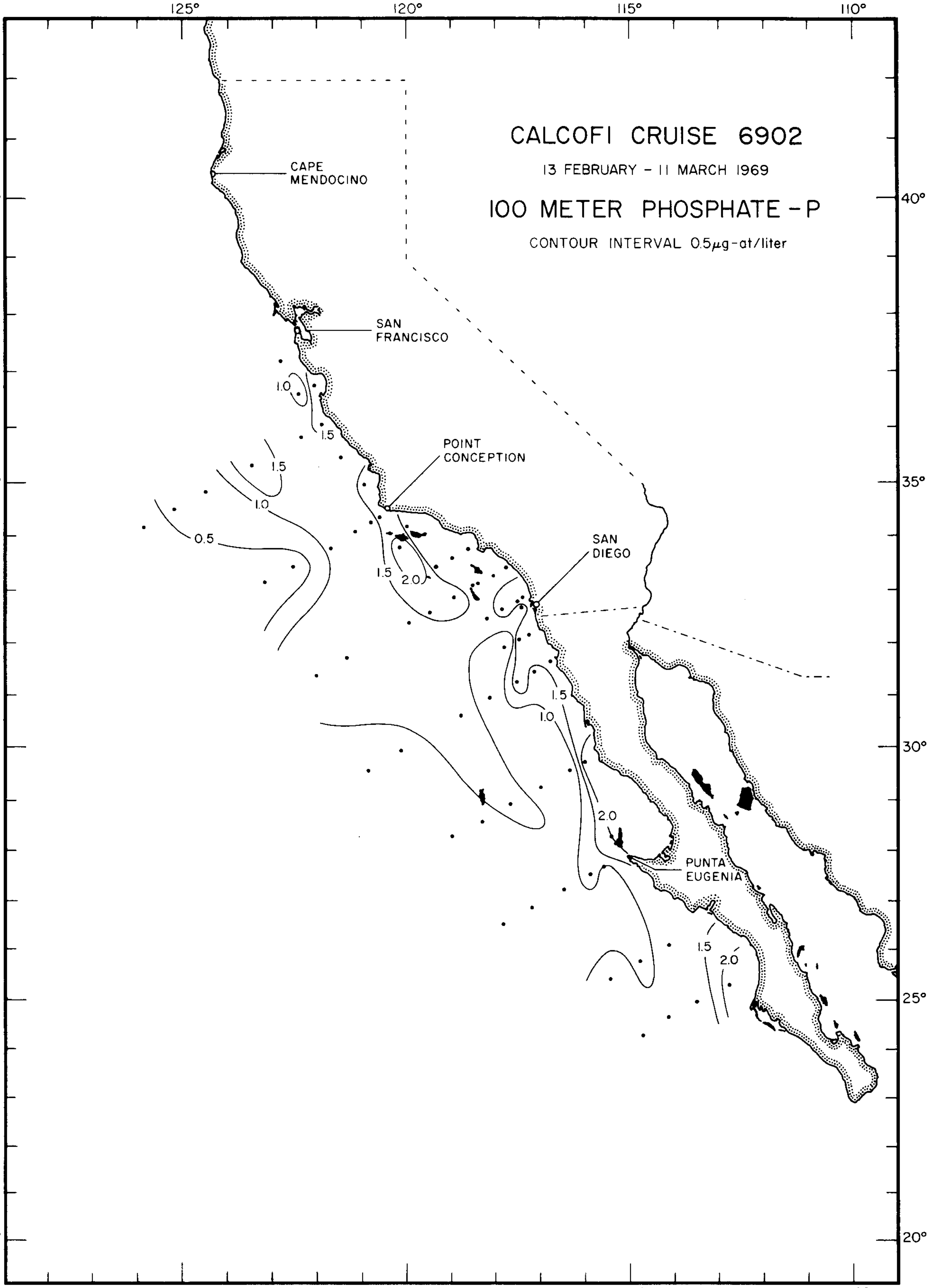
6 - 30 JANUARY 1969
100 METER PHOSPHATE - P
CONTOUR INTERVAL 0.5μg-at/liter
CAPE MENDOCINO
SAN FRANCISCO
POINT CONCEPTION
SAN DIEGO
PUNTA EUGENIA
125°
120°
115°
110°
40°
35°
30°
25°
20°
1.5
1.0
2.0
0.5


CALCOFI CRUISE 6902
13 FEBRUARY - 11 MARCH 1969
100 METER PHOSPHATE - P
CONTOUR INTERVAL 0.5μg-at/liter
CAPE
MENDOCINO
SAN
FRANCISCO
POINT
CONCEPTION
SAN
DIEGO
PUNTA
EUGENIA
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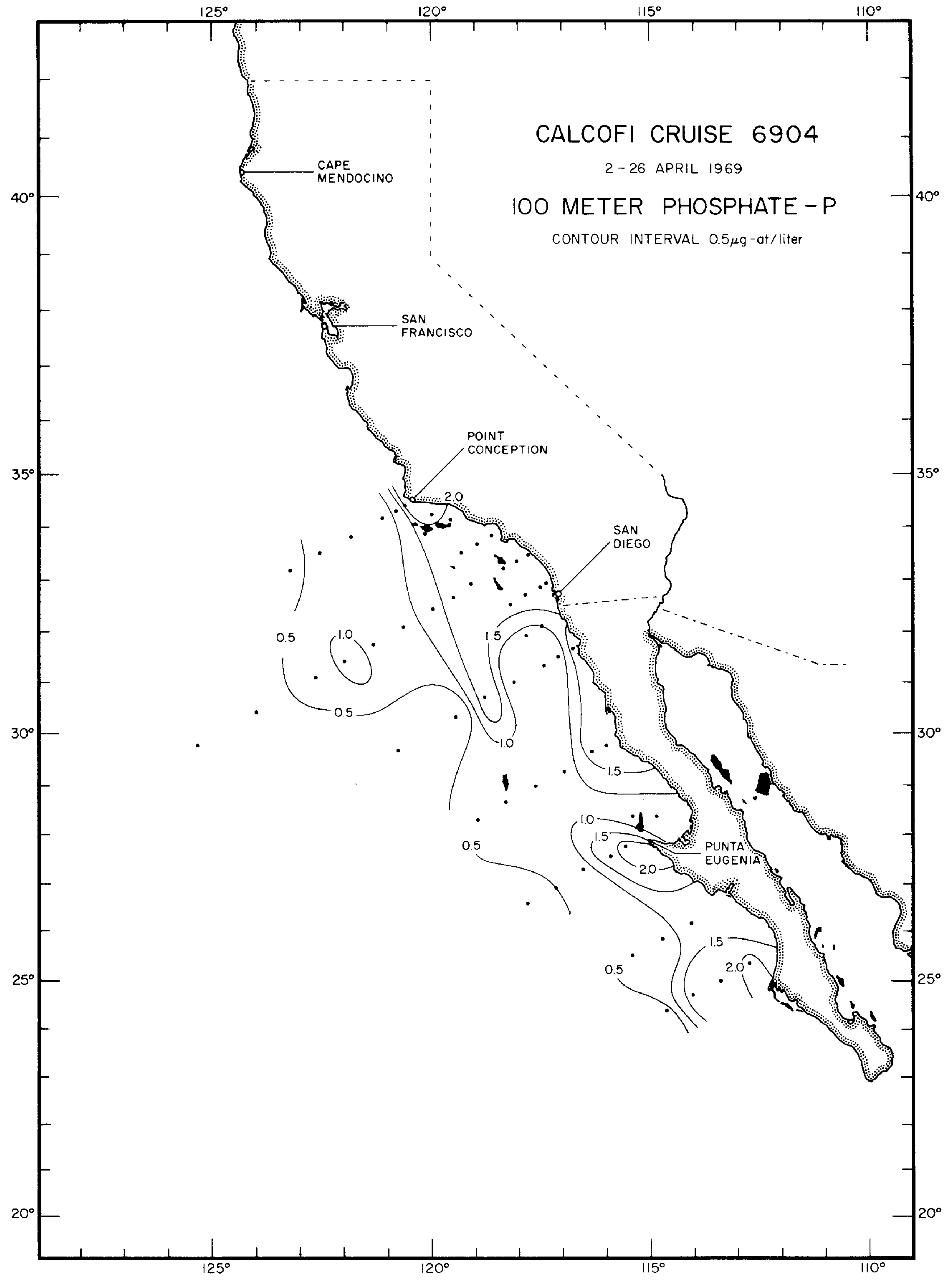
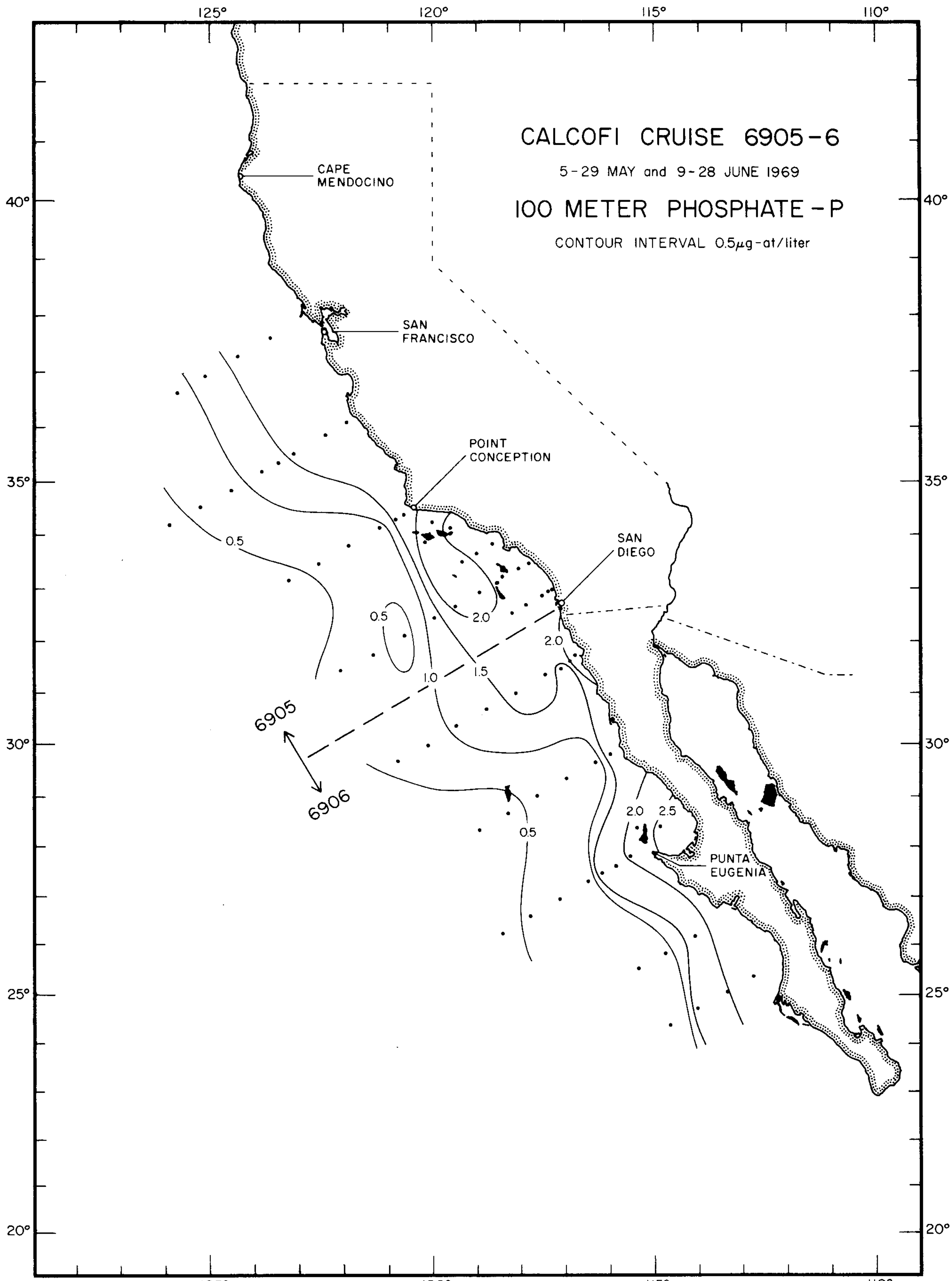
2.0



100m PHOSPHATE- P

6904



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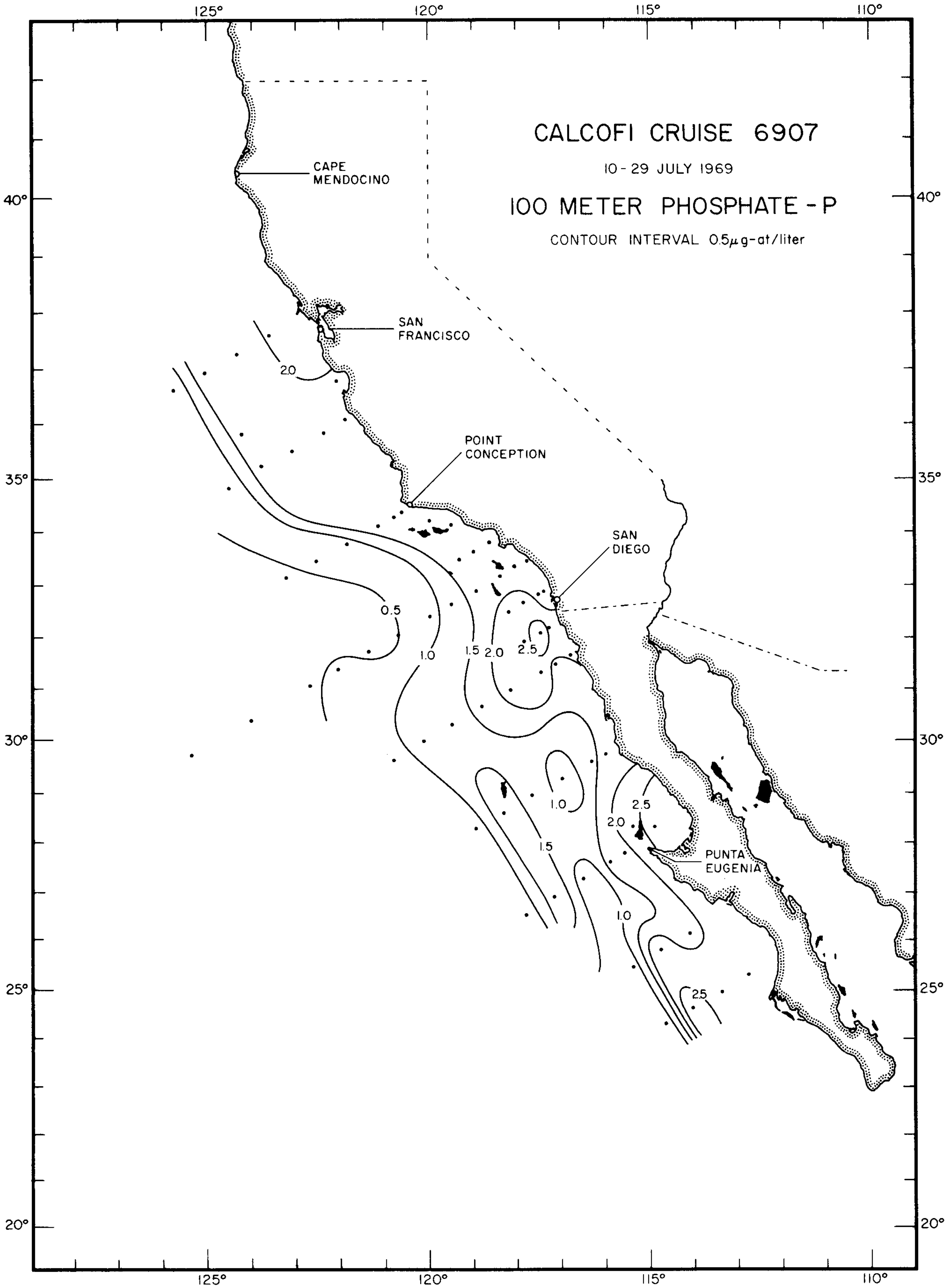
6905-6



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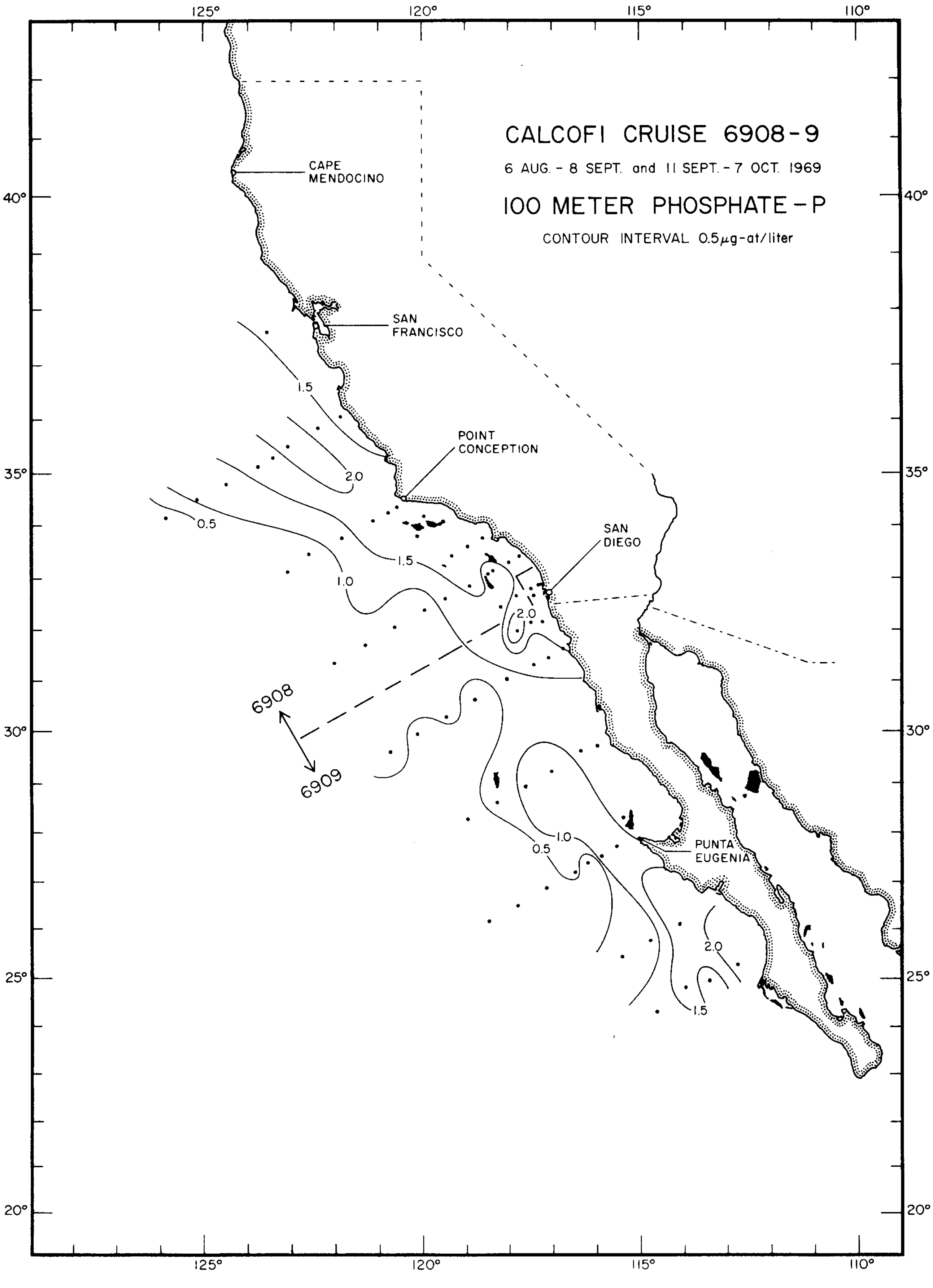
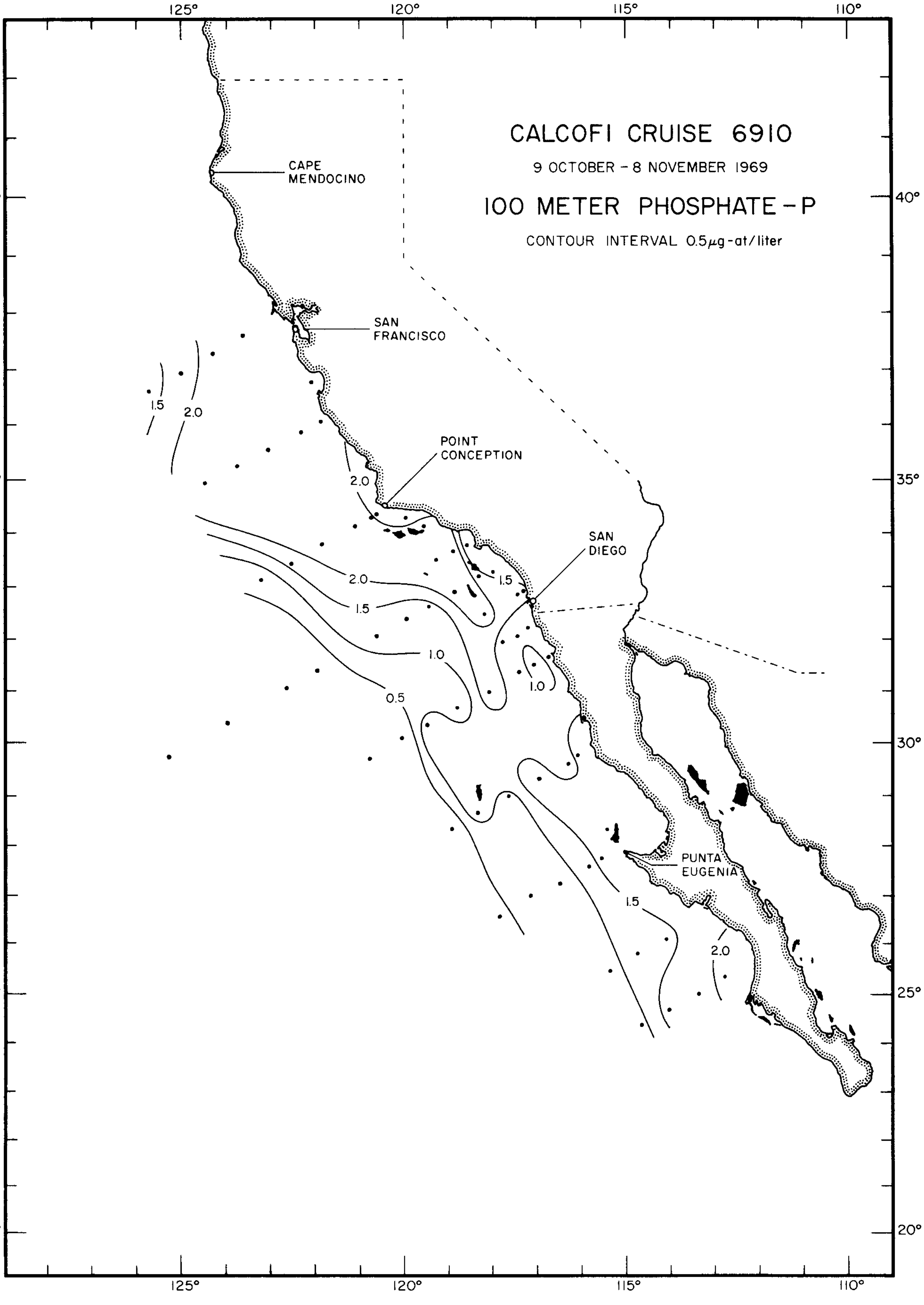


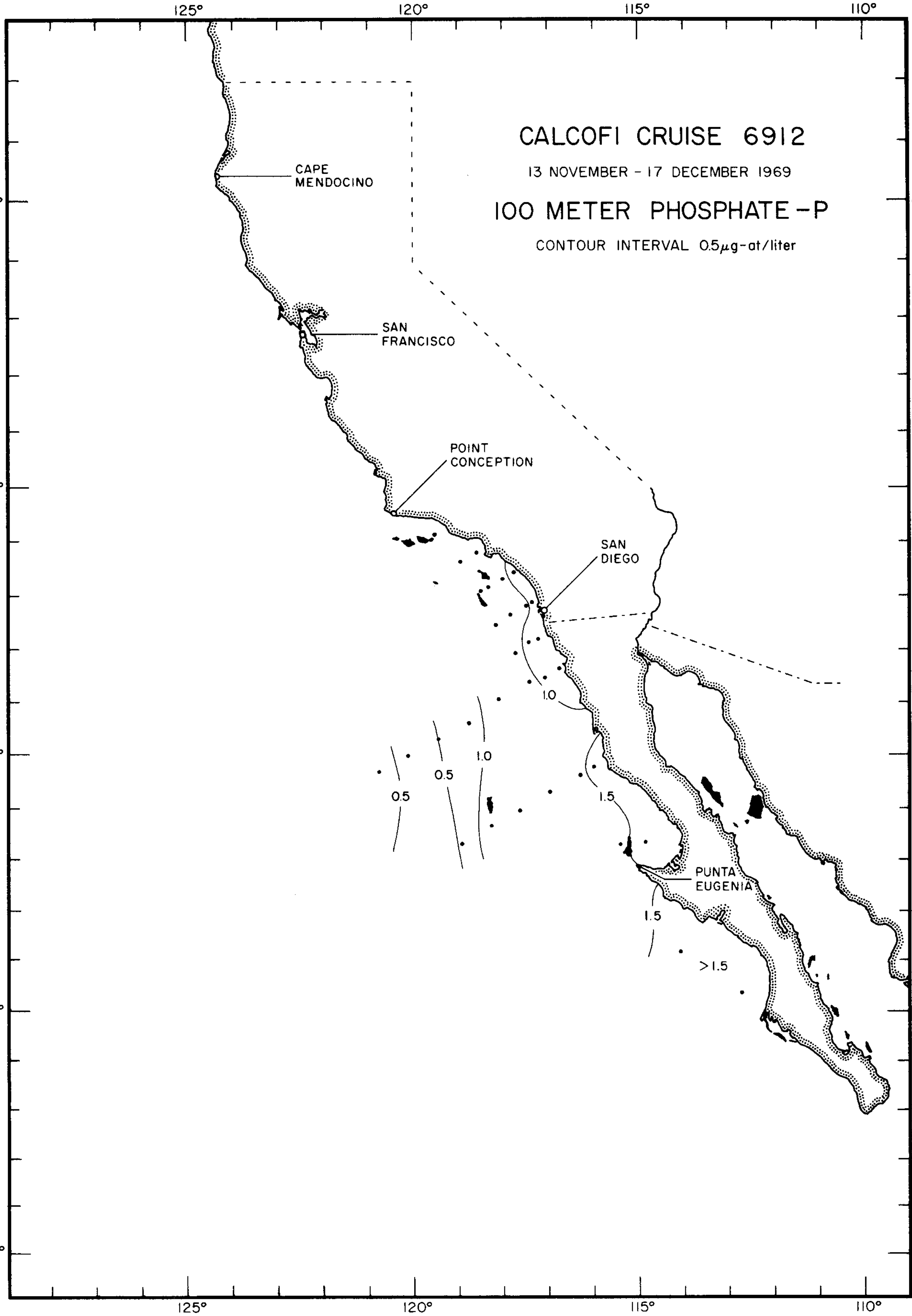
100 m PHOSPHATE-P

6908-9



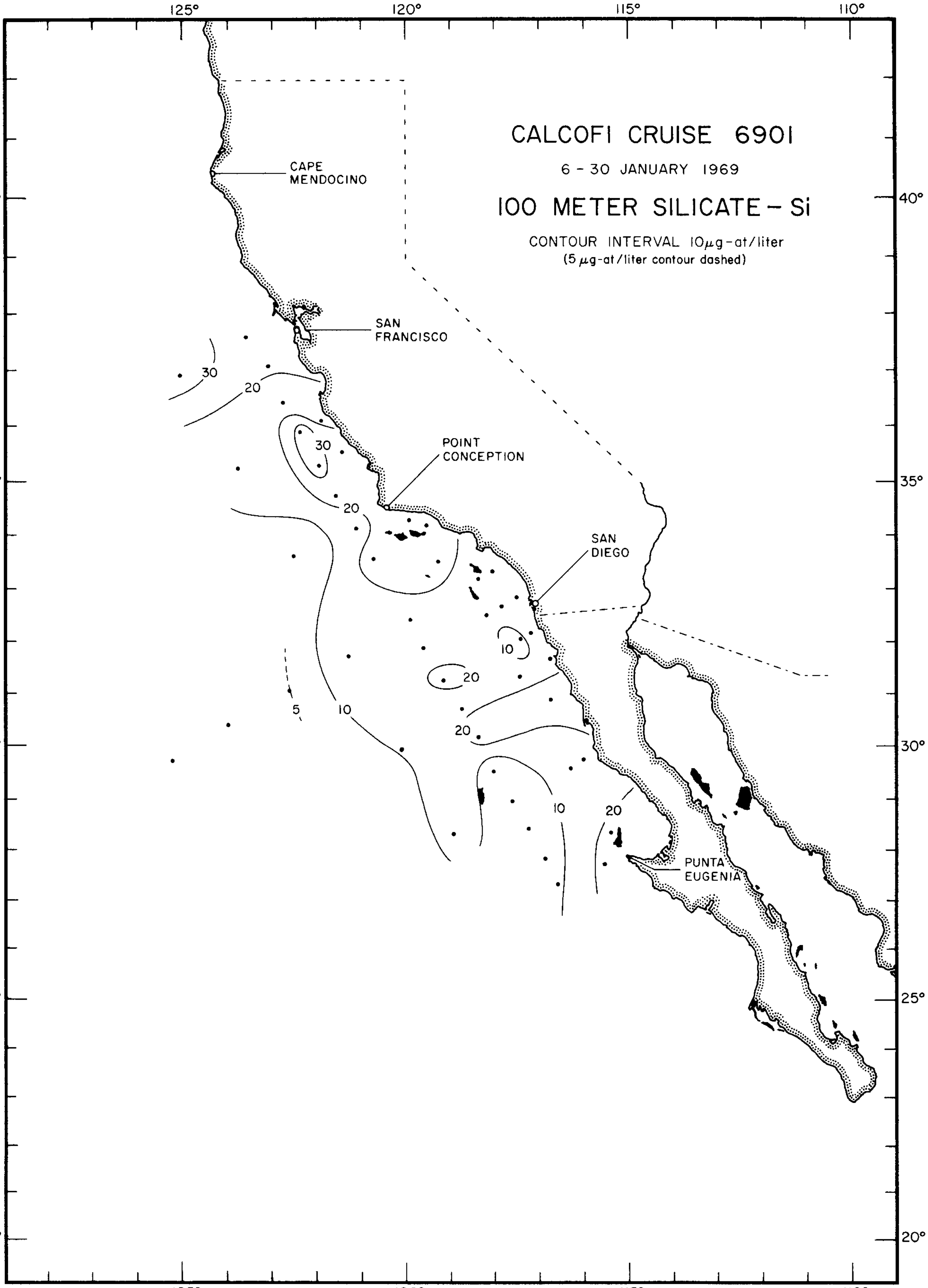
100m PHOSPHATE-P

6910



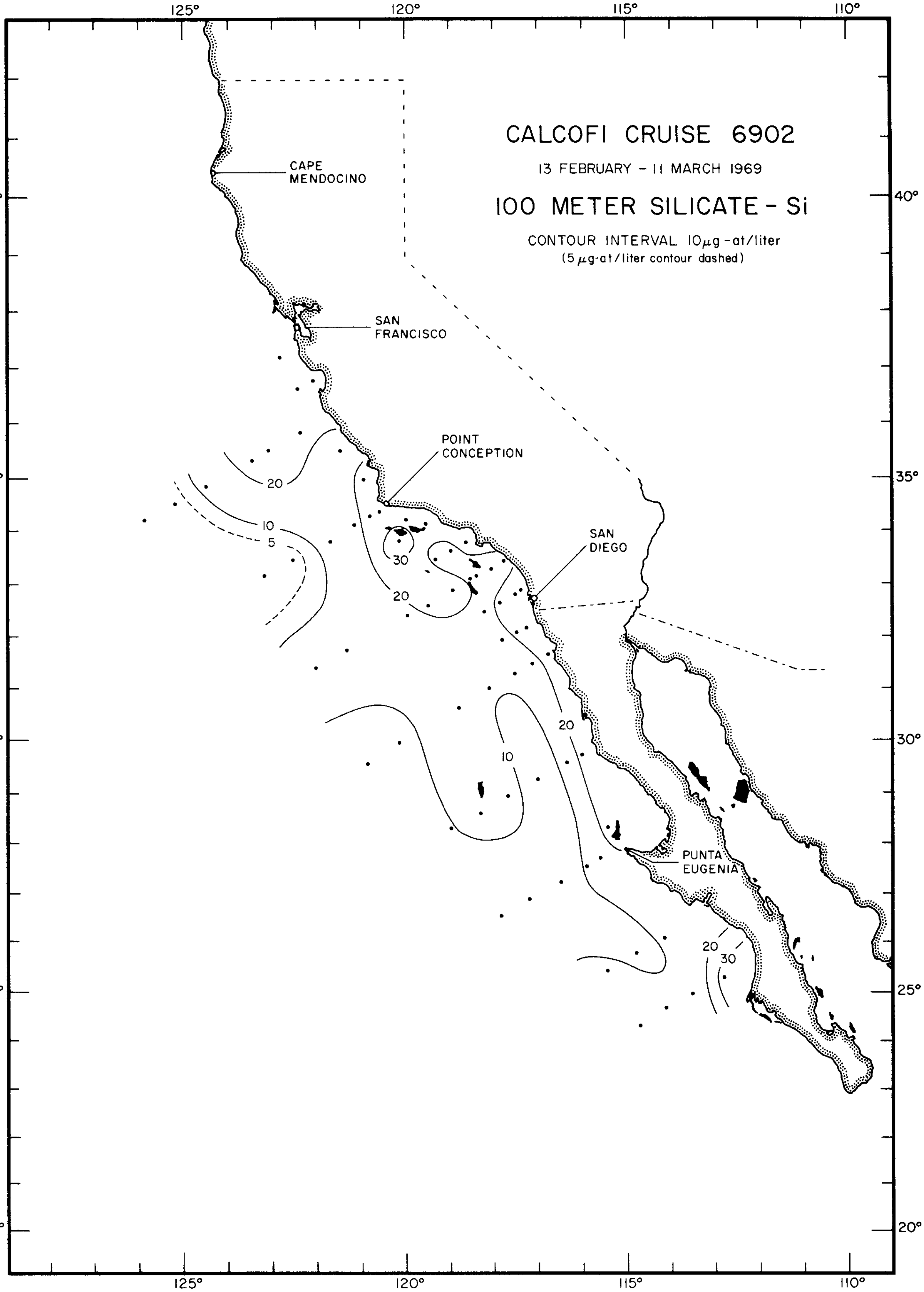
100m PHOSPHATE-P

6912



100m SILICATE-Si

6901



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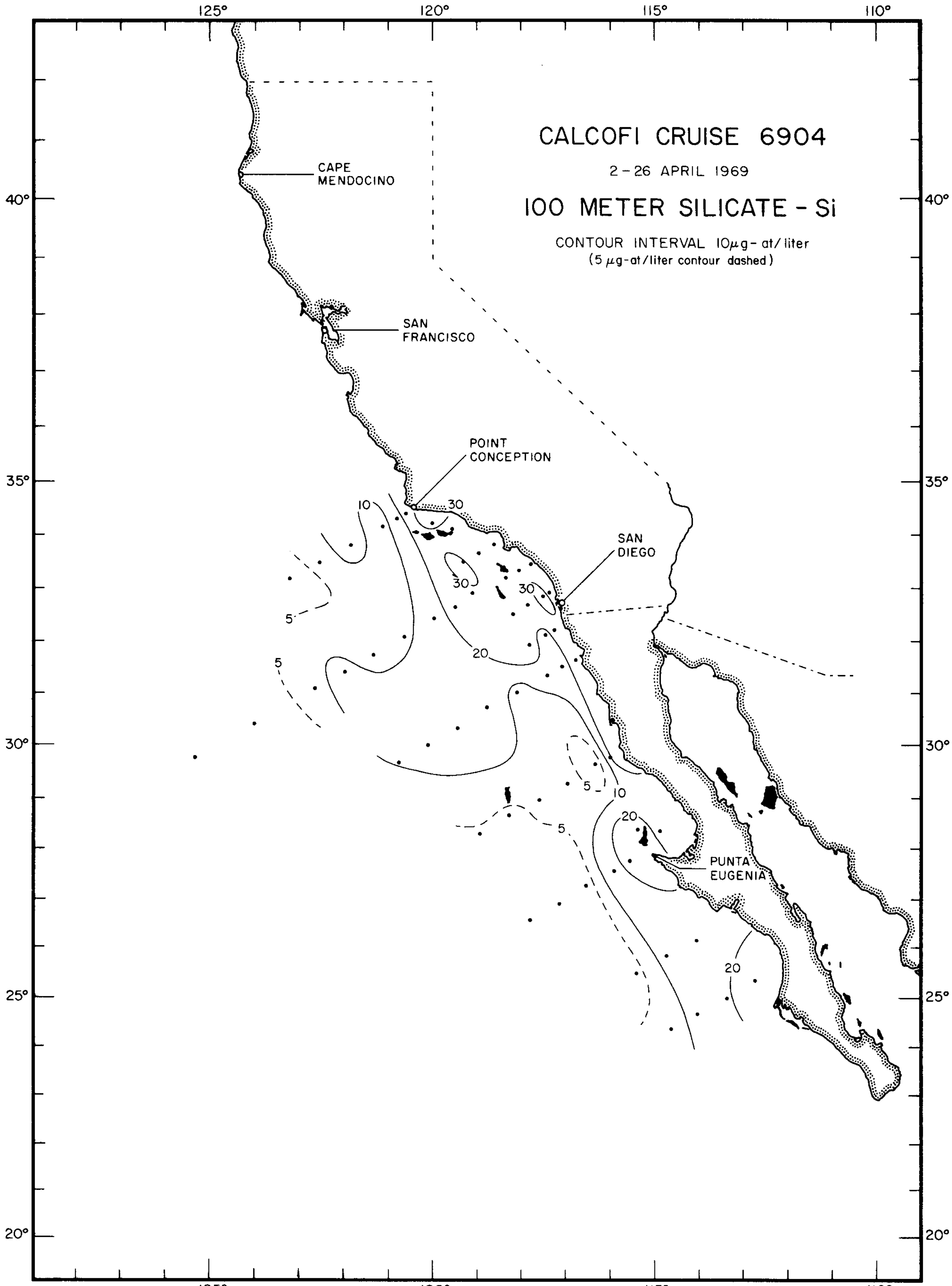
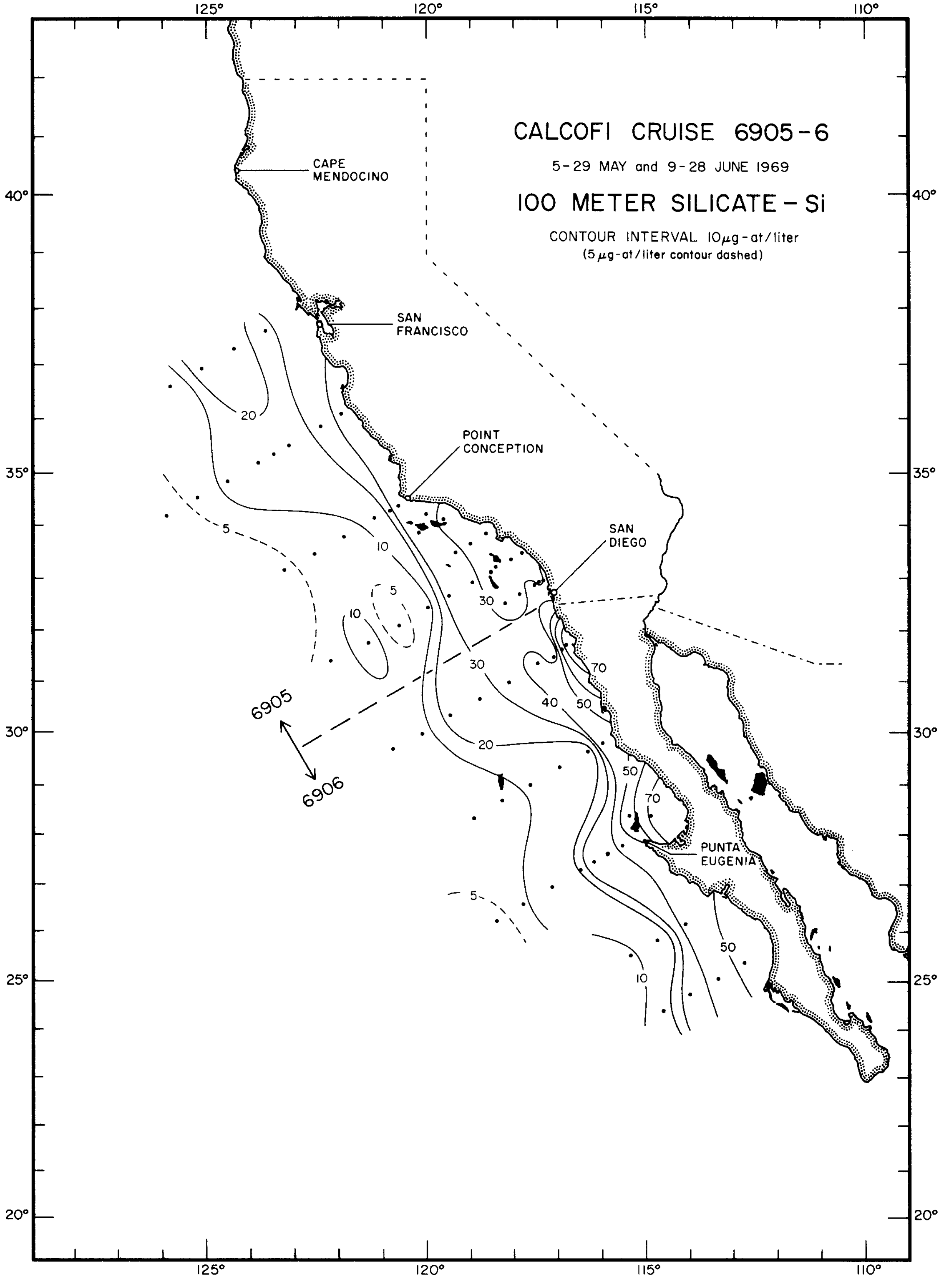
6902



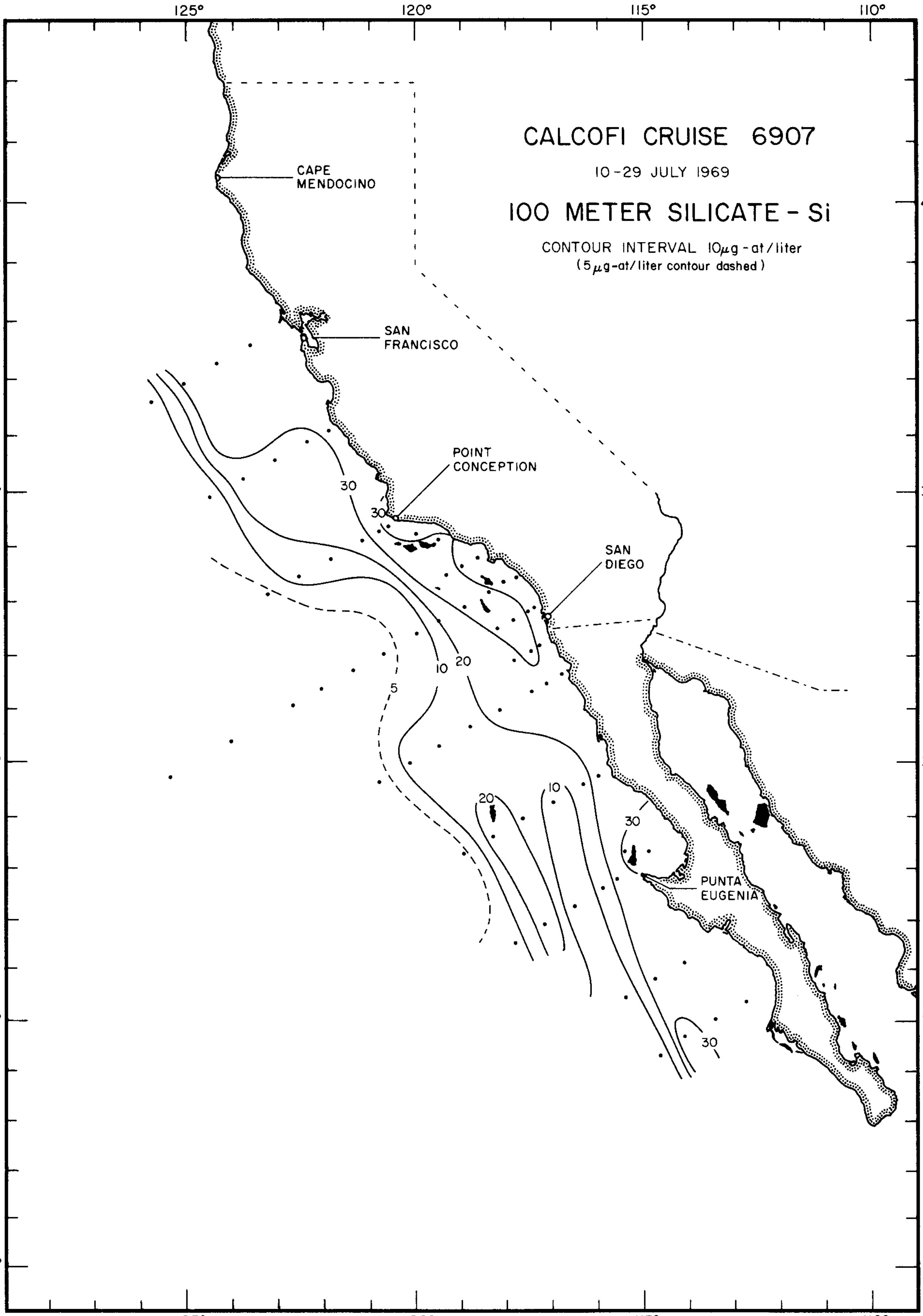
100m SILICATE-Si

6904



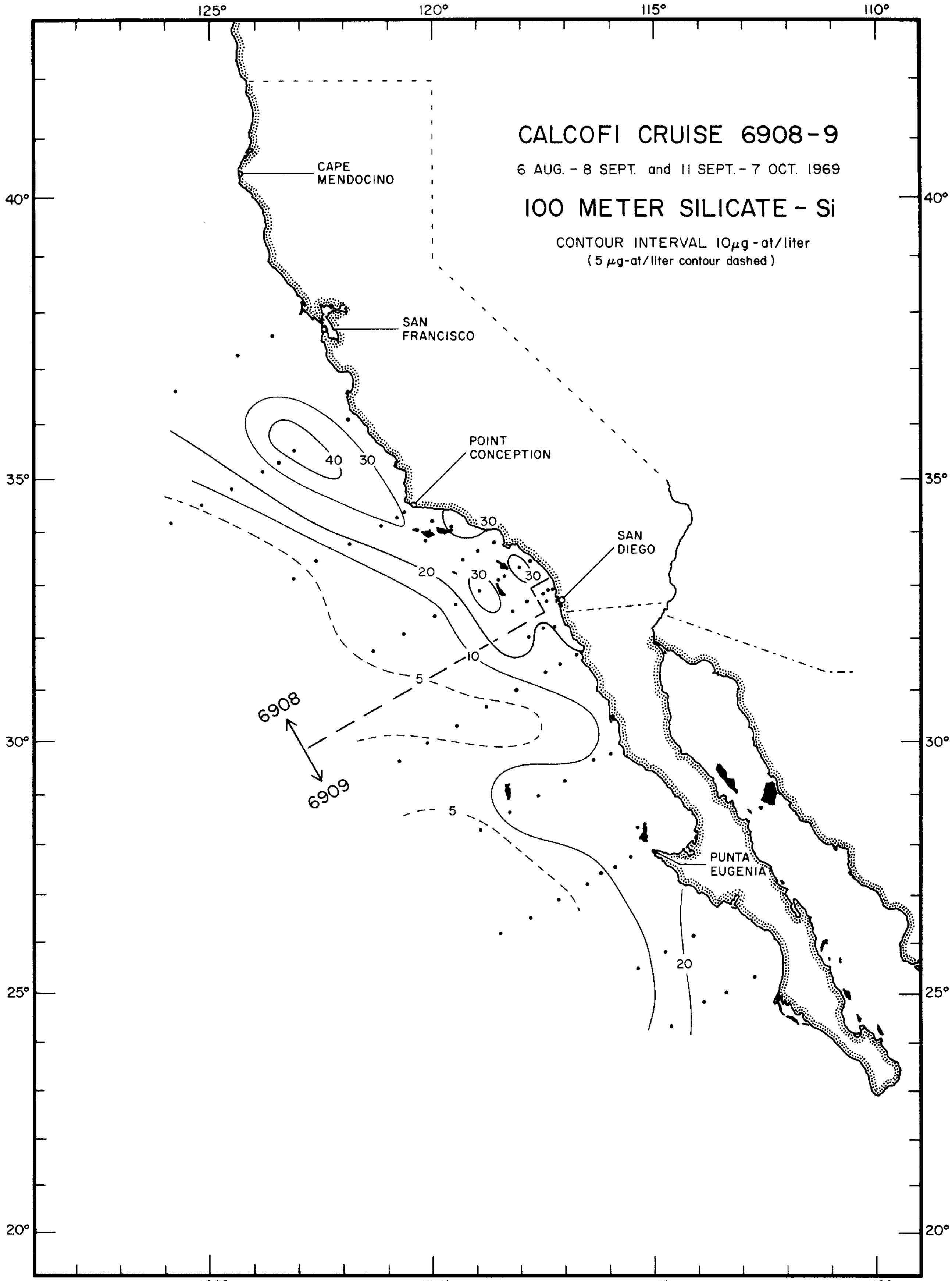
100m SILICATE-Si

6905-6



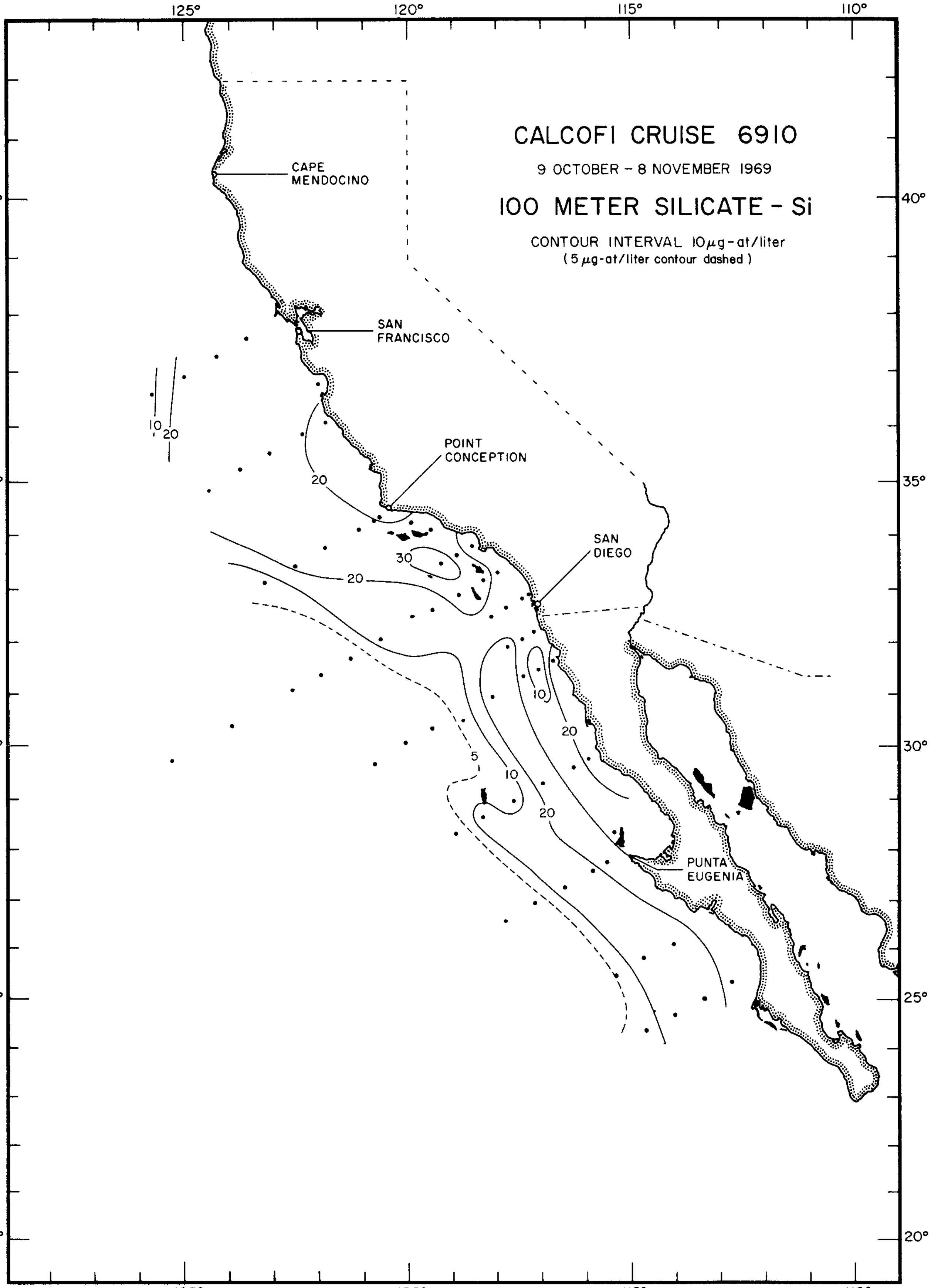
100m SILICATE-Si

6907



100m SILICATE-Si

6908-9



100m SILICATE-Si

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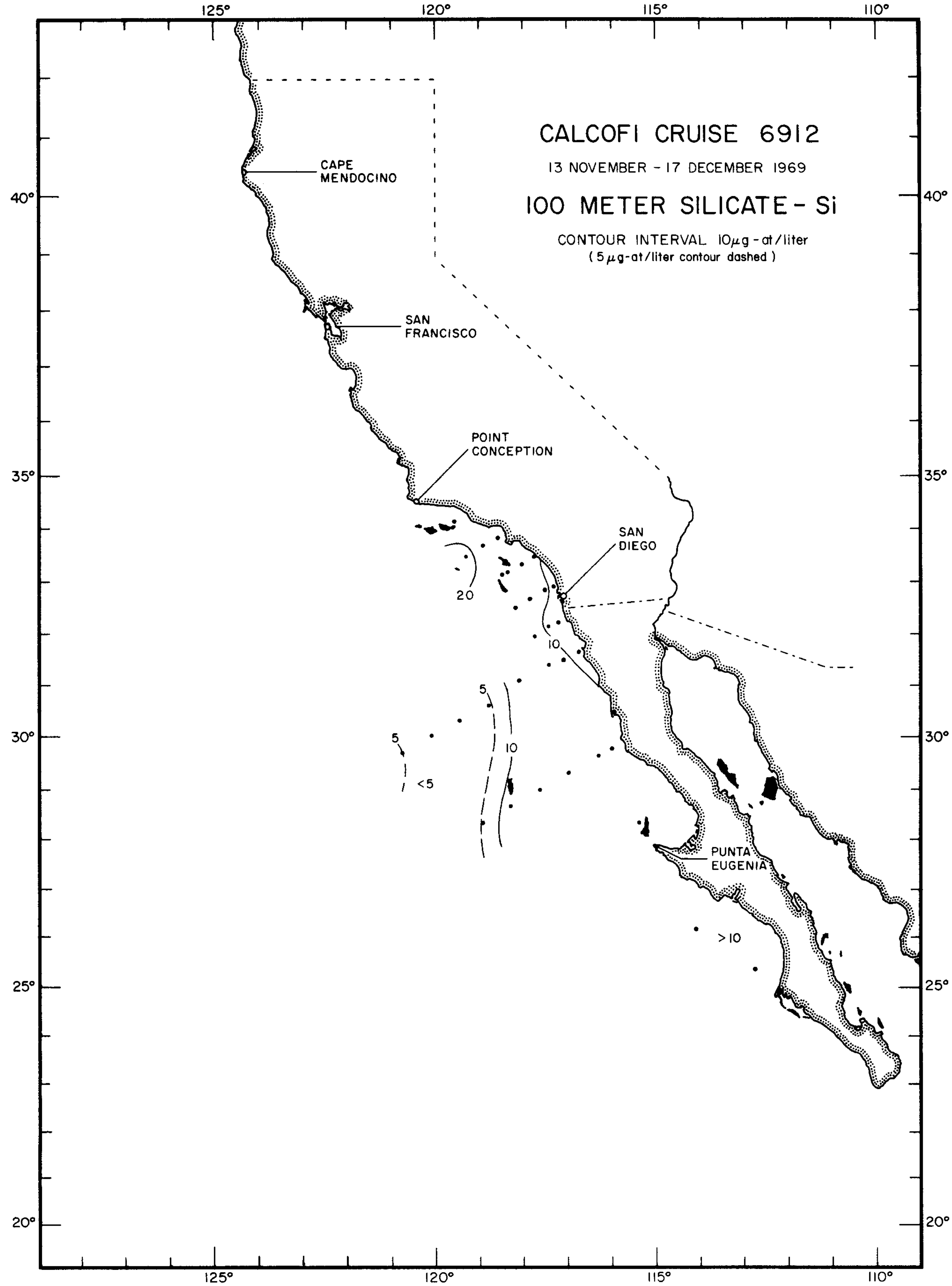

100m SILICATE-Si

6912

DISTRIBUTION OF PRIMARY PRODUCTION, PLANT PIGMENTS, AND SECCHI DEPTH IN THE CALIFORNIA CURRENT REGION, 1969

R. W. Owen, Jr.[1]

Introduction

The charts presented in the phytoplankton section of this atlas summarize measurements obtained systematically in the California Current region during 1969. Together with subsequent measurements, the data assume special significance since they are the only extant source for estimating seasonal cycles, annual changes, and spatial variations in the region. As phytoplankton supports the natural marine food resources available to man, the postulated sensitivity of potential fish yield to phytoplankton variations and the sensitivity of these variations to more easily measured and perhaps predictable environmental changes may be confirmed through these measurements.

Phytoplankton Pigments

Pigment concentrations were determined by fluorometry using water samples from prescribed regular and special CalCOFI stations. More than 10 levels were usually sampled between the surface and 150m depth in 1969. A secchi disc measurement was usually used to determine appropriate sampling depths at each station. Where no Secchi reading was possible, standardized depths were sampled. Methods of pigment analyses were used consistent with procedures recommended by the Biological Methods Panel Committee on Oceanography, National Academc of Science (1969).

Samples in 270-ml plastic bottles were filtered under low vacuum (not exceeding -7 inches of mercury) through Whatman GF/C glass fiber filters (2.4-cm diameter) having a thin magnesium carbonate coating. Filtration was usually completed within a half hour after sample collection. In some instances, however, samples,were chilled and stored in darkness up to 12 hours before processing.

Filters were placed in 90%-v/v-spectral-quality acetone, ground for 30 seconds in a motor-driven tissue grinder and stored dark for 10 minutes to permit full extraction of the pigments. Filters and extract were separated by centrifuging for 10 minutes. Extract volume was brought up to 10.0 ml; about 5 ml was placed in a cuvette and submitted to a Turner fluorometer, Model 111, for fluorometric analysis by the method of Holm-Hansen, Lorenzen, Holmes and Strickland (1965). A blue-pass Corning 5-60 primary filter and a red-pass Corning 2-64 secondary filter were used in conjunction with the light source and the detector, a red-sensitive multiplier phototube (Hamamatsu R 136).

On occasion, a fluorometer failure occurred and sample filters were folded, stored dark in a freezer,

1. National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Southwest Fisheries Center
La Jolla, California 92037

and analyzed later aboard ship or returned frozen to La Jolla for analysis. Values so obtained were multiplied by 1.1 to account for the consistent 10% loss that occurs when samples are stored for more than a day (Author's data: Lorenzen, pers. comm.).

All phytoplankton data were card punched, verified, and submitted to the CDC 3600 computer for calculation of basic phytoplankton parameters. Computed and listed by cruise, station and depth were chlorophyll a concentration, phaeo-pigment concentration[1], total pigment concentration, phytoplankton production per unit volume and several parameters for use in editing and interpreting these basic values. Also printed were interpolations and vertical profiles of pigment and production values.

Pigment concentrations were calculated from the equations given by Lorenzen (1966):

$$\text{chlorophyll } \underline{a} \ (\text{mgm}^{-3}) = \frac{\dfrac{Fo/Fa_{\max}}{(Fo/Fa_{\max}) - 1} (k_x) (Fo - Fa)}{\text{liters filtered}}$$

$$\text{phaeophytin } \underline{a} \ (\text{mgm}^{-3}) = \frac{\dfrac{Fo/Fa_{\max}}{(Fo/Fa_{\max}) - 1} (k_x) \, [Fo/Fa_{\max} (Fa) - Fo]}{\text{liters filtered}}$$

where: Fo = fluorescence before acidification
Fa = fluorescence after acidification
$Fo/Fa_{\max}$ = maximum acid factor which can be expected in the absence of phaeophytin
k_x = calibration constant for a specific sensitivity scale

The k_x factors were determined by submitting known concentrations of chlorophyll a to each fluorometer and observing fluorescence units. Linearity of each instrument was checked by serial dilution of pigment extracts. The maximum acid factor was determined by observing fluorescence before and after acidification of extracts of diatom and dinoflagellate cultures sampled in logarithmic phase of growth when phaeo-pigments are absent.

Field measurements were examined station-by-station. Constancy of the shape of each vertical profile was considered and in the few cases where a second deep maximum occurred that was defined by a single observation, a scale reading error was presumed to have occurred and the value was rejected. In addition, the vertical profile of the acid factor (the proportional change of pigment fluorescence upon acidification of the extract) was examined. This factor normally decreased monotonically from surface layer values near 2 to deep values near 1. Where single significant departures from this pattern occurred, sample values either were justified from the original data, or, if no simple change of values could be supported in terms of analyst error, the observation was rejected. Both apparent errors and rejections were rare, never exceeding 1% on most cruises.

Plant pigments, both chlorophyll a and phaeo-pigment concentrations, were integrated to 150 m to express the total pigment under a square meter of sea surface. Only minute quantities of plant pigment occur below 150 m except in the extreme, offshore portion of the survey tracks. The integration programs were based on Simpson's Rule for irregular areas and therefore use a linear interpolation between observations. Where water depth was too shallow to permit sampling to 150 m depth, integration was performed to the deepest sample. Integration values at such stations probably underestimate water column pigment totals since the deepest sample may not be close to the bottom.

Phytoplankton production-simulated in situ method

Production measurements were made by a modification of the ^{14}C method of Steemann-Nielsen (1952). Sampling depths were chosen to span the range of light intensities over which phytoplankton production exceeds respiration. Samples drawn from biologically inert Lexan plastic samplers were placed in 270 ml glass bottles and inoculated with 10 to 20μCi of sterile $NaH^{14}CO_2$ solution buffered at pH 9.0. Directly after inoculation the samples were loaded into two cylindrical incubators. One incubator was completely opaque and the other was screened to transmit intensity of incident solar radiation present at each of the seven sampled depths. Once loaded, the incubators were placed under full exposure to sun and sky radiation. The time for collecting samples was arranged so that incubation could be started at local apparent noon. Incubation continued until local sunset, when the samples were recovered for filtration. Spectral quality of the light was not controlled. Surface sea water was pumped through the incubators to control temperature.

1. Phaeo-pigments are degradation products of chlorophyll a and represent detrital pigment.

Filtration was conducted in subdued light at a vacuum not ordinarily exceeding -7 inches of mercury using Millipore membrane filters (2.5 cm diameter) with 0.45-μm pore diameters. The filters were then glued to identified copper planchets, placed in perforated pill boxes and stored in desiccators. Upon their return to shore for radioassay, the filters were fumed over concentrated HCl for 10 minutes, sorted by station and returned to their desiccators to await beta-assay. As soon as possible after fuming, samples were turned over to the General Atomic Corporation, La Jolla, California, where they were counted on Beckman wide-beta gas flow counters. Detector end windows were of 80-μg/cm^2 Mylar with 5.72-cm diameters. Samples were counted for 3 minutes. Background counts, which usually did not exceed three per minute, were determined and subtracted from each sample count. Counter efficiencies were 27.0 and 34.0% during the entire period of analyses, as determined from point-source standards calibrated against those maintained by the National Bureau of Standards.

Production rate of the phytoplankton was calculated from the equation:

Production (mg C/m^3/day) =

$$(L - D) \frac{W}{A \times E} \times 1.05 \times 2$$

where:
L = counting rate (counts per minute) of the phytoplankton in the light bottle.
D = counting rate (counts per minute) of the phytoplankton in the dark bottle.
W = weight of carbonate carbon in the water assumed to be 25,000 mg/m^3.
A = discharges per minute by the radiocarbon added to each sample; usually 4.44×10^7 dpm
E = counter efficiency, determined experimentally for each counter.
1.05 = factor to allow for difference in uptake rate of ^{14}C as compared with that of ^{12}C
2 = correction from the half day incubation period to full day.

Criteria for rejection of production values, while applied over the whole period of the field program, were reworked frequently to ensure consistency. Averaged dark counts were submitted for a single high dark value when the latter occurred at a station, if the corresponding light count was consistent with known profile characteristics. Sets of high dark counts were accepted if they were not erratic (indicating contamination) and if they were well below the corresponding light counts. Values for entire stations were rejected if the vertical profile was so erratic as to indicate light leaks in incubators, inadvertent exposure to ambient light during filtration, or contamination of the ^{14}C stock.

Production values for the water column were obtained by computer integration to the euphotic depth. As with plant pigment integrations, Simpson's Rule was used.

Secchi Depth

Diffuse attenuation of light in the water was estimated from the Secchi depth, determined by lowering a flat 30-cm white disc until it disappeared from sight, then raising the disc until it reappeared and averaging the corresponding depths. Euphotic depth, taken to be at 1% of surface light intensity, was assumed for experimental purposes to occur at 3 X the Secchi depth. (Author's data; R.W. Eppley and J.D.H. Strickland, pers. comm.)

Chart Preparation

The spatial density of phytoplankton measurements obtained in any single cruise was considered too sparse to warrant contouring the resulting values. A number of stations were sampled repeatedly, however, and sufficient internal agreement between plant pigment and Secchi depth values was obtained from one cruise period to the next to permit pooling of the data into 3-month intervals. The coherence of the contoured patterns that arise from pooling help to confirm the validity of pooling. The particular 3-month intervals presented were chosen to span chronologically the year of observations rather than to represent extremes in the variations encountered. Inspection of the time variations over the region revealed that these pooling intervals were at least as representative of the variations as any other set of 3-month intervals, although more optimal periods might be chosen to represent seasonal change in some sub-areas of the region.

For contouring the charts of plant pigment and Secchi depth distributions, values at stations occupied more than once in the pooling interval were averaged. Contour intervals were selected simply for clarity of representing the distributions: a quasi-geometric progression was necessary for the plant pigment distributions, whereas constant intervals most clearly represented the distribution of water clarity as measured by Secchi depth. In situ production observations were so sparse in time and space as to preclude meaningful contouring.

Computed values by station and cruise of chlorophyll a, phaeo-pigments, production and Secchi depths, from which these charts were prepared, are reported by Owen and Sanchez (1974) together with insolation and mixed-layer depth.

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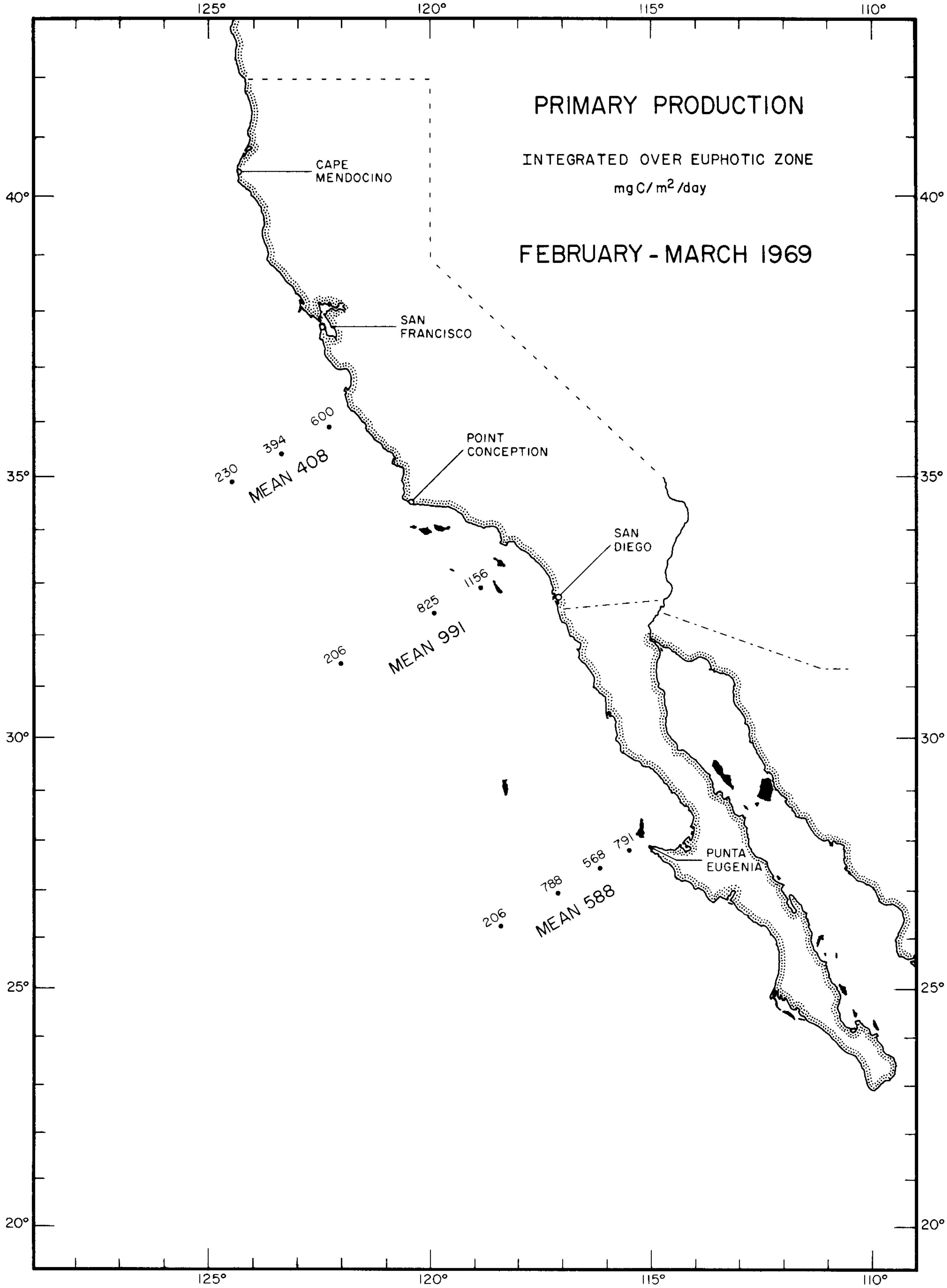
Lorenzen, C.J., 1966. A method for the continuous measurement of in vivo chlorophyll concentration. Deep-Sea Res. 13: 223-227.

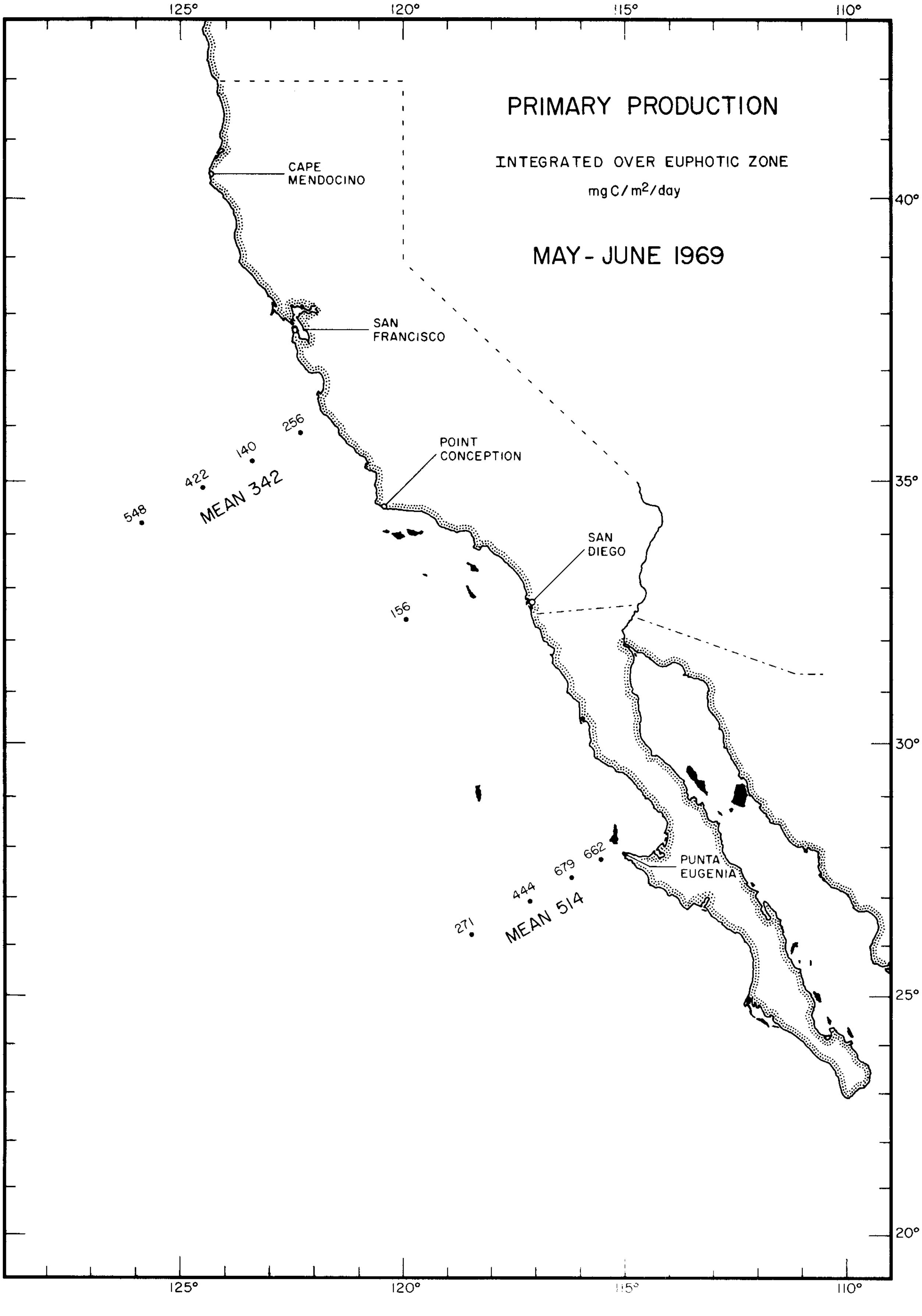
Owen, R.W., Jr. and C.K. Sanchez, 1974. Phytoplankton pigment and production measurements in the California Current region. 1969-72. National Marine Fisheries Service (U.S.) Data Report No. 91.

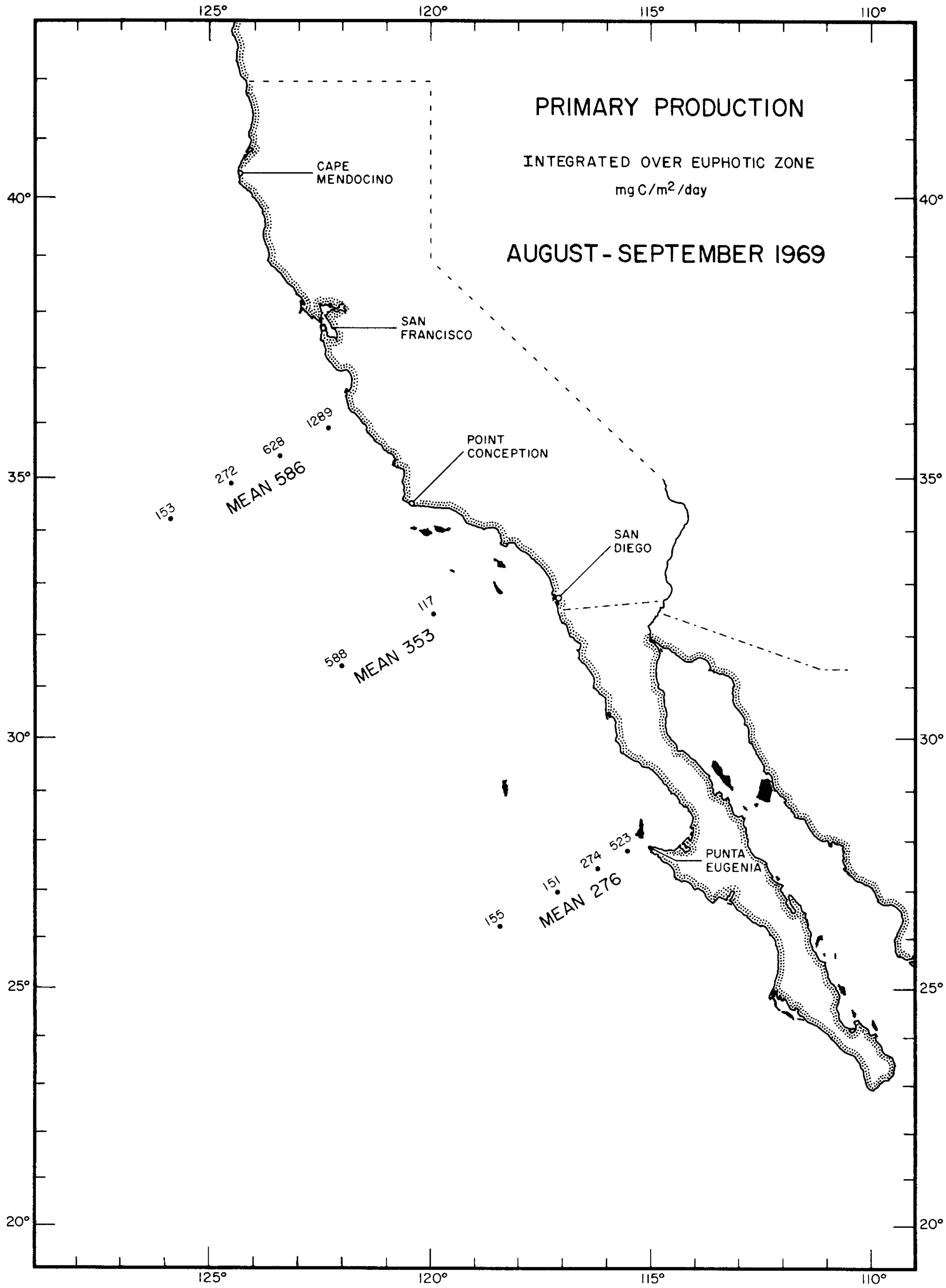
Steemann-Nielsen, E., 1952. The use of radio-active carbon for measuring organic production in the sea. J. Cons. 18: 117-140.



PRIMARY PRODUCTION

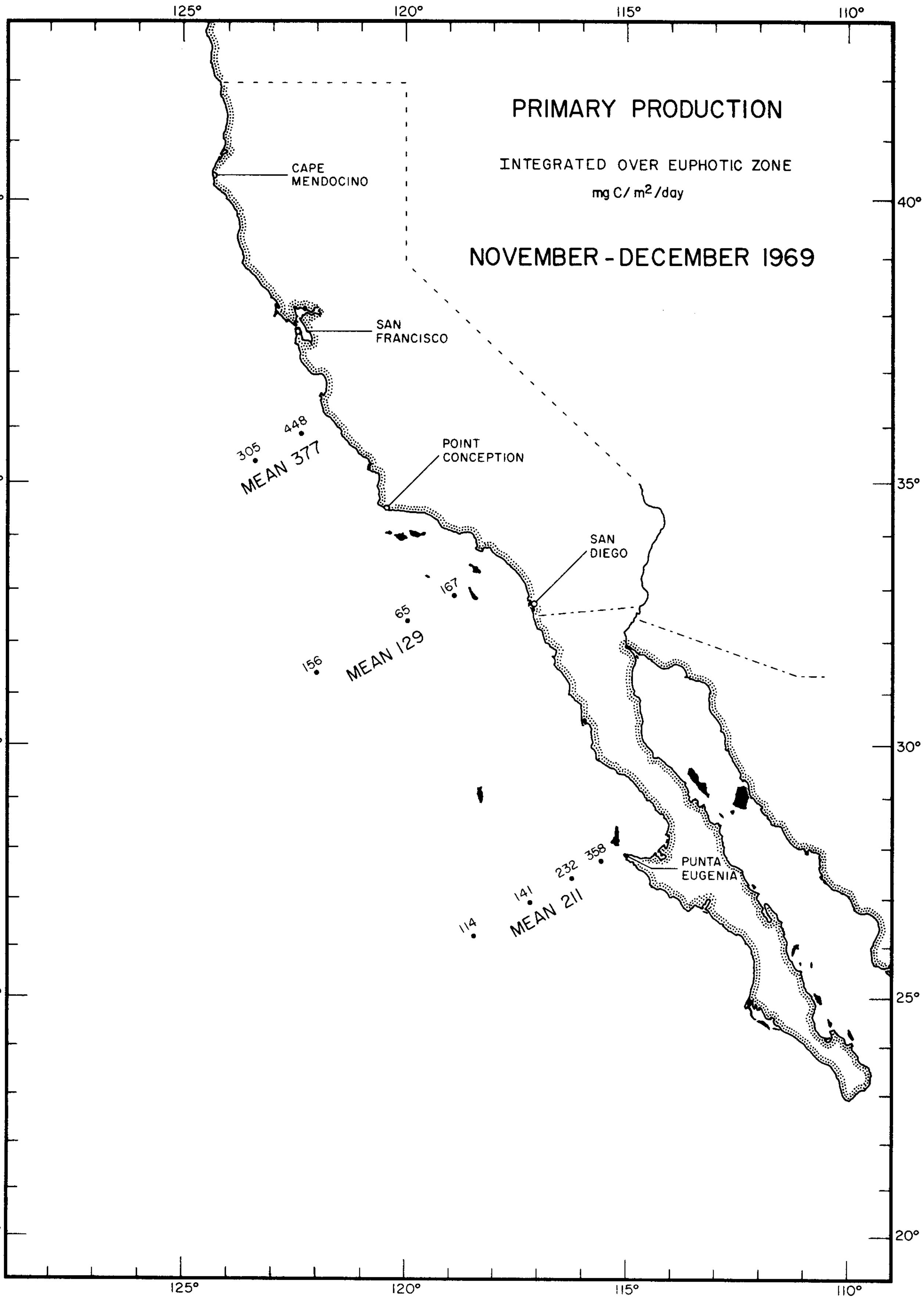
FEBRUARY - MARCH 1969


PRIMARY PRODUCTION
INTEGRATED OVER EUPHOTIC ZONE
mgC/m2/day
MAY - JUNE 1969
CAPE MENDOCINO
SAN FRANCISCO
POINT CONCEPTION
SAN DIEGO
PUNTA EUGENIA
256
140
422
548
MEAN 342
156
662
679
444
271
MEAN 514
125°
120°
115°
110°
40°
35°
30°
25°
20°



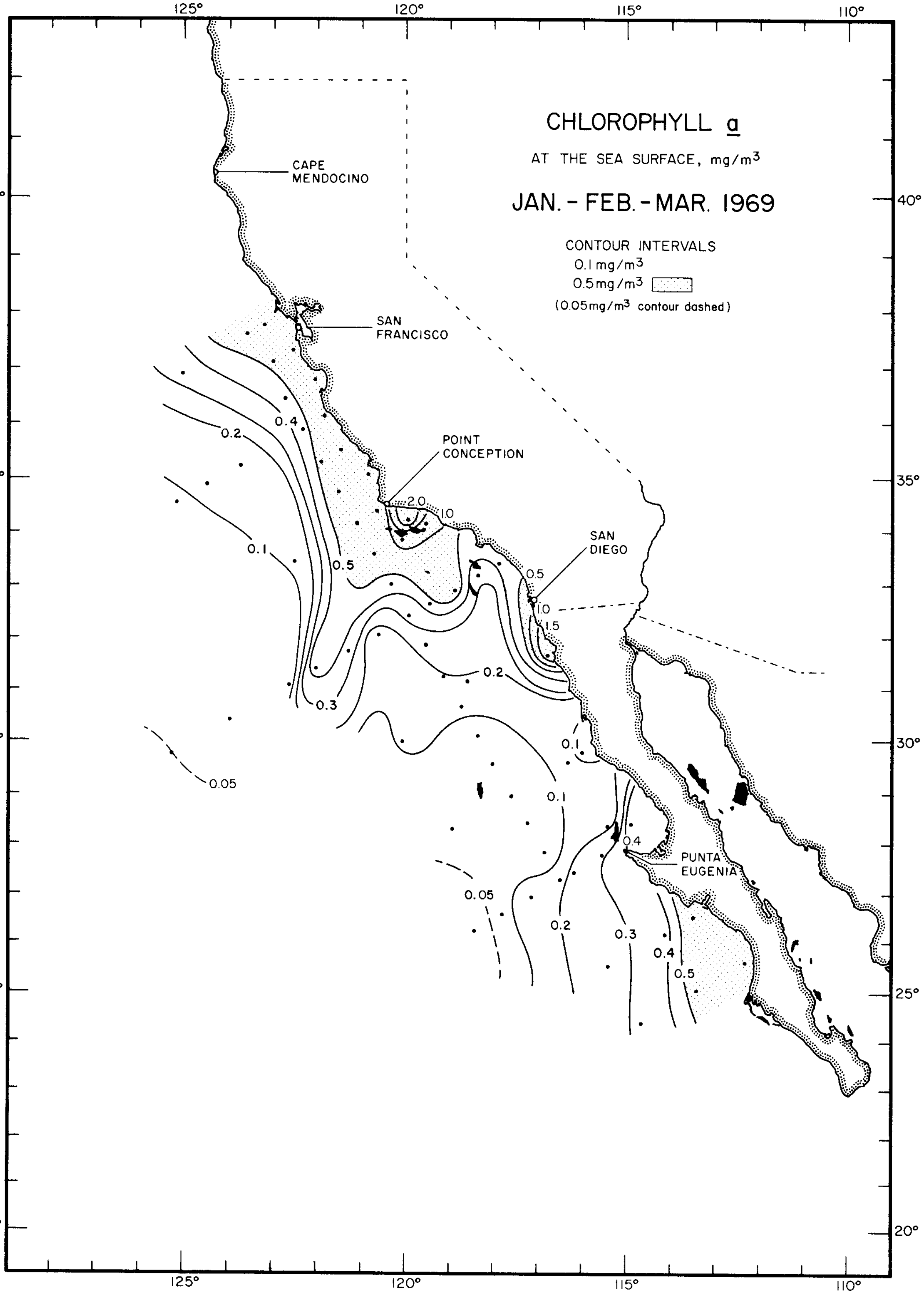
PRIMARY PRODUCTION

AUGUST - SEPTEMBER 1969

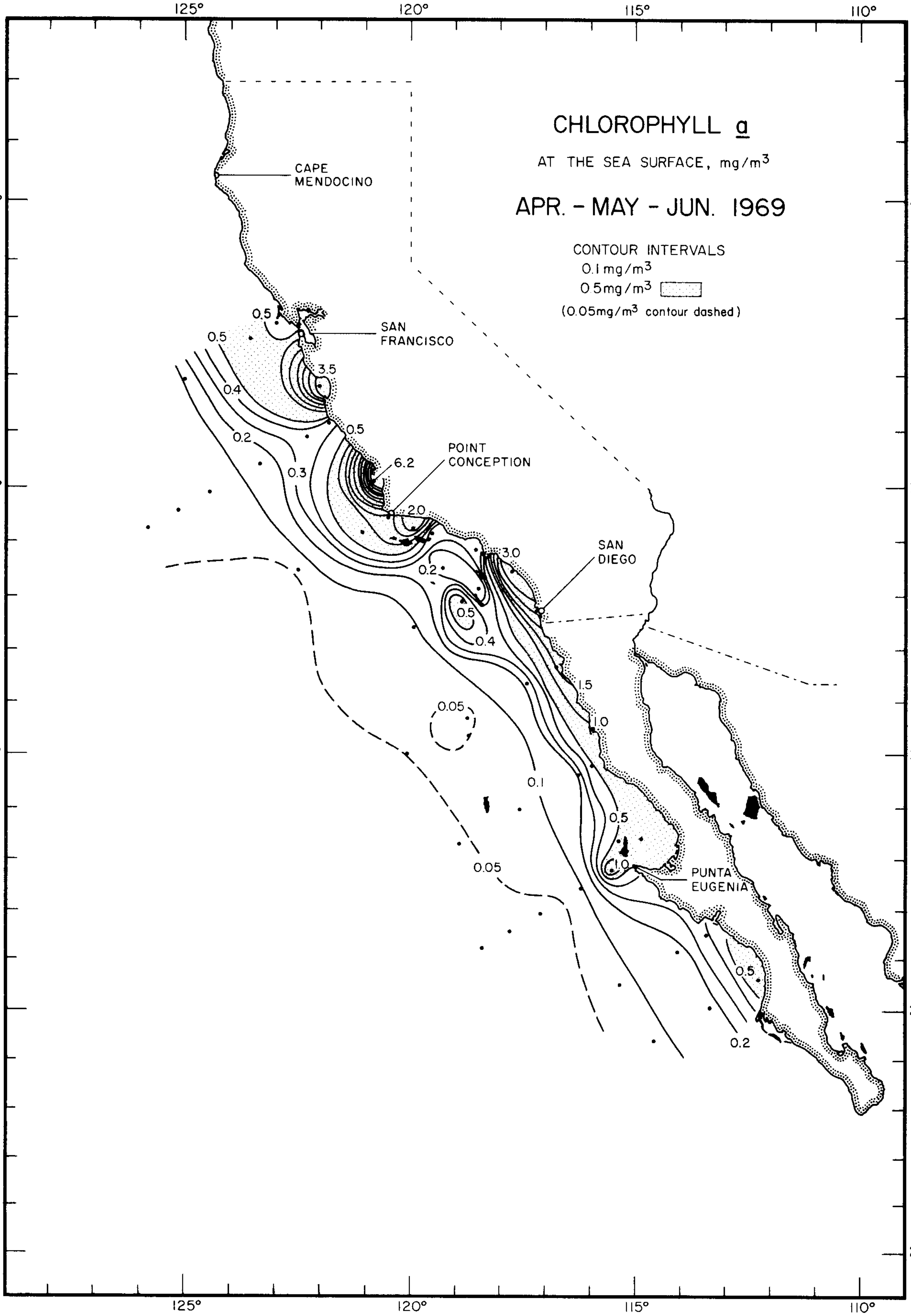


PRIMARY PRODUCTION

NOVEMBER - DECEMBER 1969



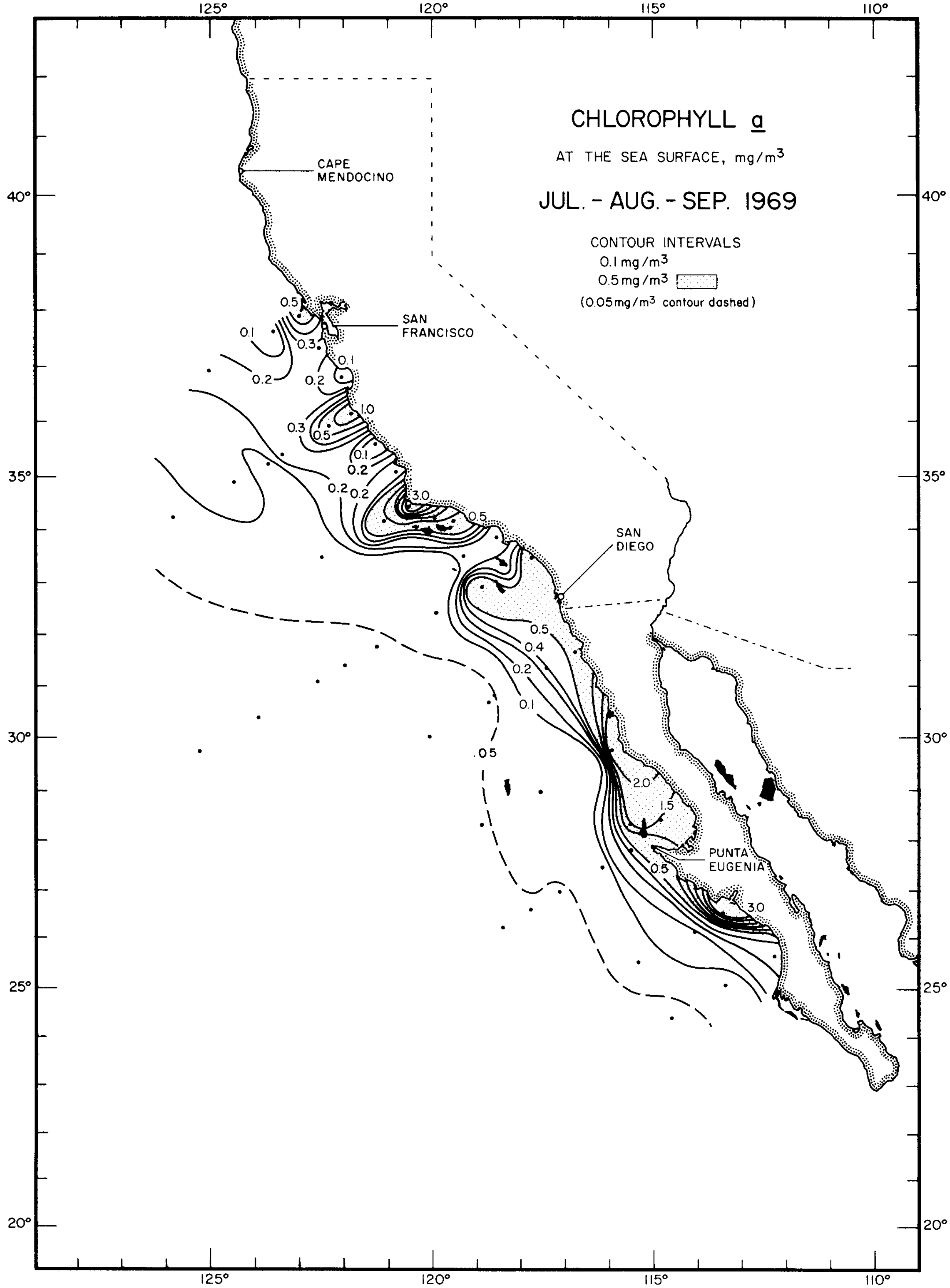
CHLOROPHYLL a
SURFACE
JAN. - FEB. - MAR. 1969



CHLOROPHYLL a

SURFACE

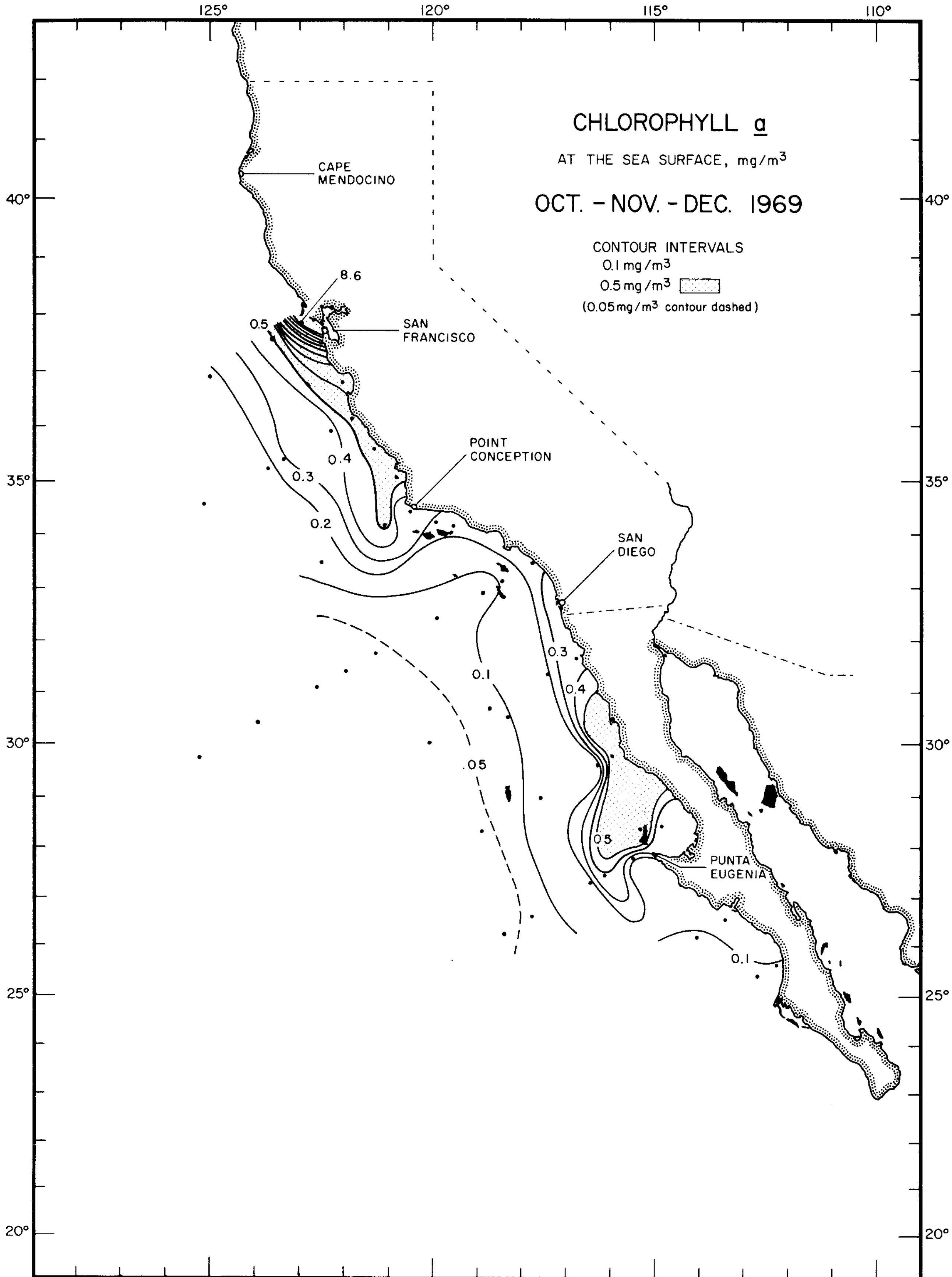
APR. - MAY - JUN. 1969



CHLOROPHYLL a

SURFACE

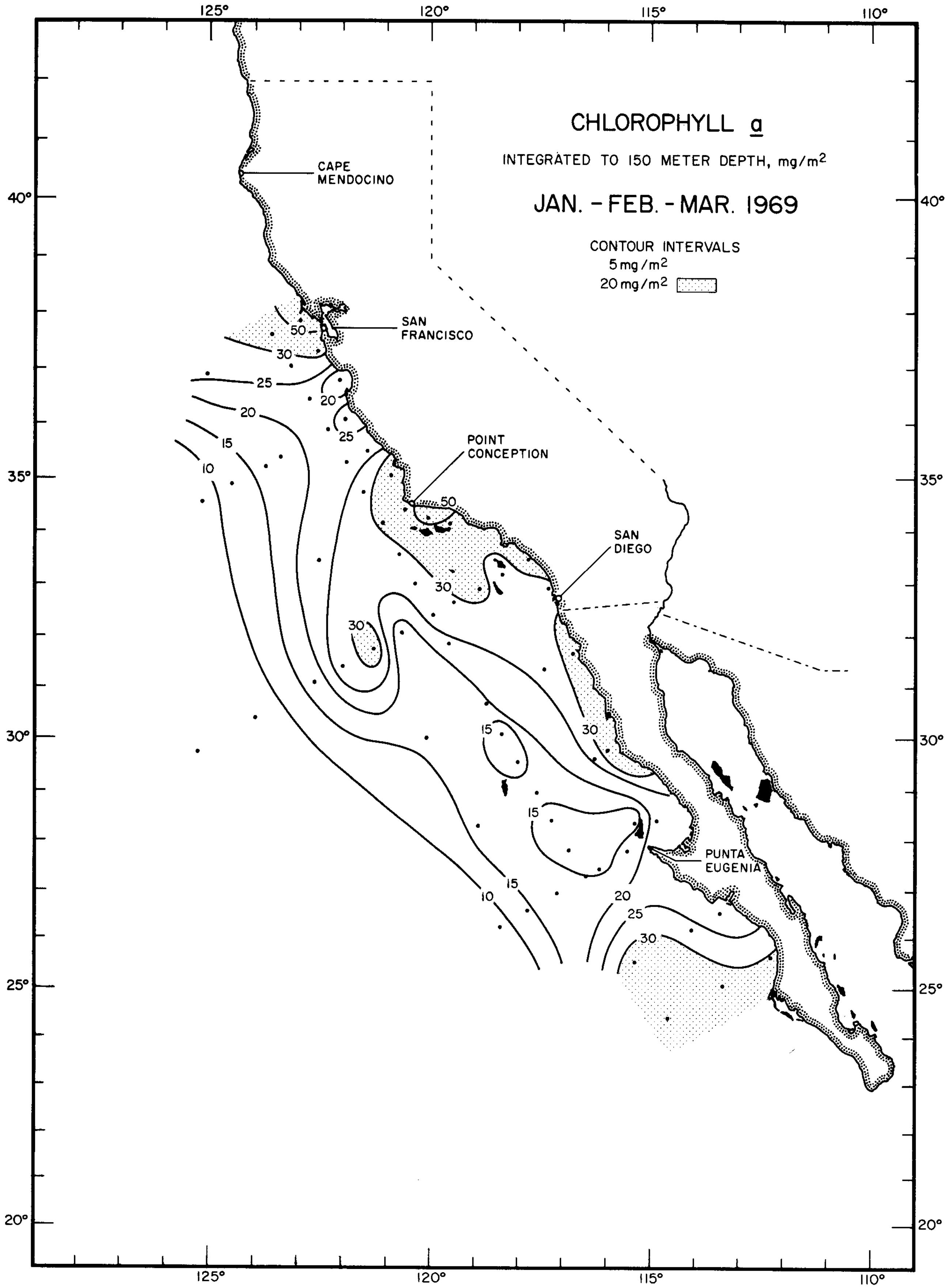
JUL. - AUG. - SEP. 1969



CHLOROPHYLL a

SURFACE

OCT. - NOV. - DEC. 1969



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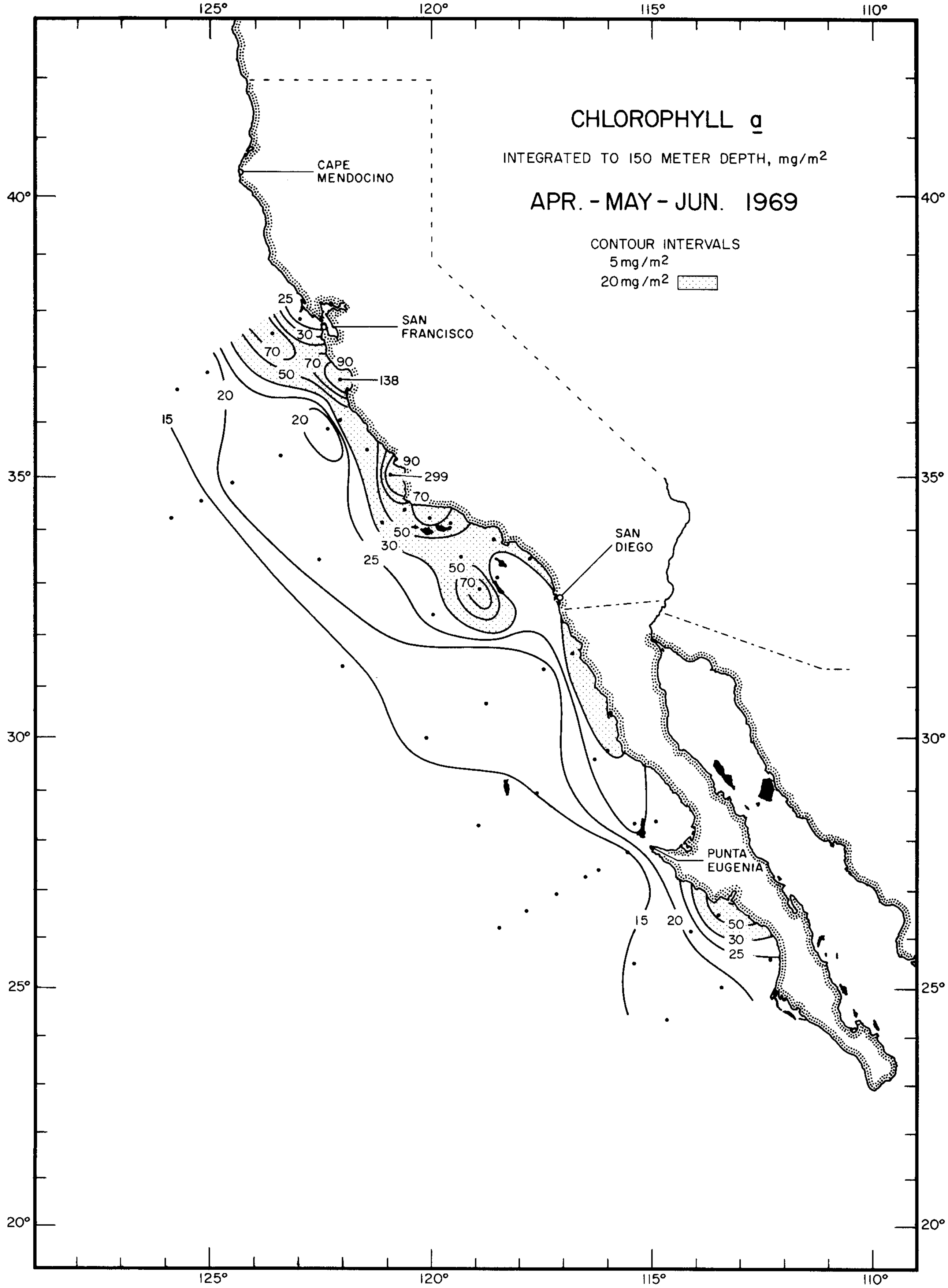
JAN. - FEB. - MAR. 1969



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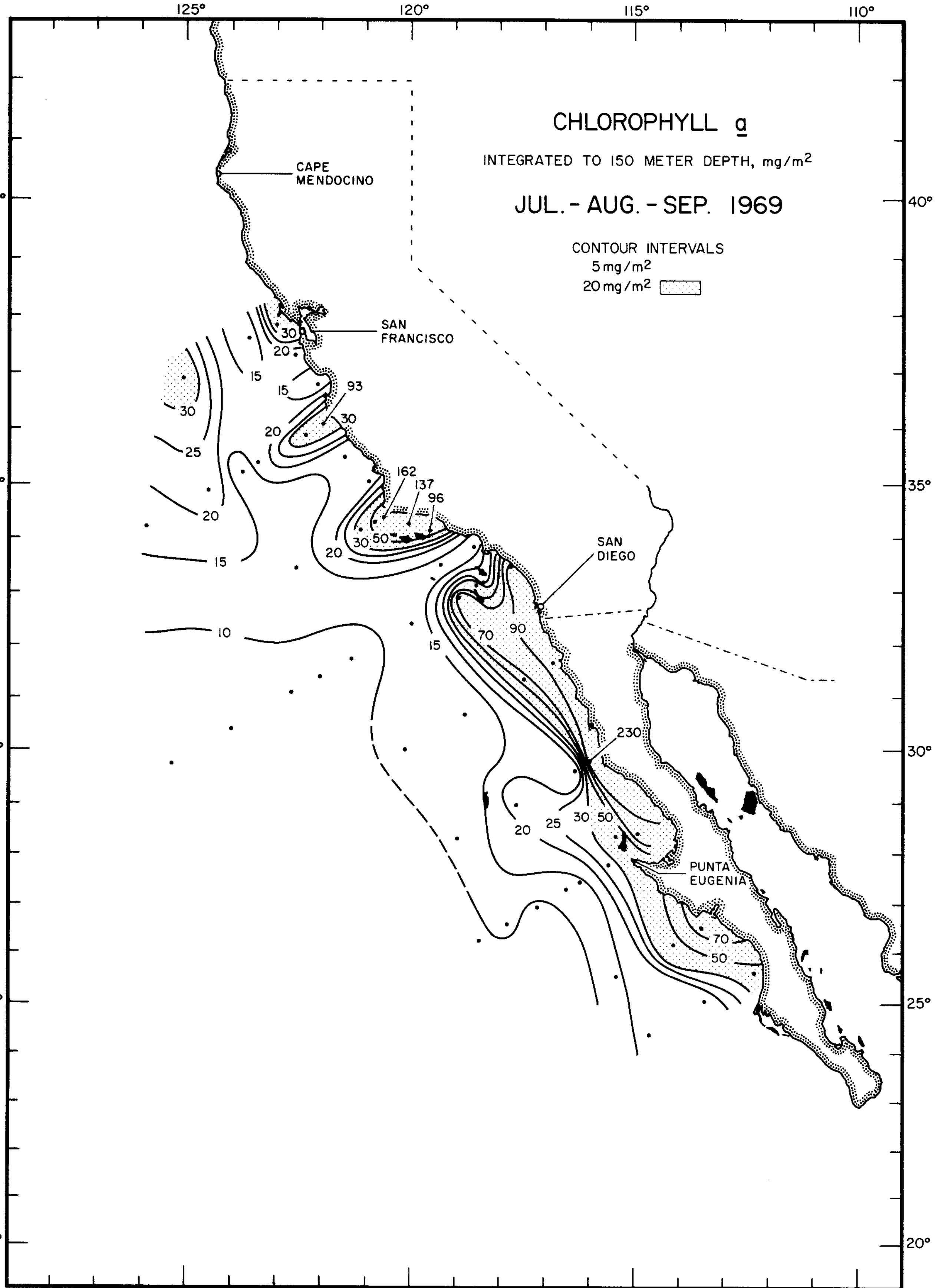

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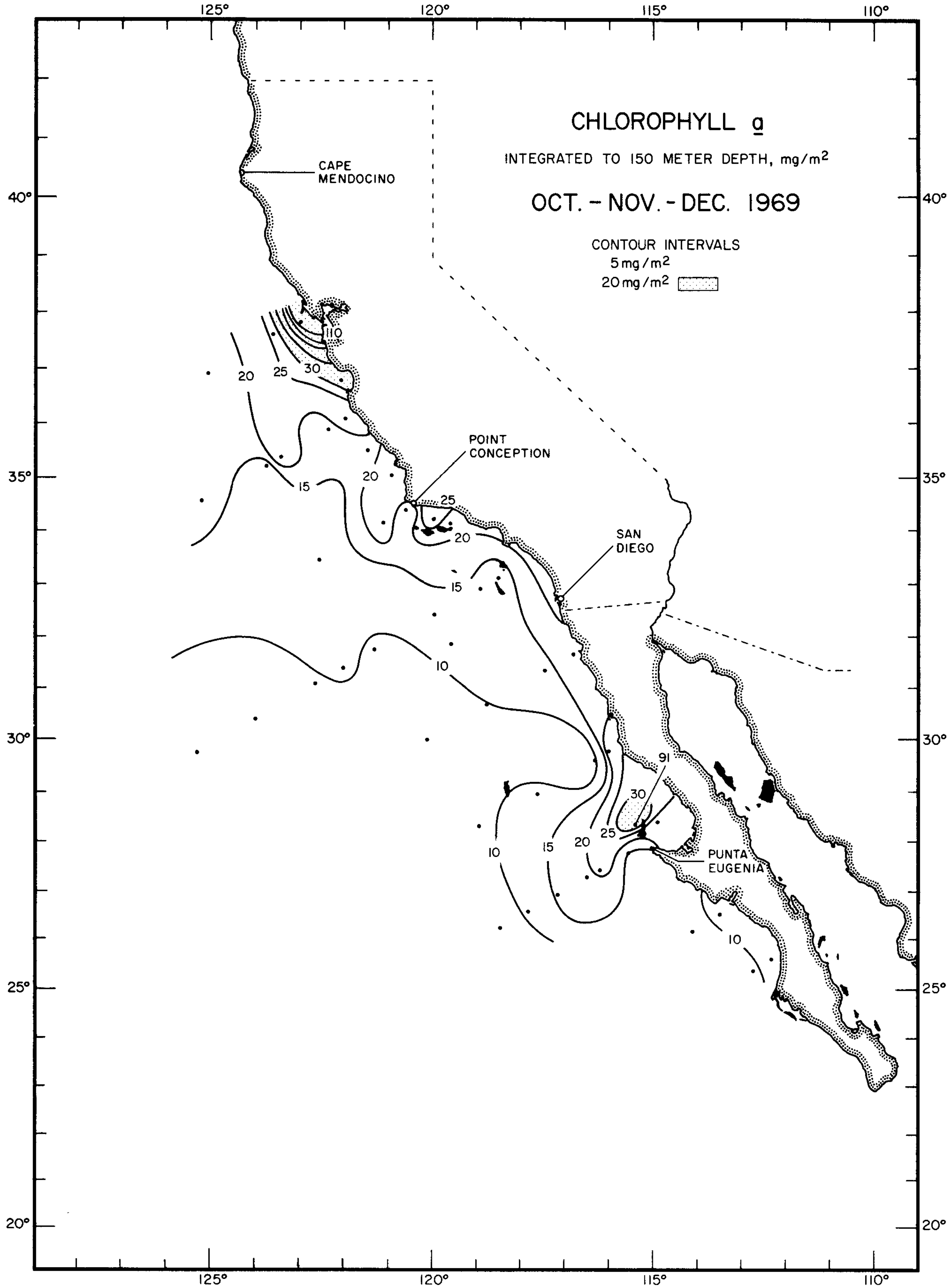
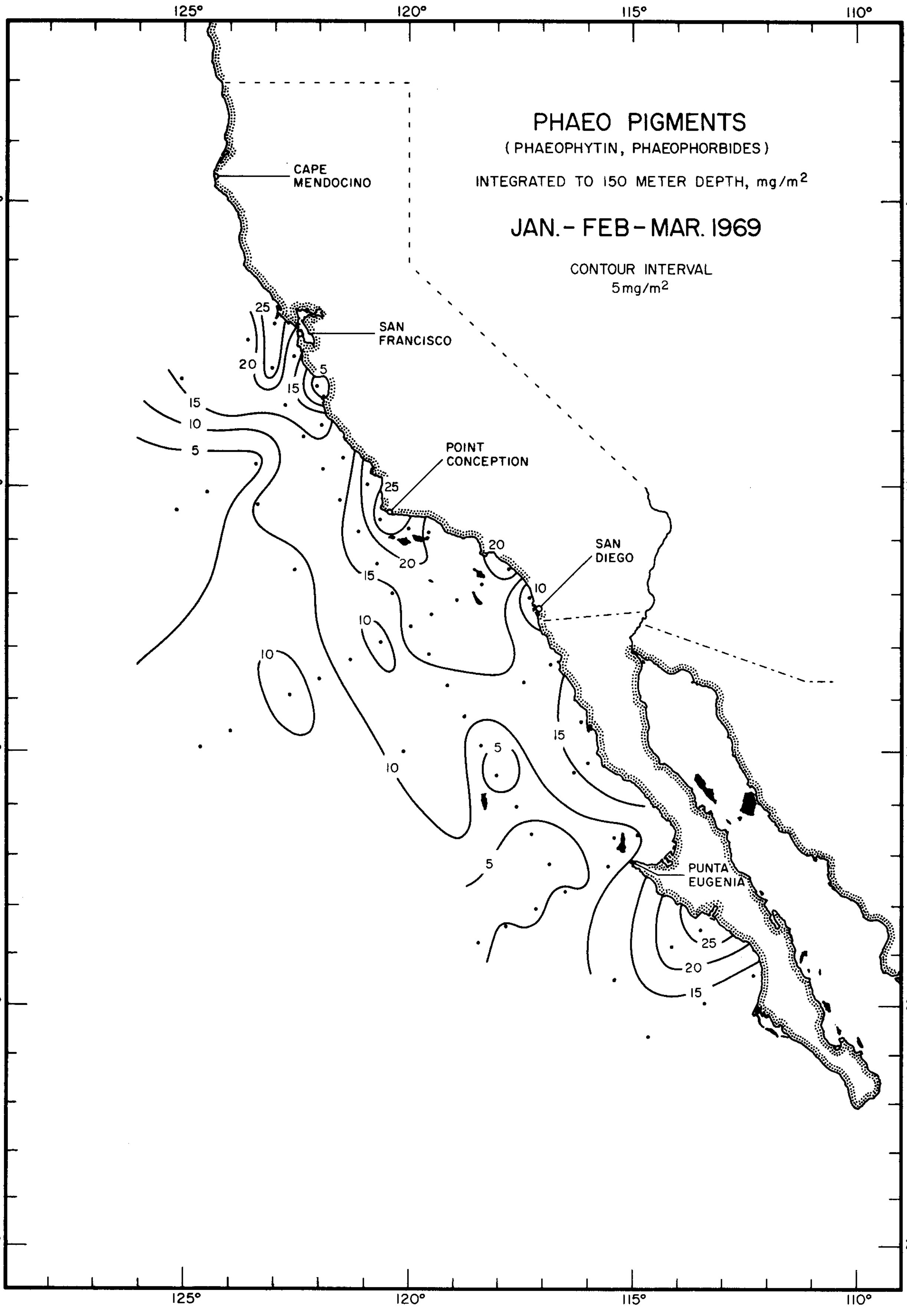
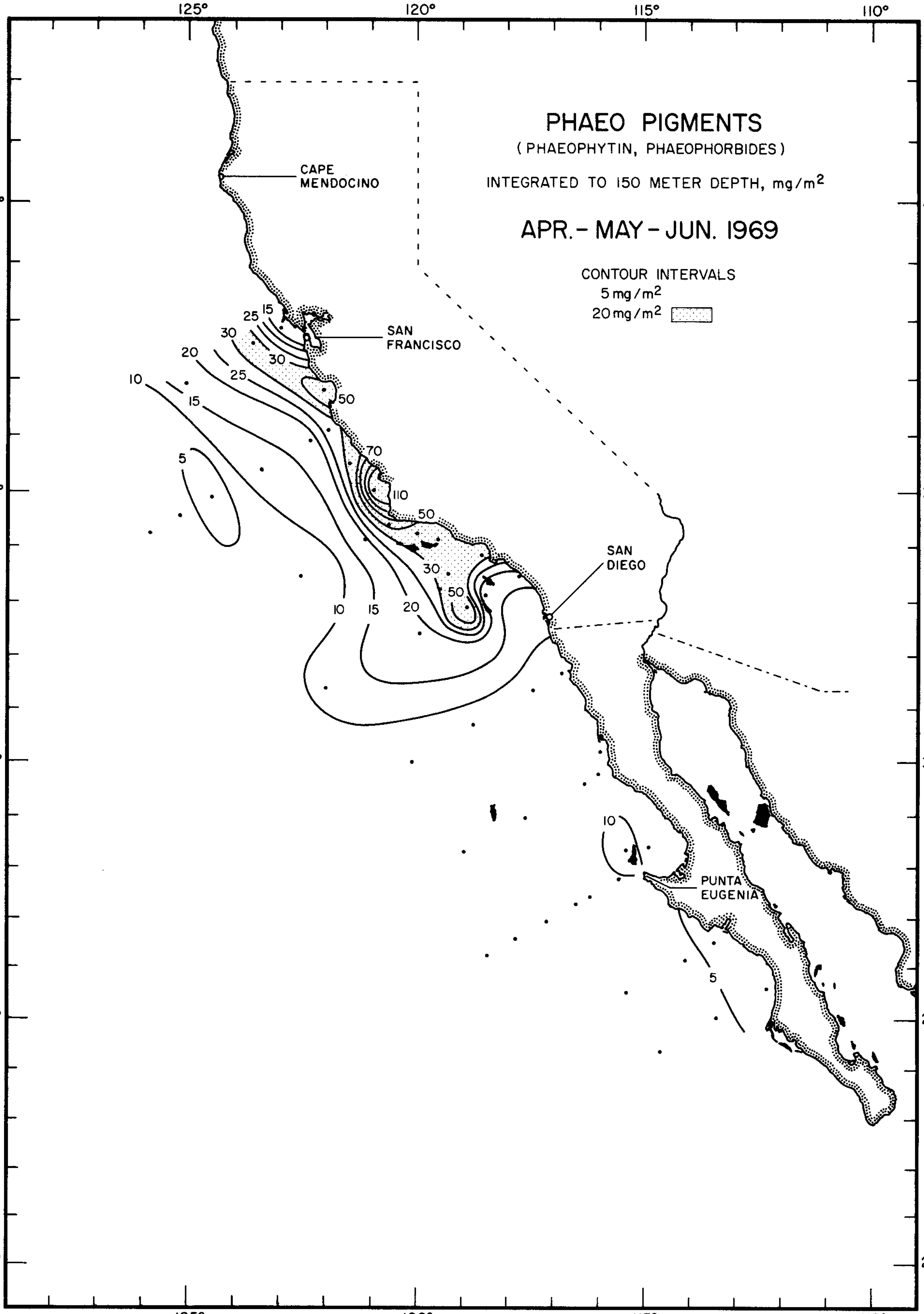


CHLOROPHYLL a
INTEGRATED
OCT. - NOV. - DEC. 1969



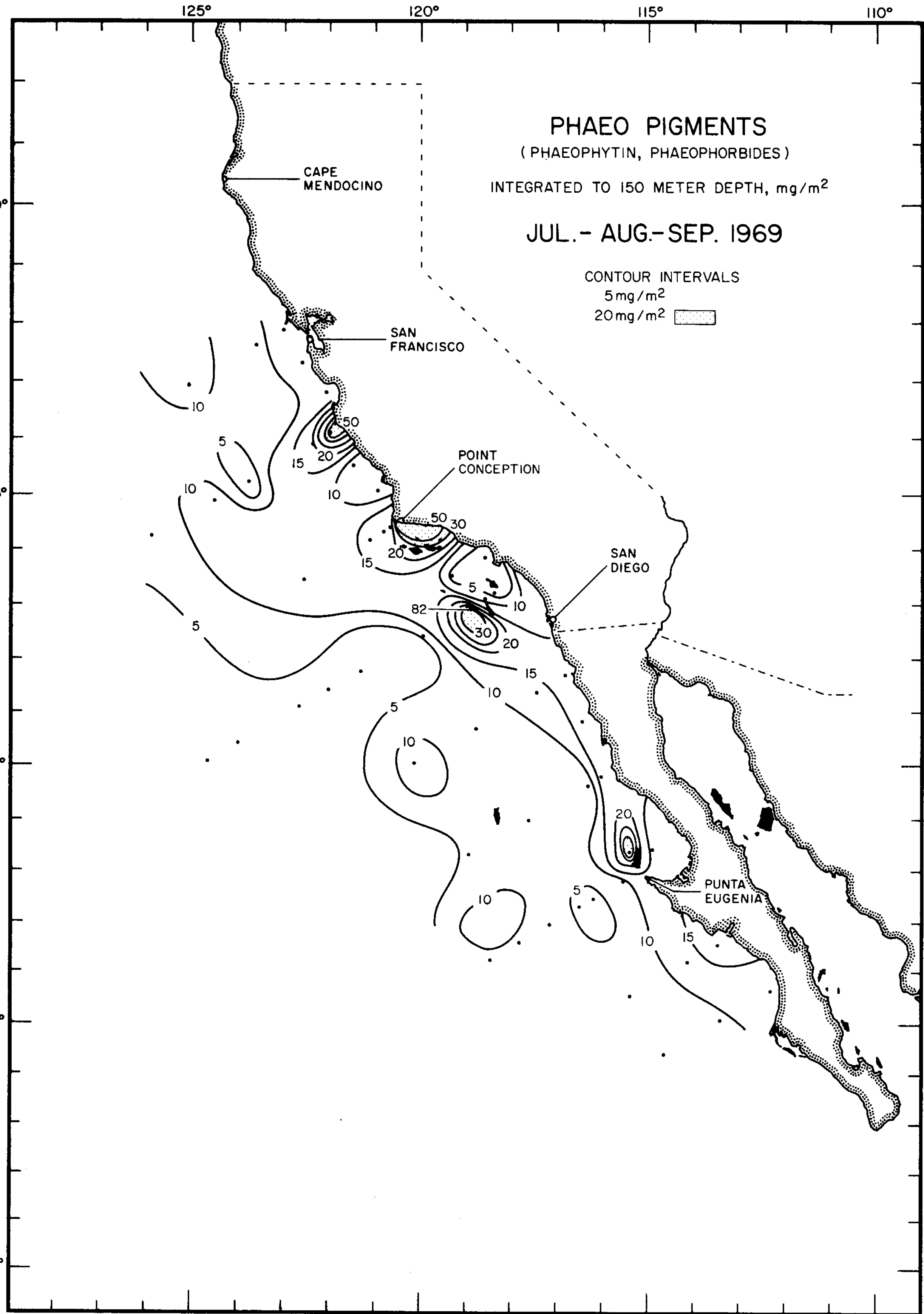
PHAEO PIGMENTS

JAN. - FEB. - MAR. 1969



PHAEO PIGMENTS

APR. - MAY - JUN. 1969



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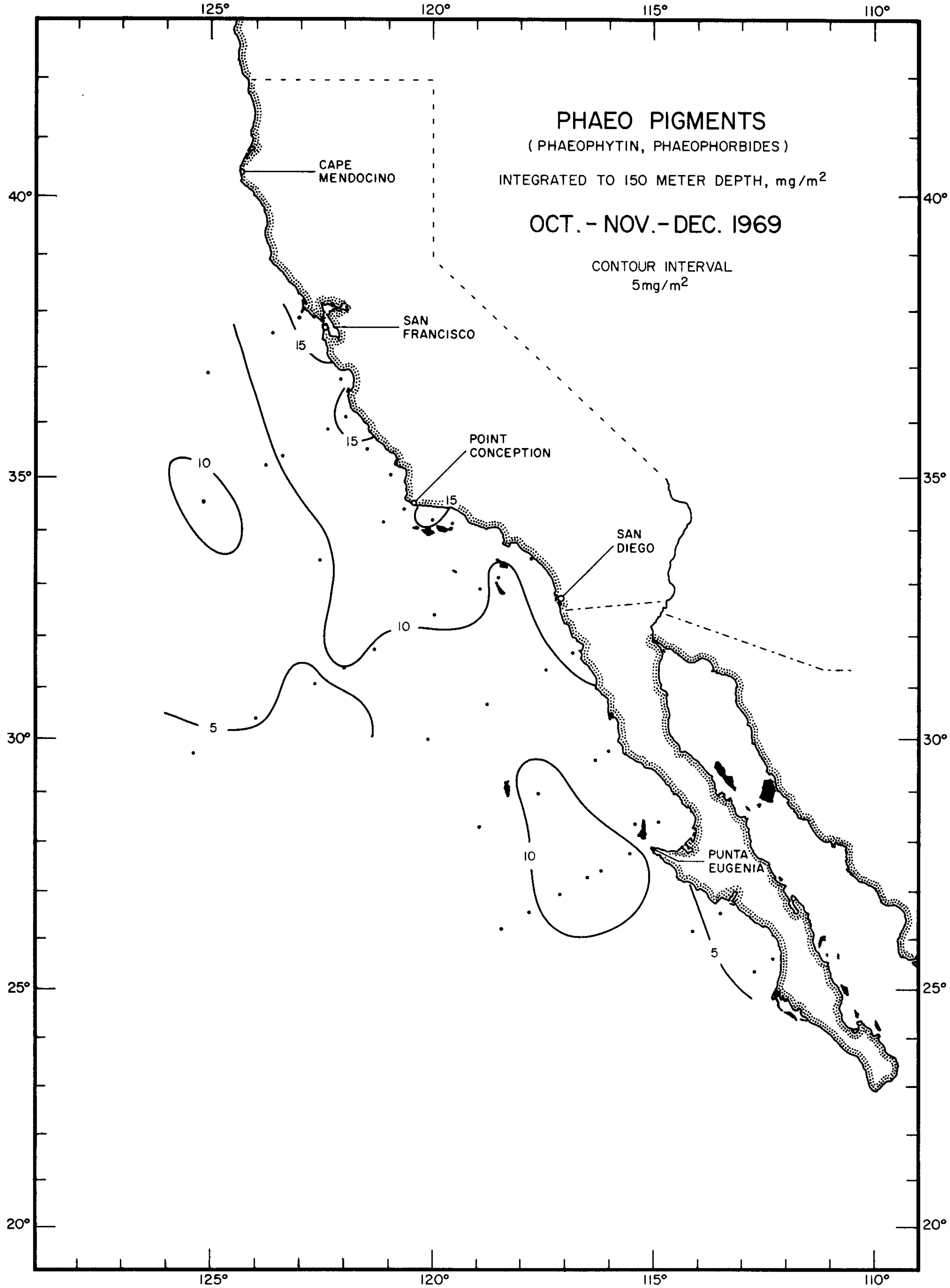
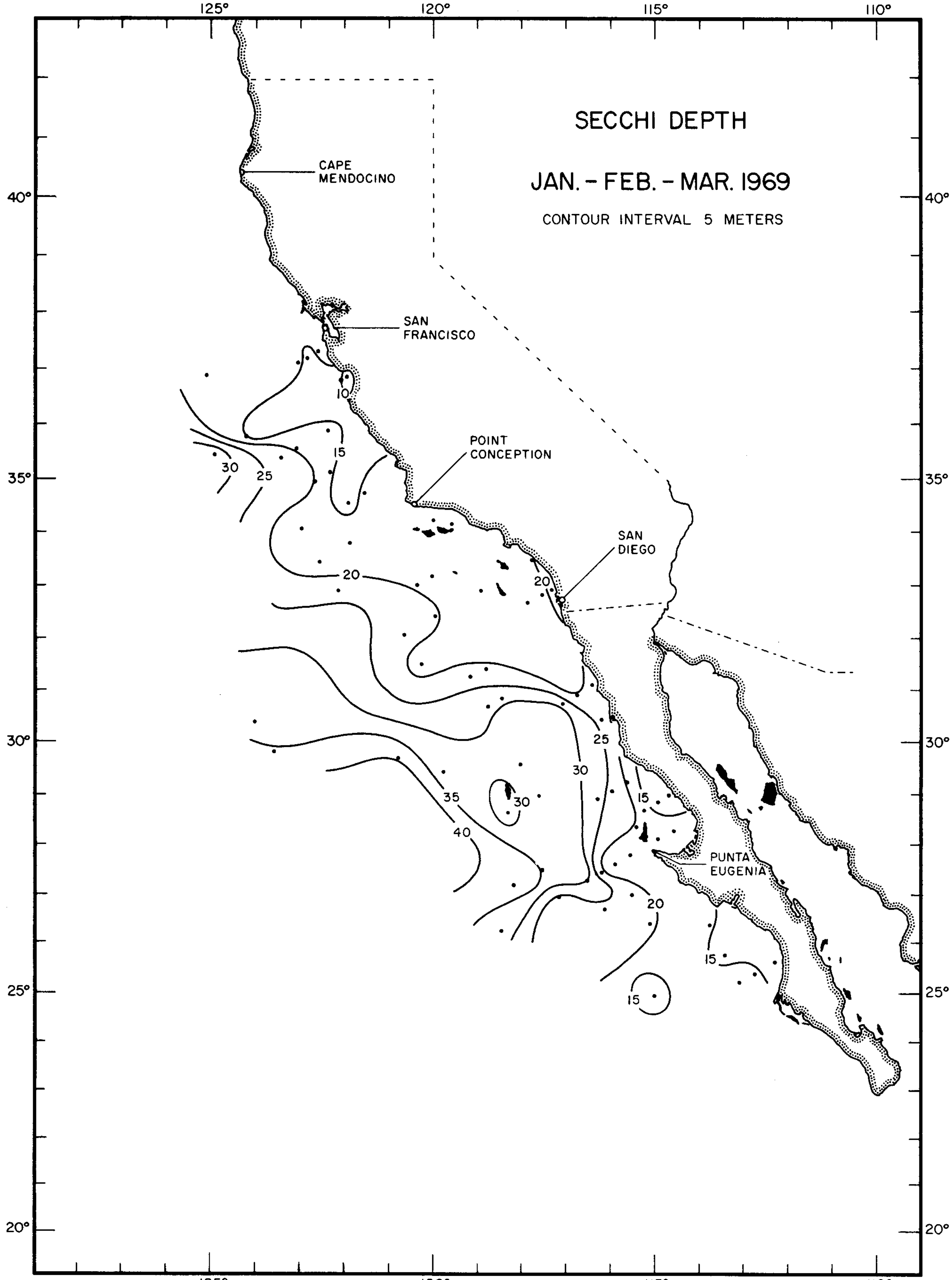


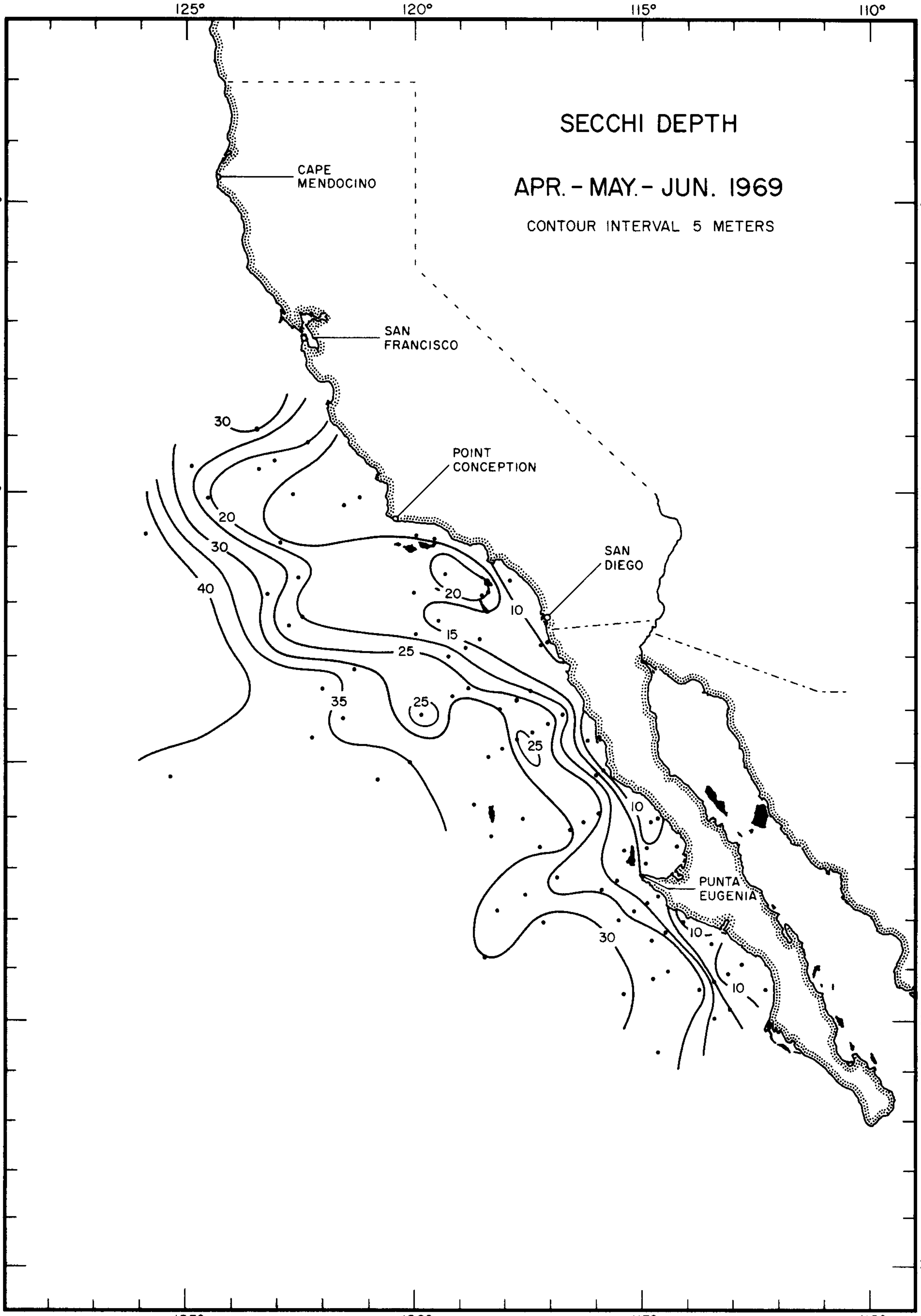
PHAEO PIGMENTS

OCT. - NOV. - DEC. 1969



SECCHI DEPTH

JAN. - FEB. - MAR. 1969



SECCHI DEPTH

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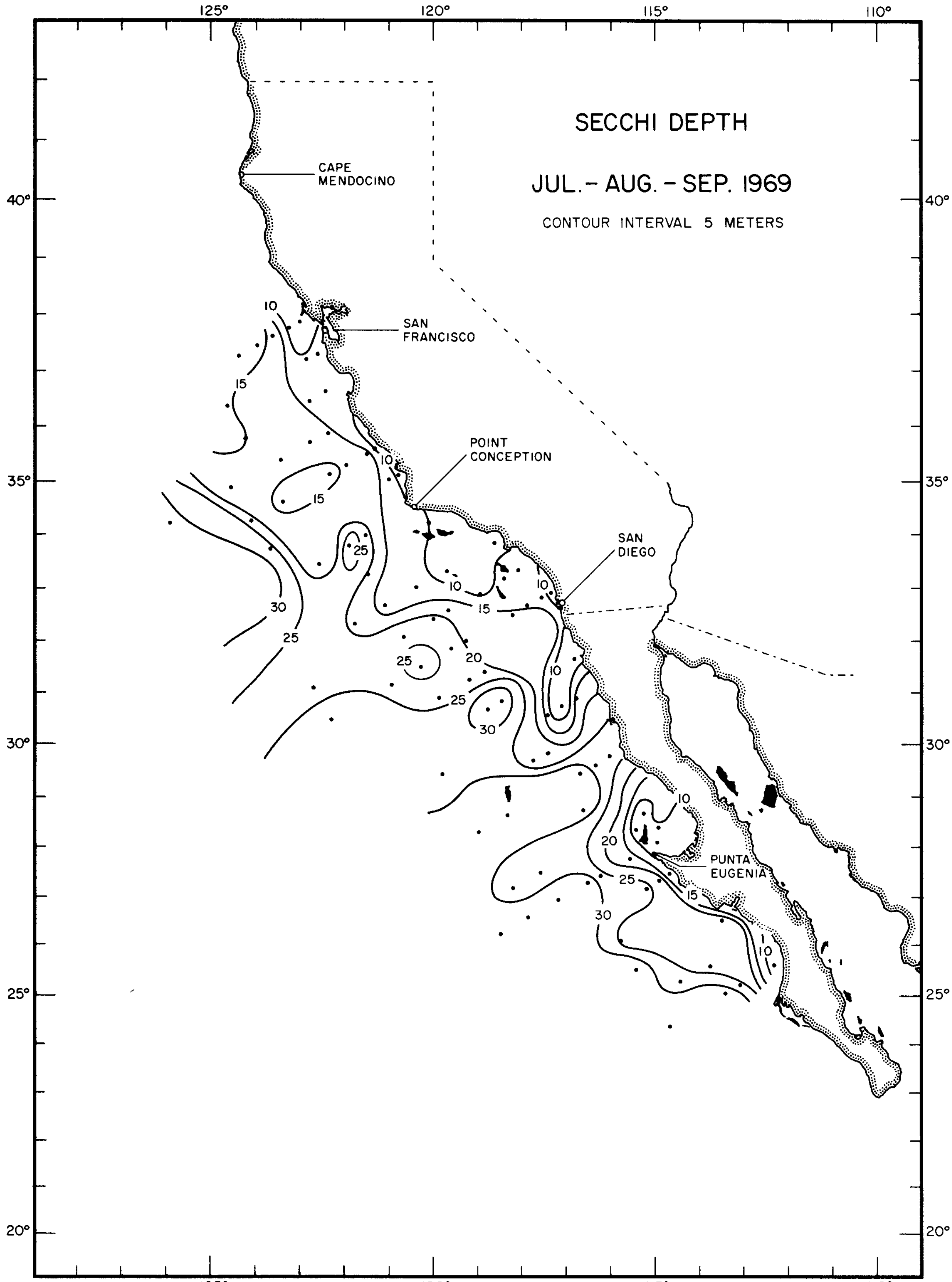

SECCHI DEPTH

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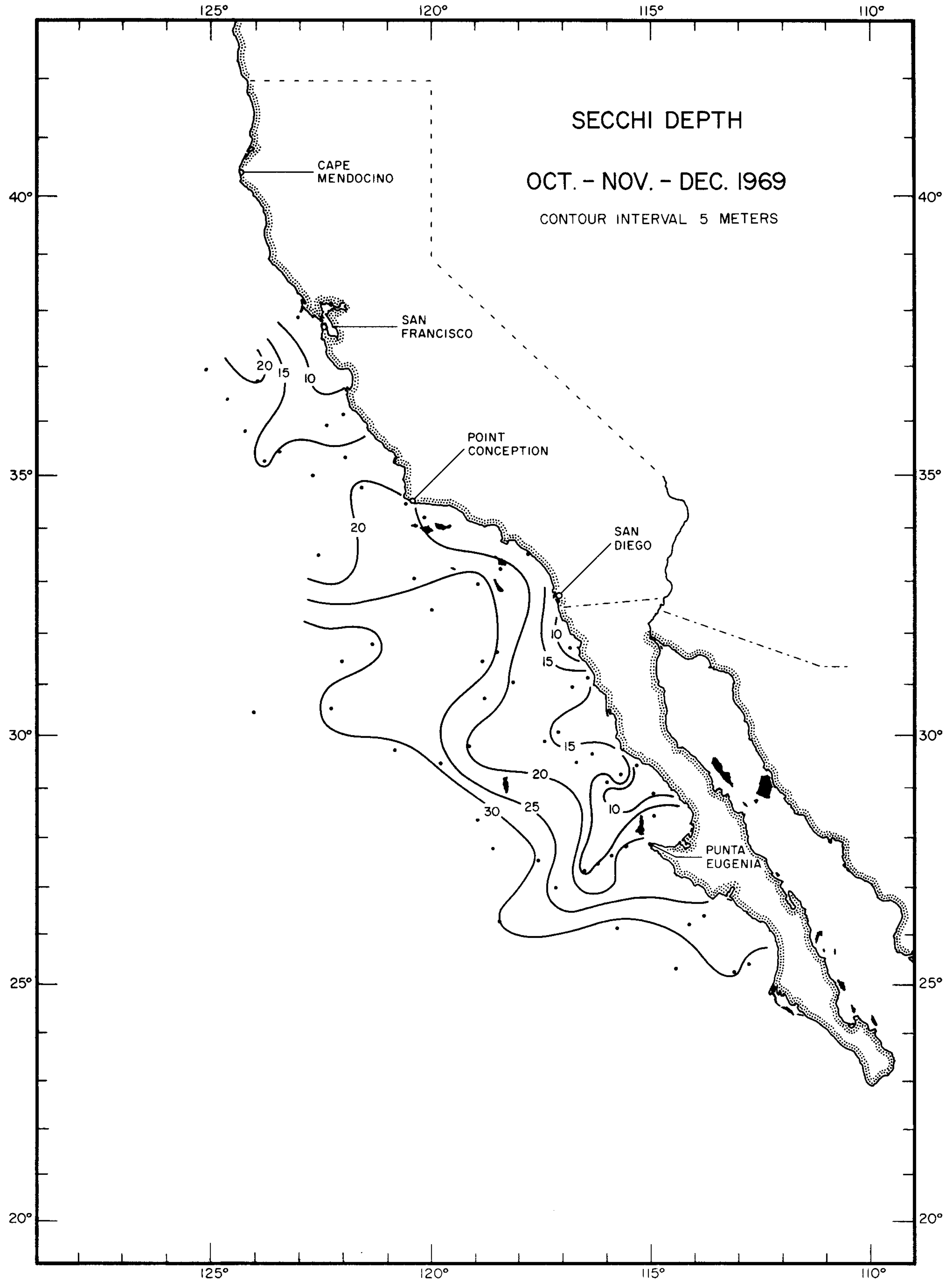

SECCHI DEPTH

OCT. - NOV. - DEC. 1969

DISTRIBUTION OF ZOOPLANKTON VOLUMES IN THE CALIFORNIA CURRENT REGION, 1969

Paul E. Smith[1]

Introduction

This report presents contoured charts summarizing displacement volumes of zooplankton samples that were collected systematically during regular CalCOFI cruises carried out in 1969.

The sampling in 1969 differs in two details from that carried out in the years 1951 to 1966 described by Smith (1971): 1. The depth of the standard CalCOFI oblique tow was increased to approximately 210 meters by paying out and retrieving 300 meters of cable at the usual rates of release and return (50 meters per minute out and 20 meters per minute in). 2. The standard CalCOFI net was constructed of a single grade of nylon fabric with mesh apertures of 0.505 mm. Previous nets were constructed of two grades of bolting silk, the anterior section having apertures of 0.55 mm and the posterior section having apertures of 0.25 mm.

A sampling study considering the effects of the two types of nets and the two depths of tow on the displacement volume was carried out at CalCOFI station 93.30 which lies ten miles west of La Jolla (latitude 32° 50.5' N, longitude 117° 31.0' W, bottom depth 805 meters). The object was to facilitate comparison of the systematic measurements of zooplankton volumes obtained in 1969 with those from previous CalCOFI cruises. Sets of replicate samples were collected at 10, 6 and 2 hours before and after local apparent noon by oblique tows with silk and nylon nets deployed in randomized order from 140 m and 210 m depth. A total of 42 tows were made between 2100 PST June 28 and 0300 PST July 1, 1968 (Table 1). All other field and laboratory procedures used to obtain and process the test samples and the samples from the 1969 cruises follow those described by Kramer et al (1972). Omitting the abnormally large catch by the nylon net taken at 1020PST (838 cc/1000m^3) the general results (Table 2) indicate that in the test area zooplankton concentrates above 140 meters are much greater proportionately than between 140 m and 210 m depth, in both day and night sampling periods. The day to night ratio of average volume of zooplankton remains virtually the same between the 140 meter silk net tows (D/N=0.797) and the 210 meter nylon tows (D/N = 0.803). However, in terms of cc/1000m^3 the volumes from the 1969 type tows tend to be 25 - 30% less than those from the previous years (Smith 1971), a decrease that will affect the contoured abundance to a limited degree.

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TABLE 1

A COMPARISON OF PLANKTON VOLUMES BY PRE-1969 AND POST-1969 SAMPLING TECHNIQUES

	NIGHT					DAY				
	TIME	VOLUME FILTERED	ESTIMATED DEPTH	DISPLACEMENT VOLUME		TIME	VOLUME FILTERED	ESTIMATED DEPTH	DISPLACEMENT VOLUME	
TOW TYPE	PST	m^3	m	$cc/1000m^3$	$ml\ m^{-2}$	PST	m^3	m	$cc/1000m^3$	$ml\ m^{-2}$
CalCOFI Silk	2153	444	138	347	47.89	1018	436	139	250	34.75
Net to 140 m	0153	438	138	215	29.67	1313	455	135	217	29.30
As 1951-68	0548	429	138	182	25.12	1743	447	136	204	27.74
Type A	2138	441	140	295	41.30	0908	456	140	261	36.54
	0143	433	141	296	41.74	1343	449	141	276	38.92
	0623	432	138	331	45.68	1738	431	138	304	41.95
	2203	454	138	432	59.62					
	0108	422	140	434	60.76					
Mean		436.6	138.9	316.5	43.97		445.7	138.2	252.0	34.87
Standard Deviation		9.9	1.2	90.68	12.63		10.2	2.3	37.13	5.50
Mult. Error Factor				1.36	1.36				1.16	1.18
CalCOFI Silk	2120	617	210	170	35.70	0950	630	213	130	27.69
Net to 210 m	0225	604	208	200	41.60	1345	660	204	129	26.32
Type B	0515	645	207	155	32.09	1815	630	209	255	53.30
(Test)	2110	667	210	336	70.56	0950	643	210	218	45.78
	0215	631	211	212	44.73	1415	641	211	192	40.51
	0515	619	208	205	42.64	1710	656	206	189	38.93
	2140	637	212	308	65.30					
	0140	606	211	271	57.18					
Mean		628.3	209.6	232.1	48.73		643.3	208.8	185.5	38.76
Standard Deviation		21.3	1.8	65.51	14.01		12.6	3.3	49.42	10.40
Mult. Error Factor				1.32	1.33				1.32	1.32
CalCOFI Nylon	2225	695	209	204	42.64	0915	743	201	137	27.54
Net to 210 m	0115	644	207	236	48.85	1420	696	206	124	25.54
Type C	0620	670	212	131	27.77	1715	674	205	172	35.26
As 1969-ff	2205	679	209	196	40.96	1020*	686	209	838*	175.14*
	0110	663	210	244	51.24	1305	679	208	212	44.10
	0550	656	208	243	50.54	1810	665	208	262	54.50
	2105	643	209	274	57.27					
	0205	618	211	280	59.08		690.5	206.2	290.83	60.35
Mean		658.5	209.4	226.0	47.29		27.8	2.9	272.78	57.26
Standard Deviation		23.9	1.6	48.32	10.07				2.01	2.03
Mult. Error Factor				1.28	1.27					
*Omitted from Mean									181.4	37.39
Standard Deviation									56.34	12.04
Mult. Error Factor									1.36	1.37

TABLE 2.

VOLUME FILTERED

Type of Net and Tow	Average Volume Strained m^3	
140 meter Silk	440	
210 meter Silk	635	increase 44.3% over 140 m Silk
210 meter Nylon	671	increase 52.5% over 140 m Silk
		increase 5.7% over 210 m Silk

CONCENTRATION

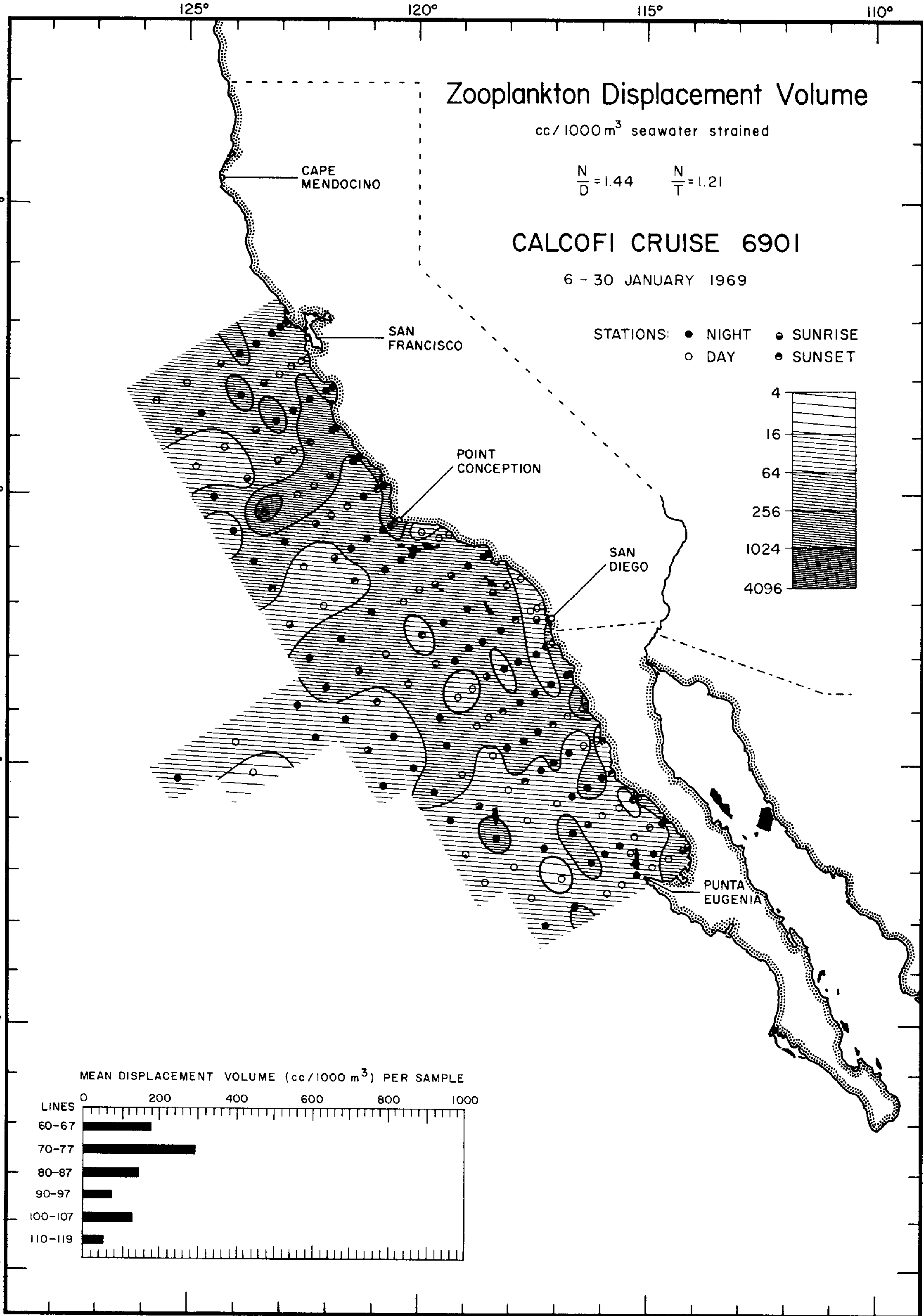
	Average Concentration cc/1000m^3	
140 meter Silk	289	
210 meter Silk	212	decrease 26.6% from 140 m Silk
210 meter Nylon	209*	decrease 27.7% from 140 m Silk
		decrease 1.4% from 210 m Silk

*Omitting large 1020 PST day value for 210 meter Nylon net.

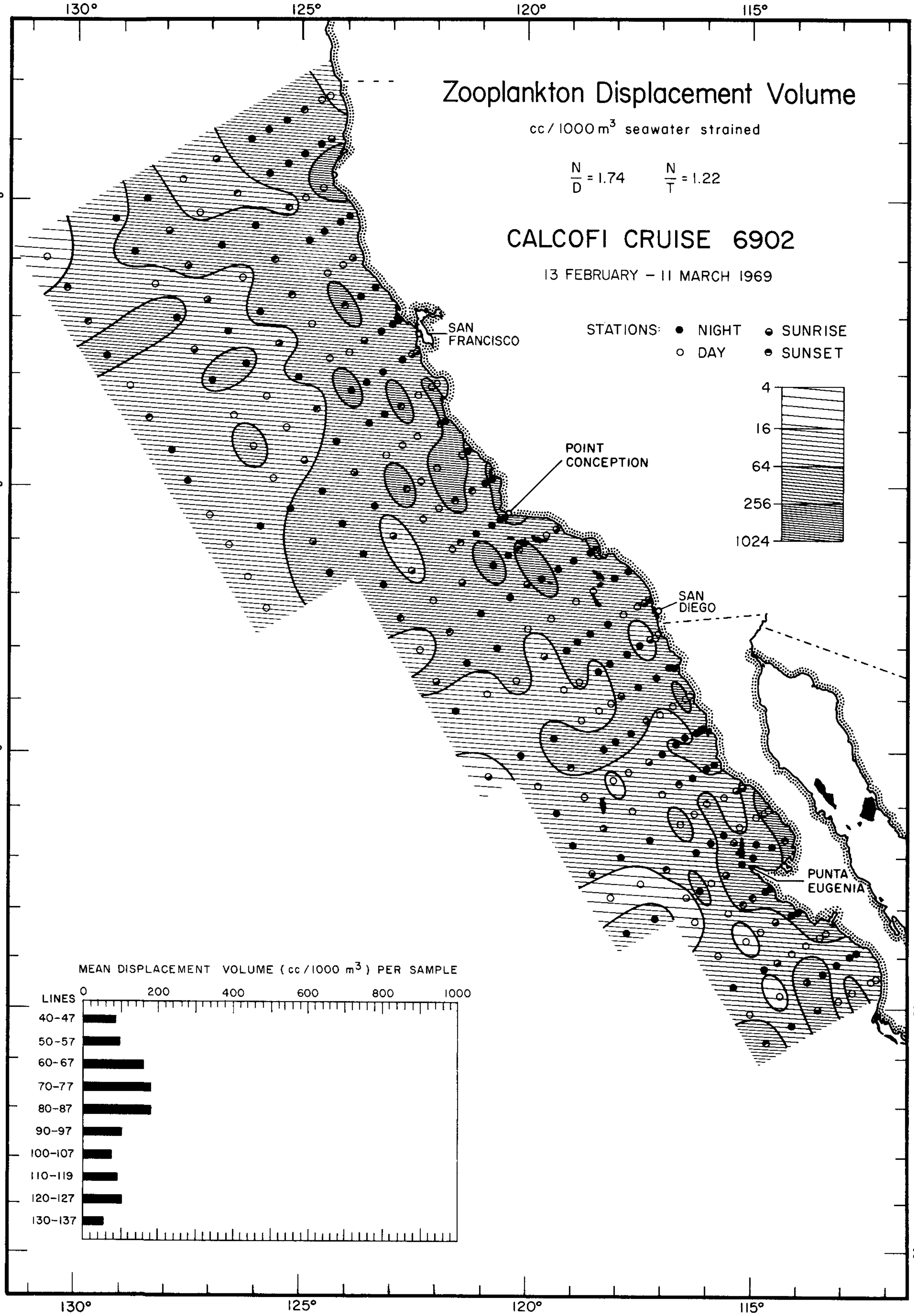
REFERENCES CITED

Smith, P.E., 1971. Distributional atlas of zooplankton volume in the California Current region, 1951 through 1966. CalCOFI Atlas No. 13.

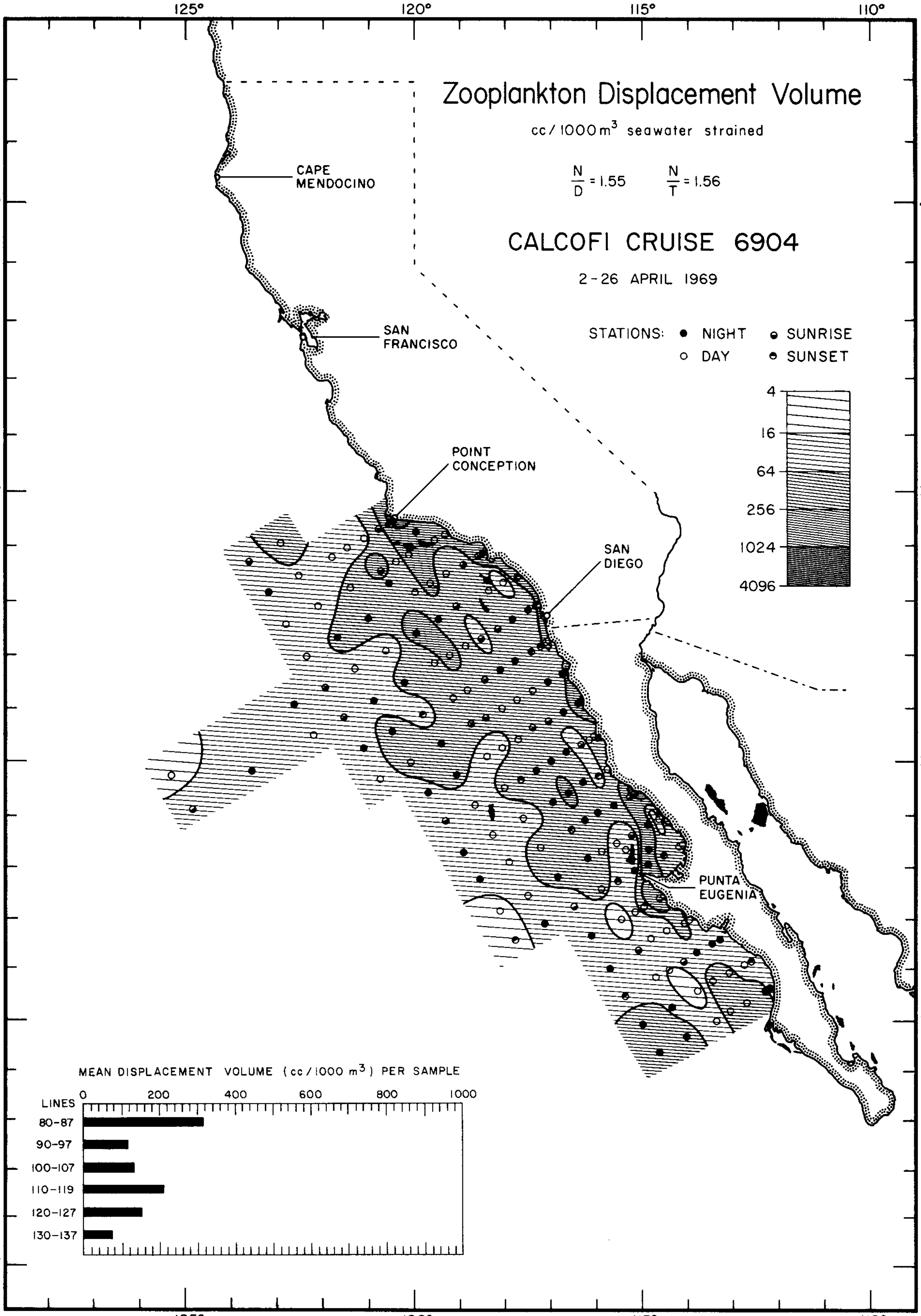
Kramer, D., Mary J. Kalin, Elizabeth G. Stevens, James R. Thrailkill and James R. Zweifel, 1972. Collecting and Processing Data on Fish Eggs and Larvae in the California Current Region. National Oceanic and Atmospheric Administration Tech. Rpt. National Marine Fisheries Service. Circ. - 370.



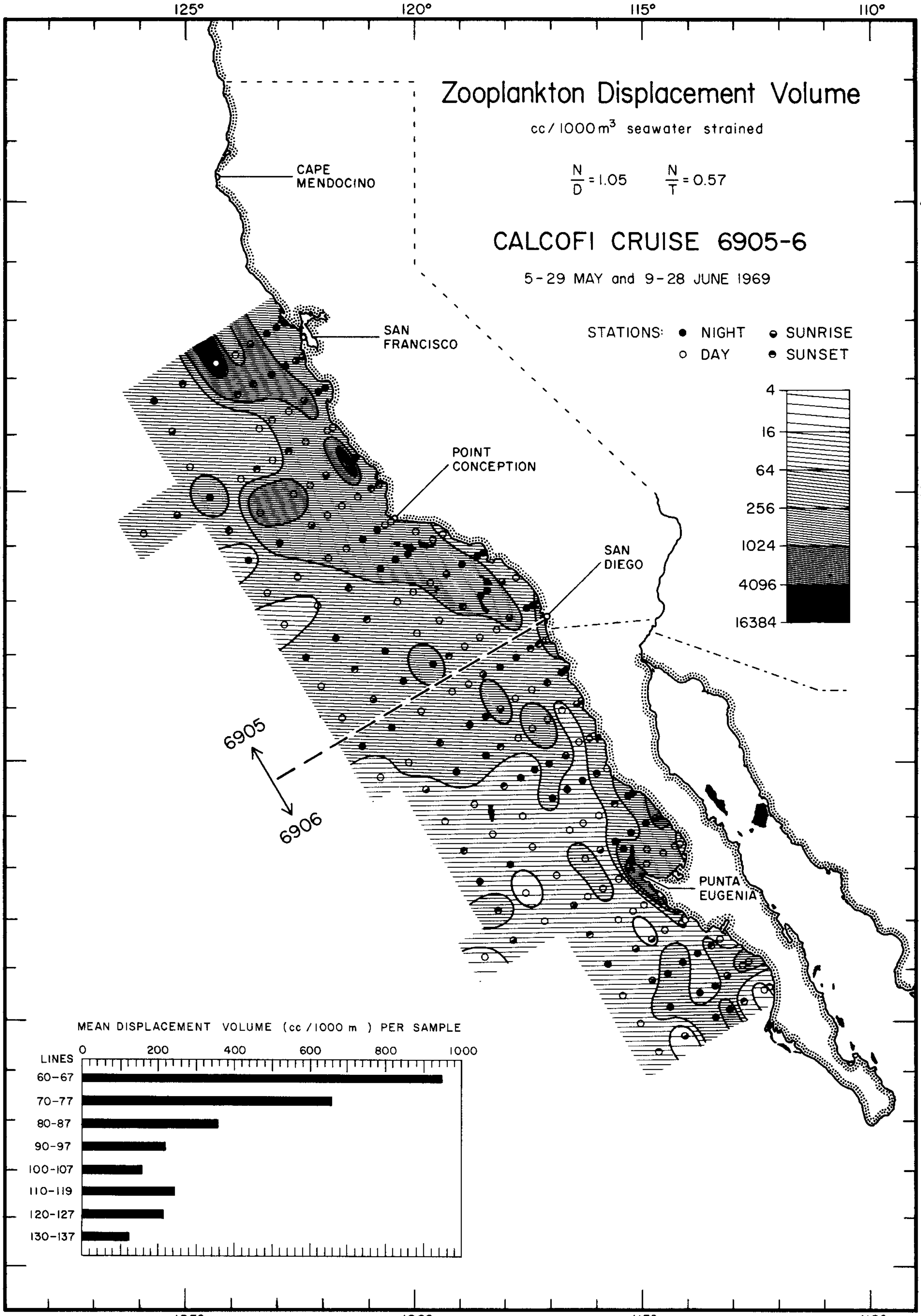
Zooplankton Displacement Volume
cc/1000 m³ seawater strained
N/D = 1.44   N/T = 1.21
CALCOFI CRUISE 6901
6 - 30 JANUARY 1969
STATIONS: ● NIGHT ○ DAY ◒ SUNRISE ◓ SUNSET
4
16
64
256
1024
4096
CAPE MENDOCINO
SAN FRANCISCO
POINT CONCEPTION
SAN DIEGO
PUNTA EUGENIA
125°
120°
115°
110°
40°
35°
30°
25°
20°
MEAN DISPLACEMENT VOLUME (cc/1000 m³) PER SAMPLE
0
200
400
600
800
1000
LINES
60-67
70-77
80-87
90-97
100-107
110-119



Zooplankton Displacement Volume
cc/1000 m³ seawater strained
N/D = 1.74
N/T = 1.22
CALCOFI CRUISE 6902
13 FEBRUARY – 11 MARCH 1969
STATIONS: ● NIGHT ◒ SUNRISE
○ DAY ◓ SUNSET
4
16
64
256
1024
SAN FRANCISCO
POINT CONCEPTION
SAN DIEGO
PUNTA EUGENIA
130°
125°
120°
115°
40°
35°
30°
25°
20°
MEAN DISPLACEMENT VOLUME (cc/1000 m³) PER SAMPLE
LINES
0
200
400
600
800
1000
40-47
50-57
60-67
70-77
80-87
90-97
100-107
110-119
120-127
130-137

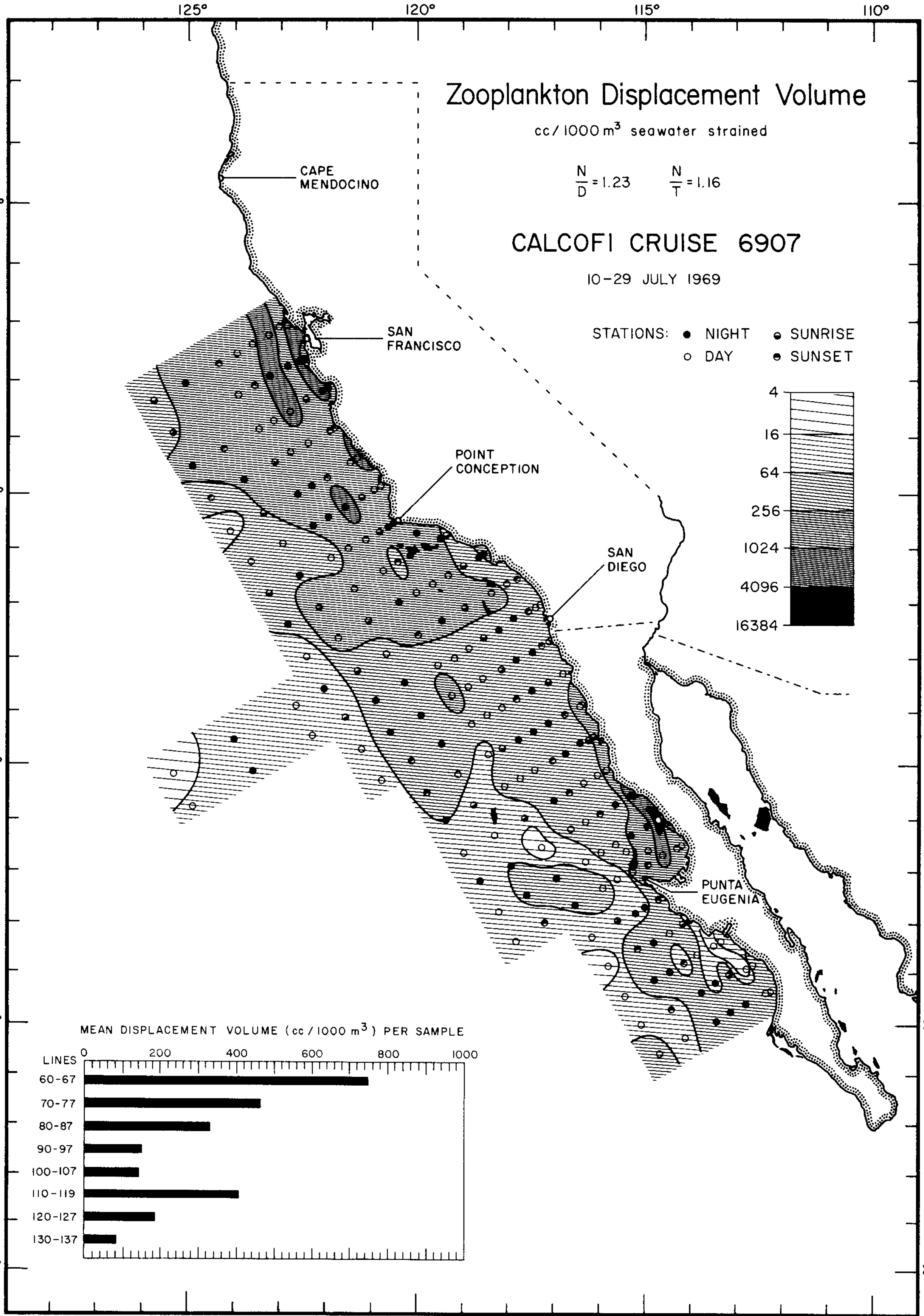


Zooplankton Displacement Volume
cc/1000m^3 seawater strained
$\frac{N}{D}$ = 1.55 $\frac{N}{T}$ = 1.56
CALCOFI CRUISE 6904
2-26 APRIL 1969
STATIONS: ● NIGHT ○ DAY SUNRISE SUNSET
4
16
64
256
1024
4096
CAPE MENDOCINO
SAN FRANCISCO
POINT CONCEPTION
SAN DIEGO
PUNTA EUGENIA
125° 120° 115° 110°
40° 35° 30° 25° 20°
MEAN DISPLACEMENT VOLUME (cc/1000 m^3) PER SAMPLE
LINES
0 200 400 600 800 1000
80-87
90-97
100-107
110-119
120-127
130-137



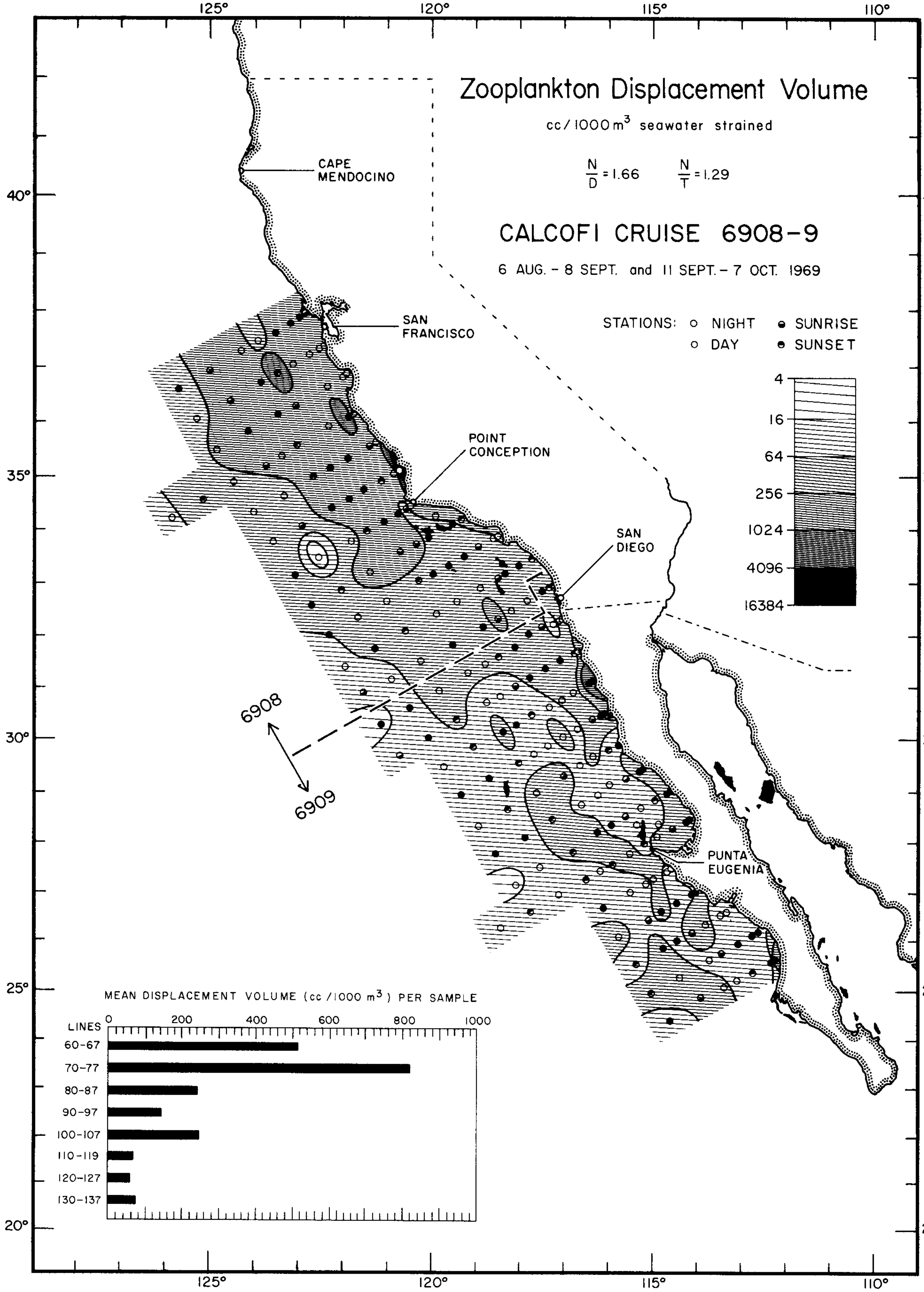
Zooplankton Displacement Volume

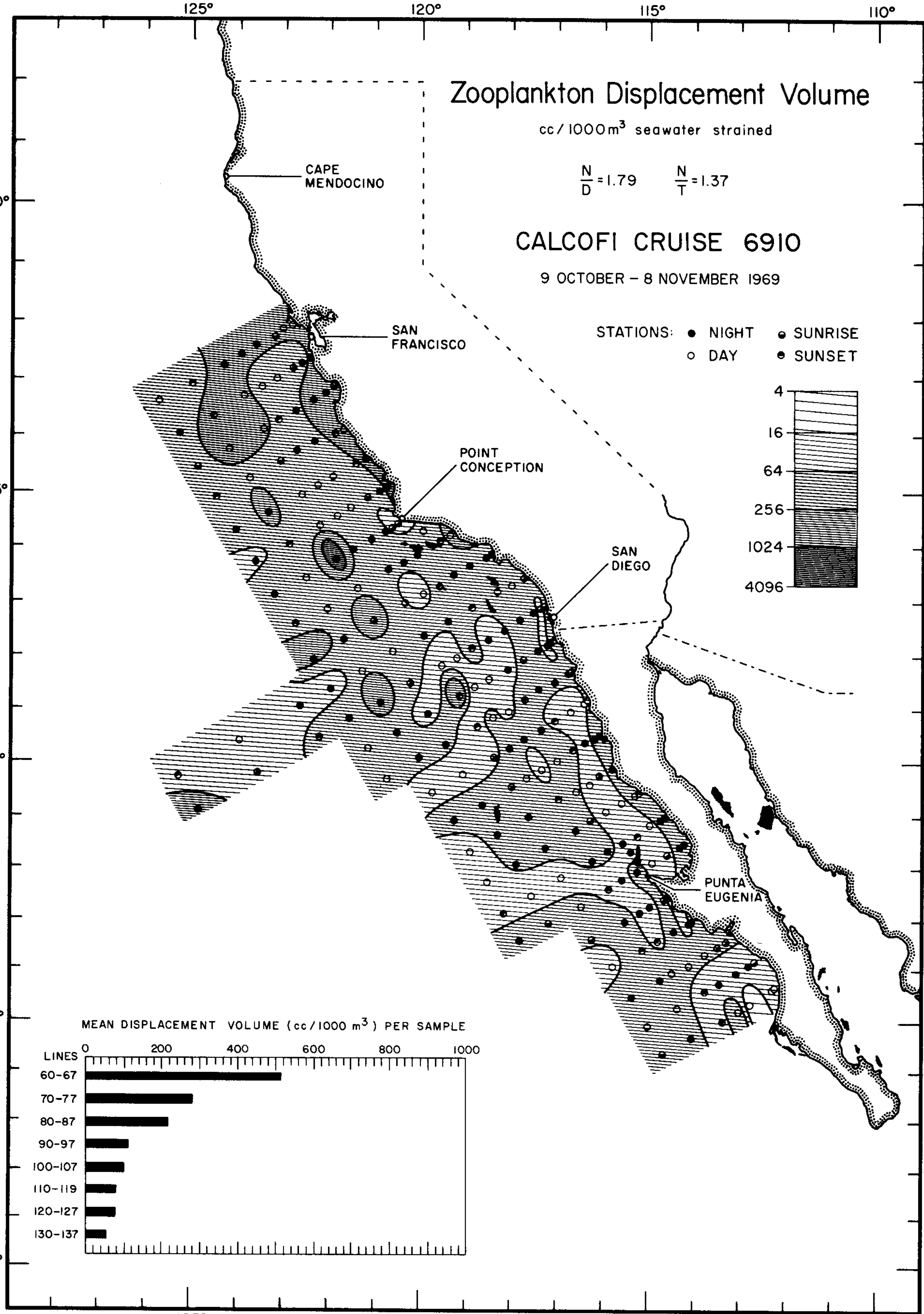
6905-6



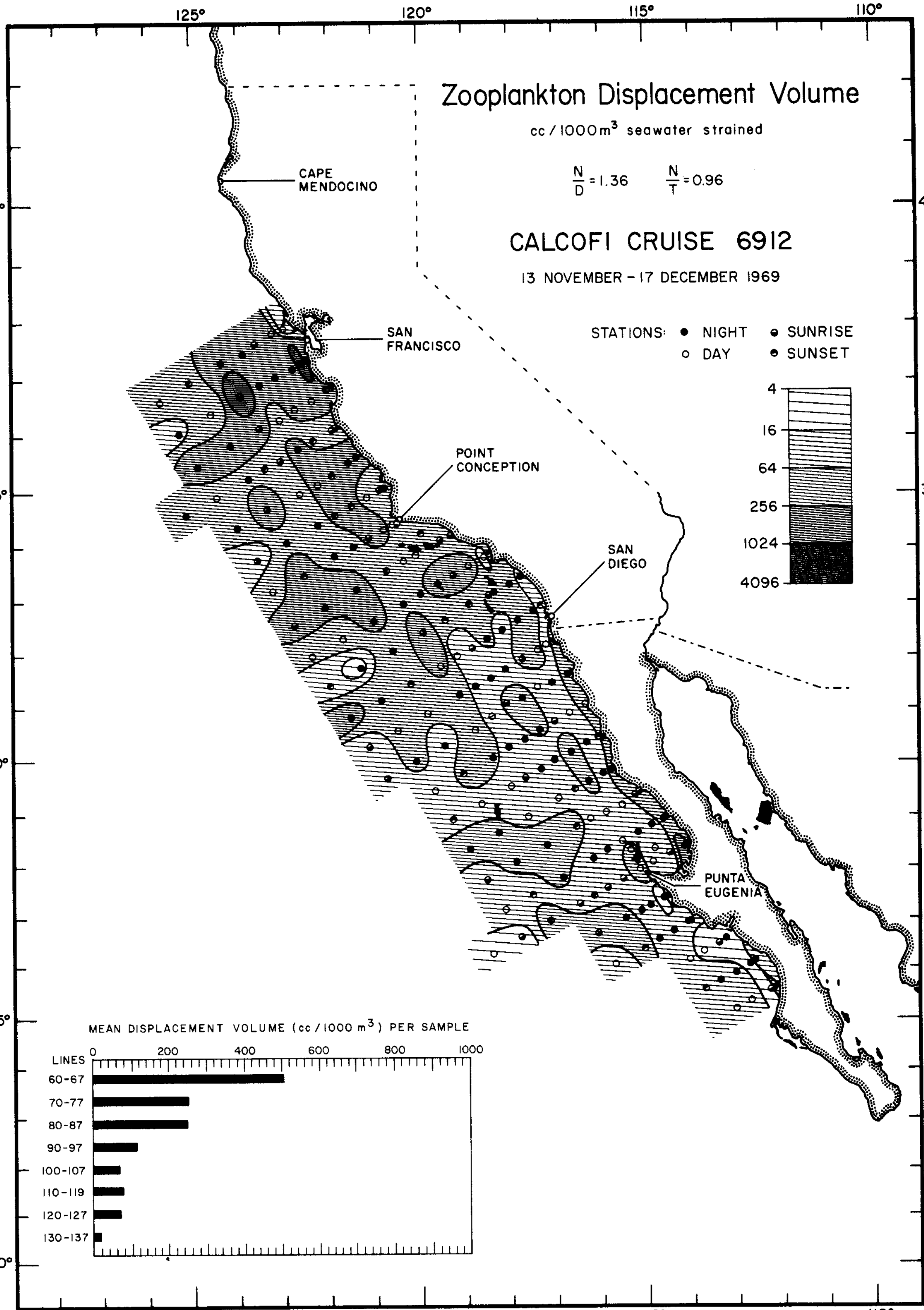
Zooplankton Displacement Volume

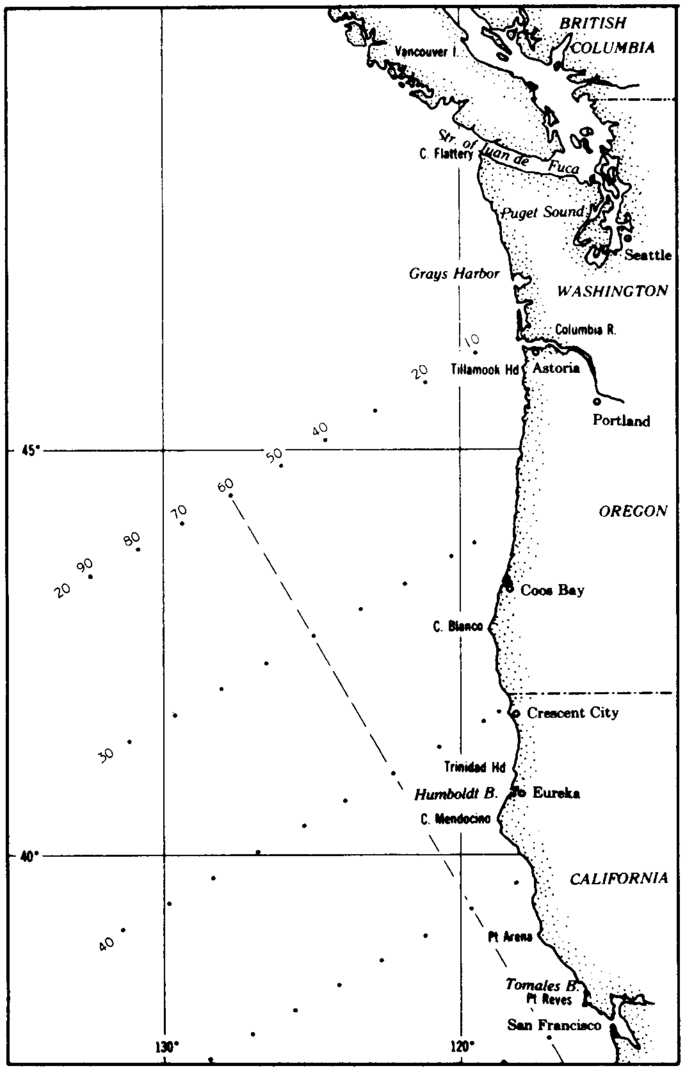
6907

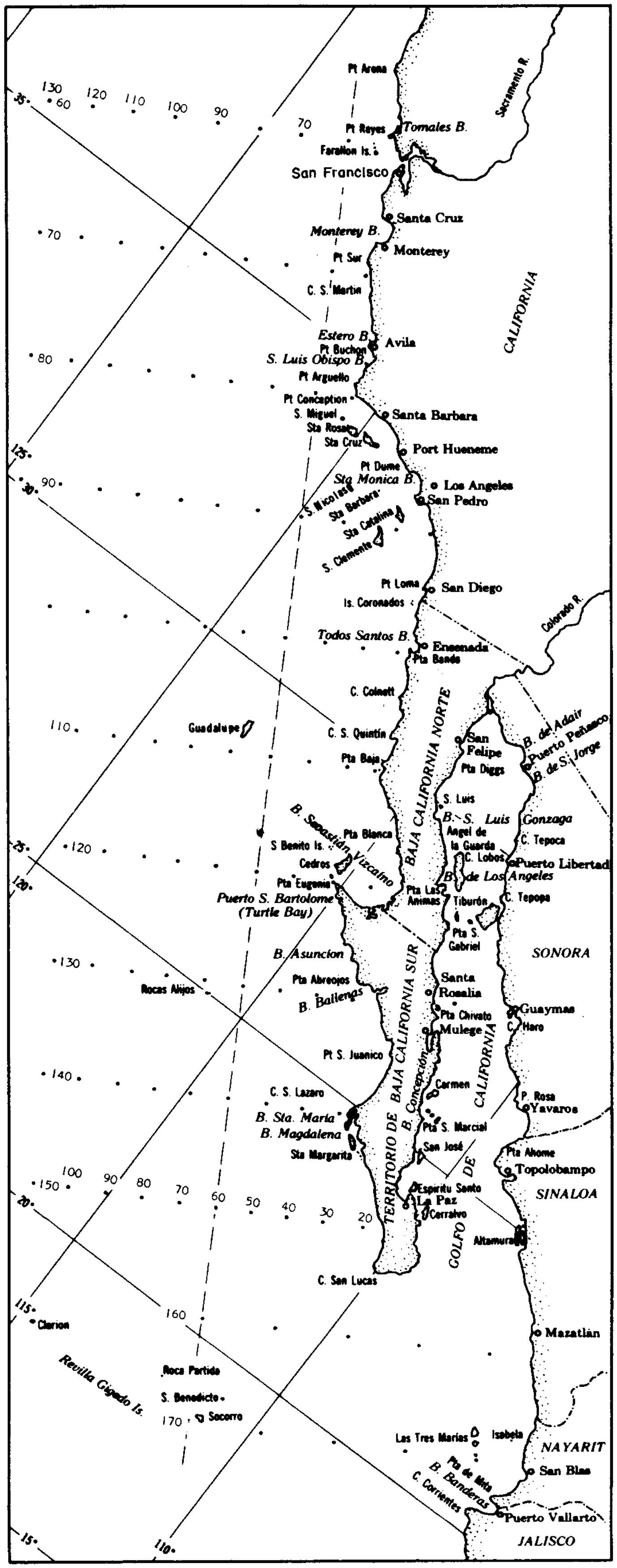

Zooplankton Displacement Volume
cc/1000 m3 seawater strained
N/D = 1.66 N/T = 1.29
CALCOFI CRUISE 6908-9
6 AUG. - 8 SEPT. and 11 SEPT. - 7 OCT. 1969
STATIONS: NIGHT DAY SUNRISE SUNSET
4
16
64
256
1024
4096
16384
CAPE MENDOCINO
SAN FRANCISCO
POINT CONCEPTION
SAN DIEGO
PUNTA EUGENIA
6908
6909
MEAN DISPLACEMENT VOLUME (cc/1000 m3) PER SAMPLE
LINES
0 200 400 600 800 1000
60-67
70-77
80-87
90-97
100-107
110-119
120-127
130-137
125° 120° 115° 110°
40° 35° 30° 25° 20°



Zooplankton Displacement Volume
cc/1000m³ seawater strained
N/D = 1.79 N/T = 1.37
CALCOFI CRUISE 6910
9 OCTOBER – 8 NOVEMBER 1969
STATIONS: ● NIGHT ○ DAY SUNRISE SUNSET
4
16
64
256
1024
4096
CAPE MENDOCINO
SAN FRANCISCO
POINT CONCEPTION
SAN DIEGO
PUNTA EUGENIA
125° 120° 115° 110°
40° 35° 30° 25° 20°
MEAN DISPLACEMENT VOLUME (cc/1000 m³) PER SAMPLE
0 200 400 600 800 1000
LINES
60-67
70-77
80-87
90-97
100-107
110-119
120-127
130-137


Zooplankton Displacement Volume
cc / 1000 m^3 seawater strained
$\frac{N}{D}$ = 1.36 $\frac{N}{T}$ = 0.96
CALCOFI CRUISE 6912
13 NOVEMBER - 17 DECEMBER 1969
STATIONS: NIGHT SUNRISE
DAY SUNSET
4
16
64
256
1024
4096
CAPE MENDOCINO
SAN FRANCISCO
POINT CONCEPTION
SAN DIEGO
PUNTA EUGENIA
125°
120°
115°
110°
40°
35°
30°
25°
20°
MEAN DISPLACEMENT VOLUME (cc / 1000 m^3) PER SAMPLE
0
200
400
600
800
1000
LINES
60-67
70-77
80-87
90-97
100-107
110-119
120-127
130-137





These maps are designed to show essential details of the area most intensively studied by the California Cooperative Oceanic Fisheries Investigations. This is approximately the same area as is shown in color on the front cover. Geographical place names are those most commonly used in the various publications emerging from the research. The cardinal station lines extending southwestward from the coast are shown. They are 120 miles apart. Additional lines are utilized as needed and can be as closely spaced as 12 miles apart and still have individual numbers. The stations along the lines are numbered with respect to the station 60 line, the numbers increasing to the west and decreasing to the east. Most of them are 40 miles apart, and are numbered in groups of 10. This permits adding stations as close as 4 miles apart as needed. An example of the usual identification is 120.65. This station is on line 120, 20 nautical miles southwest of station 60.

The projection of the front cover is Lambert's Azimuthal Equal Area Projection. The detail maps are a Mercator projection.

CONTENTS