PROPOSAL NO.: UCSD-86 1160

IRS #95-6006144-W
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EXXON Production Co.
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TITLE OF PROPOSAL: Electromagnetic surveying of the Continental Shelf and Slope

PROJECT PERIOD: 1 year From: December 1, 1985 Through: November 30, 1986

AMOUNT REQUESTED: $57,000

AGENCY CONTRACT OR GRANT NO.: New

PRINCIPAL INVESTIGATOR:
(NAME, TITLE, ADDRESS & TELEPHONE)

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Charles S. Cox
Prof. of Oceanography
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Steven Constable
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(619) 452 2409

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OFFICER TO WHOM AWARD DOCUMENTS SHOULD BE MAILED:

Mr. Norman J. Sattler
Assistant Manager
Contracts and Grants Administration A010
Scripps Institution of Oceanography
La Jolla, CA 92093

Signature Robert A Knox for C S Cox Steve Constable Date: 11/5/85
Typed Name & Title: Alan D. Chave, Assoc. Res. Geop. | Charles S. Cox, Professor of Oce | Steven Constable, Asst. Res. Geop.

Signature Robert A Knox [signature] Date: 11/6/85
Typed Name & Title: R. Knox Acad. Adm. IGPP | J. Gieskes Chairman ORD

OFFICIALS AUTHORIZED TO SIGN FOR INSTITUTION

Signature [signature] III Date: 11/8/85
Typed Name & Title: W. A. Nierenberg, Director
Scripps Institution of Oceanography

Signature ____ Date ____
Typed Name & Title:

PROPOSAL NO.: UCSD- 861156

IRS #95-6006144-W
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SOHIO Petroleum Company
Geophysical Special Projects
One Lincoln Centre
5400 LBJ Freeway, Suite 1165-LB 25
Dallas, TX 75240
Attn: R. L. Ehrenbard

TITLE OF PROPOSAL: OFFSHORE CONTROLLED SOURCE E.M. SURVEYING (THE DEVELOPMENT OF OFFSHORE ELECTROMAGNETIC SURVEYING TECHNIQUES)

PROJECT PERIOD: 1 Year From: December 1, 1985 Through: November 30, 1986

AMOUNT REQUESTED: $30,000

AGENCY CONTRACT OR GRANT NO.: SOHIO 75 4485 Continuation

PRINCIPAL INVESTIGATOR:
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Assistant Manager
Contracts and Grants Administration A010
Scripps Institution of Oceanography
La Jolla, CA 92093

Signature [signature] C S Cox [signature] Date: 11/5/85
Typed Name & Title A. D. Chave, Assoc. Res. Geop. — C. S. Cox, Prof. of Oce. — S. Constable, Asst. Res. Geop.

Signature [signature] [signature] Date: 11/6/85
Typed Name & Title R. Knox Academic Adm. IGPP — J. Gieskes, Chair ORD

OFFICIALS AUTHORIZED TO SIGN FOR INSTITUTION

Signature [signature] III Date: 11/8/85
Typed Name & Title For: W. A. Nierenberg, Director
Scripps Institution of Oceanography

Signature ______ Date ______
Typed Name & Title

FO 2054

PROPOSAL NO.: UCSD-86 1157

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Departmente Recherche
Elf Aquitaine (Production)
26, Avenue Des Lilas
64018 Pau Cedex. FRANCE

ATTN: Dr. Patrick Unternehr, Direction Exploration

TITLE OF PROPOSAL: OFFSHORE CONTROLLED SOURCE E.M. SURVEYING (THE DEVELOPMENT OF OFFSHROE ELECTROMAGNETIC SURVEYING TECHNIQUES)

PROJECT PERIOD: 1 Year From: December 1, 1985 Through: November 30, 1986

AMOUNT REQUESTED: $30,000

AGENCY CONTRACT OR GRANT NO.: n°5943 continuation

PRINCIPAL INVESTIGATOR:
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OFFICER TO WHOM AWARD DOCUMENTS SHOULD BE MAILED:

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Assistant Manager
Contracts and Grants Administration A010
Scripps Institution of Oceanography
La Jolla, CA 92093

Signature Robert A Knox Jr Date: 11/5/85
Typed Name & Title: A. D. Chave, Assoc. Res. Geop. — C. S. Cox, Prof. of Oce. — S. Constable, Asst. Res. Geop.

Signature Robert A. Knox Date: 11/6/85
Typed Name & Title: R. Knox, Aca. Adm. IGPP — J. Gieskes, Chair ORD

OFFICIALS AUTHORIZED TO SIGN FOR INSTITUTION:

Signature For: Date: 11/8/85
Typed Name & Title: W. A. Nierenberg, Director
Scripps Institution of Oceanography

Signature ______ Date: ______
Typed Name & Title:

FO 2054

PROPOSAL NO.: UCSD-86 1158

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AMOCO Production Co.
Research Center
4502 East 41st Street
P.O. Box 591
Tulsa, OK 74102

Attn: Dr. Tony Nekut, Research Scientist

TITLE OF PROPOSAL: OFFSHORE CONTROLLED SOURCE E.M. SURVEYING (THE DEVELOPMENT OF OFFSHORE ELECTROMAGNETIC SURVEYING TECHNIQUES)

PROJECT PERIOD: 1 Year From: December 1, 1985 Through: November 30, 1986

AMOUNT REQUESTED: $30,000

AGENCY CONTRACT OR GRANT NO.: 81377 Continuation

PRINCIPAL INVESTIGATOR:
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Assistant Manager
Contracts and Grants Administration A010
Scripps Institution of Oceanography
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Signature Robert A Knox for / C S Cox / S Constable Date: 11/5/85
Typed Name & Title: A. D. Chave, Assoc. Res. Geop. / C. S. Cox, Professor of Oce. / S. Constable, Asst. Res. Geop.

Signature Robert A Knox / [illegible] Date: 11/5/85
Typed Name & Title: R. Knox, Aca. Adm. IGPP / J. Gieskes Chairman ORD

OFFICIALS AUTHORIZED TO SIGN FOR INSTITUTION

Signature [illegible] Date: 11/8/85
Typed Name & Title: For W. A. Nierenberg, Director
Scripps Institution of Oceanography

Signature ______ Date: ______
Typed Name & Title:

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IRS #95-6006144-W
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PROPOSAL NO.: UCSD- 86 1159

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PROPOSAL FOR RESEARCH TO BE CONDUCTED UNDER THE SPONSORSHIP OF

ARCO Oil and Gas Company
Research and Development
P. O. Box 2819
Dallas, TX 75221
Attn: Dr. Mark O. Halverson

TITLE OF PROPOSAL: OFFSHORE CONTROLLED SOURCE E.M. SURVEYING (THE DEVELOPMENT OF OFFSHORE ELECTROMAGNETIC SURVEYING TECHNIQUES)

PROJECT PERIOD: Year From: December 1, 1985 Through: November 30, 1986

AMOUNT REQUESTED: $30,000

AGENCY CONTRACT OR GRANT NO.: ARCO 4372677 Continuation

PRINCIPAL INVESTIGATOR:
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Signature Robert A Knox Jr C S Cox S Constable Date: 11/5/85
Typed Name & Title: A. D. Chave, Assoc. Res. Geop. C. S. Cox, Prof. of Oce. S. Constable, Asst. Res. Geop.

Signature Robert A Knox Joris M. Gieskes Date: 11/5/85
Typed Name & Title: R. Knox Aca. Adm. IGPP J. Gieskes Chair ORD

OFFICIALS AUTHORIZED TO SIGN FOR INSTITUTION:

Signature [signature] III Date: 11/8/85
Typed Name & Title: For W. A. Nierenberg, Director
Scripps Institution of Oceanography

Signature ________ Date: ________
Typed Name & Title:

FO 2054

The development of offshore electromagnetic surveying techniques

Research conducted at Scripps Institution of Oceanography and funded by:

Amoco Production Company

Arco Oil and Gas Company

Elf Acquitane

Sohio Petroleum Company

First Year Report (1985), and

Second Year Proposal (1986)

C.S. Cox

S.C. Constable

A.D. Chave

Laboratory electrode studies

It is important to be able to study electrode noise in the laboratory, for quality control, design improvements and the assessment towing noise. In the past, such studies have required the cumbersome procedure of running a deep-water electric field receiver and then reading the data tape. We have improved this situation by constructing a benchtop amplifier unit having both analogue output for monitoring noise with an oscilloscope and voltage controlled frequency outputs for digitization by a desktop computer. The software has not yet been developed to allow the computer to collect digital data, but by using a set of 13 narrow band pass filters we have been able to test the electrodes which were used in the June cruise (described below).

These initial tests have shown that it is extremely difficult to shield the experiments from 60 Hz powerline noise. Making measurements inside a shielded palaeomagnetic laboratory was of no use and detailed experiments will have to await the completion of the low electrical noise water tank presently planned at Scripps for the study of shark behaviour. However, with a little effort we were able to measure the noise of the electrodes used for the June cruise as being about 4 x 10^{-20} V^2/Hz (in still water) above 30 Hz. This is about the level expected for the Johnson or thermal agitation noise for these electrodes, and so is very encouraging.

Although the powerline noise problem has impeded attempts to measure electrode noise in moving water, results from the June experiment (described below) suggest that towing electrodes may not produce as much noise as anticipated.

June Experimental Cruise

In the July (1985) report we presented some initial results of a short offshore experiment utilizing one of our existing deep water recorders. The instrument was fitted with two 100 m antennae and one 1 m antenna (for noise estimation) and towed behind a small boat at speeds from 0 to 4 knots. It was allowed to settle overnight on the sea-floor in 70 m of water about 1 km offshore. Figure 1 from the July report is given here again, showing the instrument configuration.

Data from the sea-floor part of the experiment were given in the report, demonstrating that the two main sources of noise are 60 Hz powerline noise and intermittent bursts of broadband ionospheric noise (the horizontal scale on the time series is incorrect in the July report; the bar is 0.5s long, not 1s as shown).

Figure 2 shows some of this data and Figure 3 gives the spectral analysis of that record. The lower frame (A) presents the autospectra, phase and coherency of the two signal channels (1 and 2) and the upper frame (B) presents the same plots for one signal channel and the noise channel.

In contrast, Figures 4 and 5 present similar pictures for data collected while towing the instrument at 2 knots. It is very pleasing to note that noise due to towing is virtually absent at frequencies above 60 Hz.

Although the separation of the noise electrodes is only about 1/100 of the separation of the signal electrodes, the signal on the noise channel is about 1/6 of that on the signal channel (this estimate was made at coherent frequencies). As the skin depth in sea water of a 100 Hz e.m. wave is only 27 m, we think this is due to phase shifts across the length of the longer antenna. This suggests that short antennae should be used for high frequencies during a controlled source survey.

Forward modeling techniques

The computer code developed by Alan Chave for the forward computation of underwater electric fields over a layered or stratified earth has been improved and well tested. A magnetic tape of Alan's subroutine, along with an example driver program, test data and documentation will be distributed to all sponsers in the immediate future.

Model studies

We have begun an extensive set of model studies for simple geological structures, in order to establish optimum transmitter-receiver spacings and transmission frequencies. The modeling also shows in a semi-quantitative manner which parts of the structures may be resolved by the horizontal dipole e.m. method.

Figure 6 shows two examples of the models studied so far. "A" represents a permafrost structure and "B" represents a sedimentary basin buried beneath a volcanic layer. In "A", electric fields for 50 combinations of range (100 m to 1 km) and frequency (10 Hz to 1.8 kHz) were calculated. In "B", 35 combinations of range (500 m to 5 km) and frequency (30 Hz to 1 kHz) were considered. In both cases, all the computed signals were well above the noise levels encountered on the June experimental cruise, assuming a transmitter 30 m long and carrying 300 A and a stacking time of 1-10 s.

In the permafrost example, a linearized sensitivity analysis shows that all parameters except the resistivity of the deepest layer are resolved, but that the thickness of the permafrost is a "threshold" parameter. The most useful data to collect for defining the depth to the permafrost are those at a range of 300 m and at high (> 300 Hz) frequency. For defining the thickness of this layer, high frequency data at a 500 m spacing are best.

In the buried basin example, the resistivity and thickness of the basalt layer are well resolved, but the resistivity of the buried sediment is poorly resolved. Information about the basalt layer is improved by collecting high frequency data at long ranges.

These, and other, studies show that the depth to a conductive region buried beneath an electrically resistive (and possibly seismically opaque) layer may be resolved using e.m. techniques. If the resistive layer is in turn buried beneath conductive material, the depth to its upper surface is very well resolved.

Inverse techniques

An algorithm and computer program has been developed for the inversion of geophysical sounding data. This work has been done in conjunction with our programme of deep sounding of the oceanic lithosphere, funded by the Defence Advanced Research Program Agency. The algorithm utilizes the computational efficiency of layered models, but with enough layers (> 40) to produce a continuous conductivity profile. The scheme produces the smoothest model which fits the data adequately, with a convergence rate which is dramatically superior to Marquardt (ridge regression or damped least squares) methods.

The program accepts resistivity, M.T., or E.M. data, or combinations of these. This work is essentially completed, and pre-prints will be distributed this year, with the code being released after extensive testing.

Future work

Our primary goal is to finish constructing the prototype equipment (the transmitter and multichannel receiver) and make some initial measurements off San Diego. We expect that this will take place early next year (1986). The first tests will be with the transmitter and receiver towed in tandem behind a single boat or small ship (Figure 7).

The linearized model studies will be extended to establish more fully the effects of water depth, source-receiver separation and operating frequency on the resolving capabilities of e.m. surveying. We will follow up suggestions made at our recent (October) meeting and compare sounding curves (both graphically and statistically) as a strategic parameter is changed in the model. This work will be written up in the form of a report or short paper and distributed in early 1986.

Alan Chave is presently starting work on using moving finite element analysis for 2 and 3 dimensional e.m. modeling. This work is being funded by N.S.F., and so is not covered by the provisions of our contracts with the oil industry, but is applicable to our e.m. work and will certainly be available to our sponsors.

The moving finite element method allows the size and location of elements to vary during the computation. This results in the computational efficiency of having few nodes in uniform regions of the model and many nodes in critical regions, in an adaptive manner, allowing differential equation solvers to be used with larger step sizes. It will be ideal for inverse modeling, as the discretization as well as the model may change at each iteration. The initial work will concentrate on M.T. methods over the next year, but is expected to be extended to transient and frequency domain controlled source e.m. after that.

It was noted from the June cruise that ionospheric activity is a major source for offshore e.m. surveying. This result was, of course, to be expected. We propose to establish a short-period recording magnetometer at a relatively noise-free location owned by U.C.S.D. (about 15 km inland from Scripps) as a remote reference station. Underwater e.m. signals which are correlated with the magnetometer data may be recognised as ionospheric noise and removed. We expect that such techniques will improve the signal-to-noise ratio of the underwater data considerably.

Preparation for electromagnetic sounding experiment

The equipment necessary for an experiment with a towed transmitter and receiver is under construction. The transmitter is to be powered from shipboard using a power source which generates 5 kW alternating current at any frequency in the range of 30 to 1000 Hz. The power source is presently under construction with completion expected this year. The AC power will be transmitted to the sea floor antenna through a cable which also serves an a strength member for towing the antenna and receiver over the sea floor. This cable has been assembled on a winch. The winch has slip rings which enable electrical power to be transmitted while the winch drum is turning. This facility is necessary to enable the transmitter antenna to remain in contact with the sea bed despite depth changes.

Electrical power transmission through the towing cable is carried at high voltage. A transformer within a pressure case is to be used to convert to the low voltage and high current needed by the antenna. These items are on hand, but the source antenna itself has yet to constructed.

One receiver is now being assembled. A light and easily handled pressure case has been built and pressure tested. The receiver electronics include a four channel amplifier and digitizer system together with a microprocessor and digital tape recorder. Each amplifier (see schematic diagram Figure 8) contains a bridge chopper feeding a step up transformer to achieve a low effective input noise in the frequency range below one kiloherz. The noise has been measured to be less than the Johnson noise of a one ohm resister and is therefore less than the electrode noise.

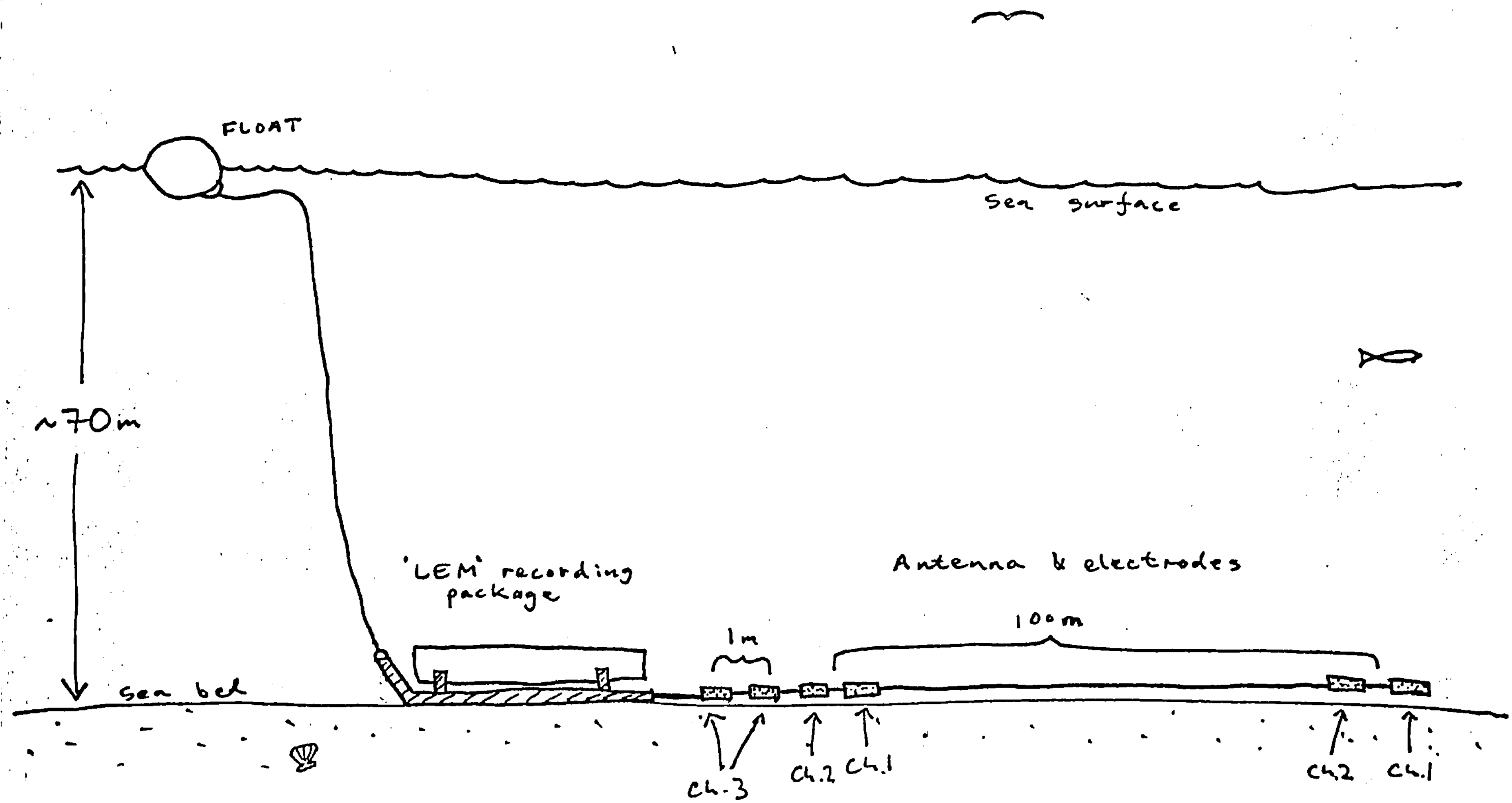
FLOAT
Sea surface
~70m
'LEM' recording package
Antenna & electrodes
1m
100m
Sea bed
Ch.3
Ch.2
Ch.1
Ch.2
Ch.1

Figure 1

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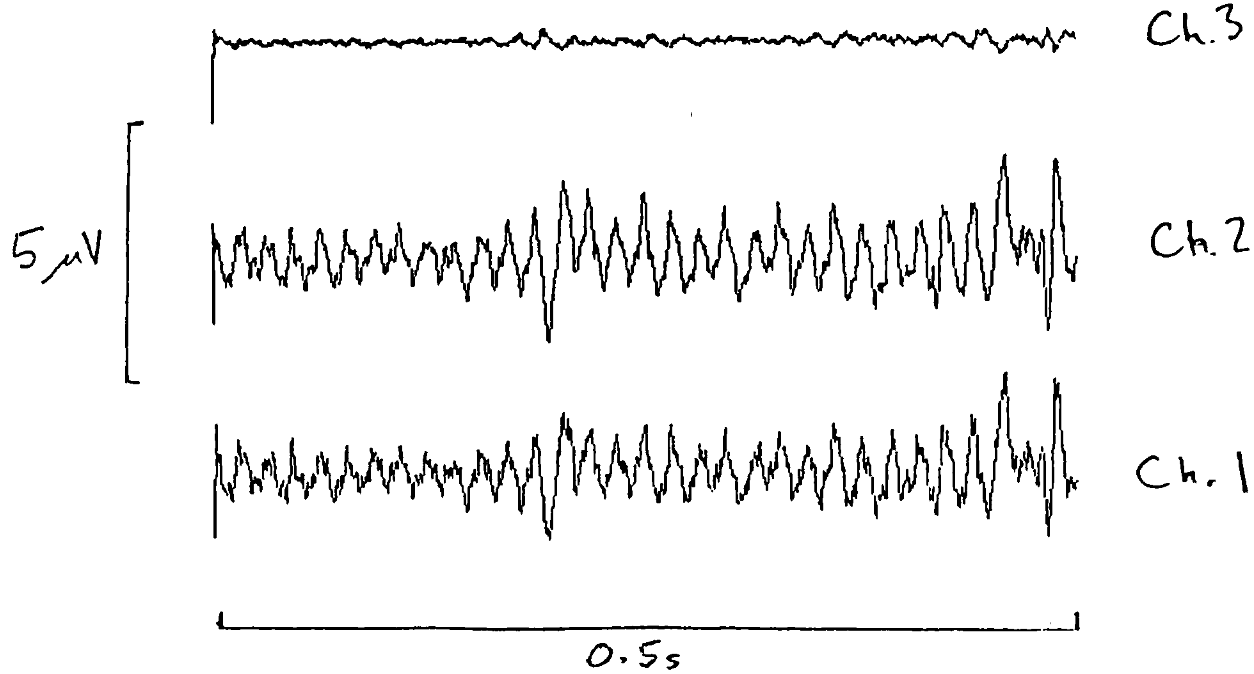
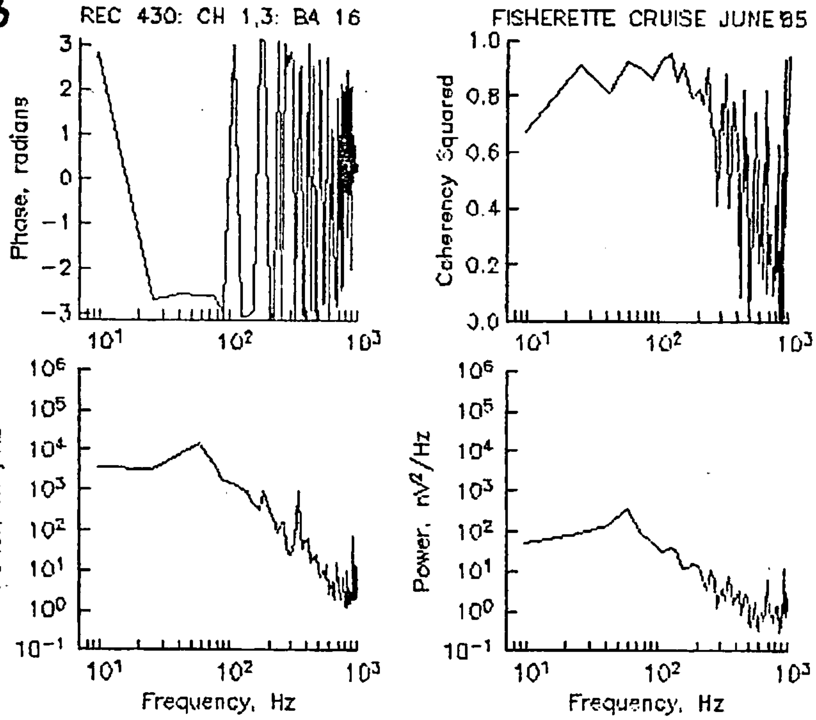
POINTS 1 1024



STEVE (08) 10/29/85 10:44 AM

B



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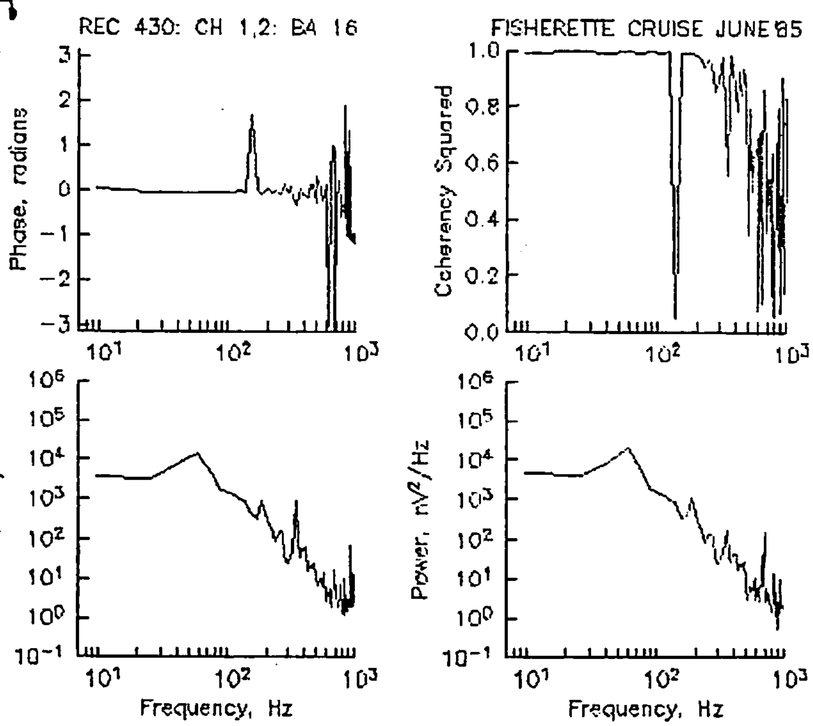

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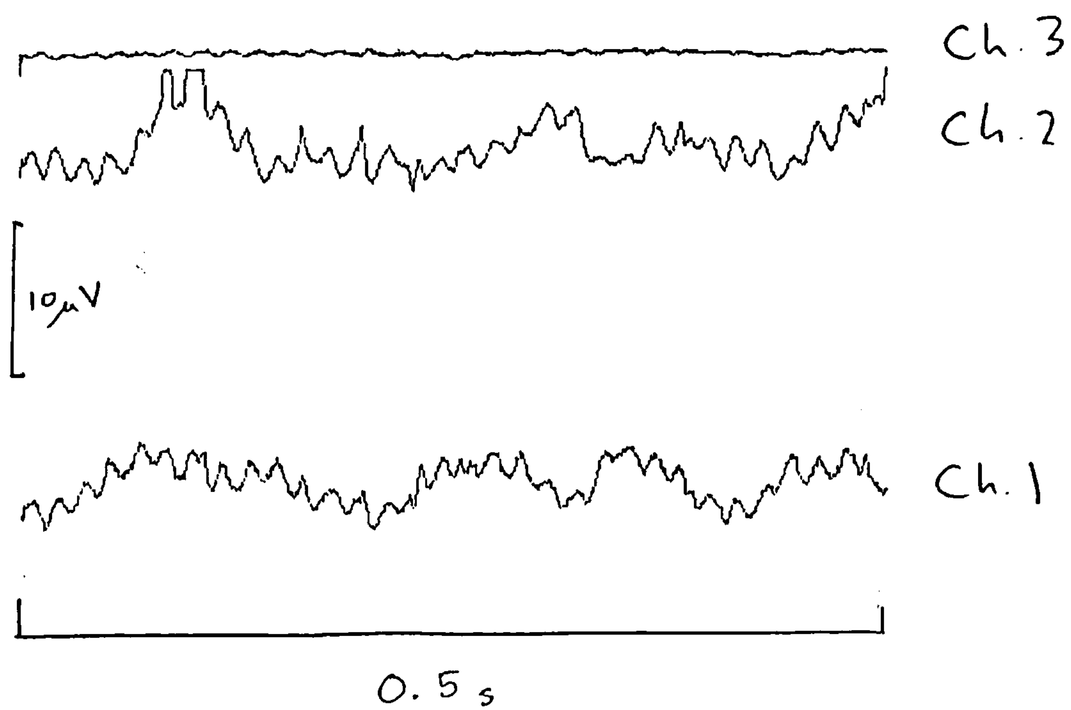

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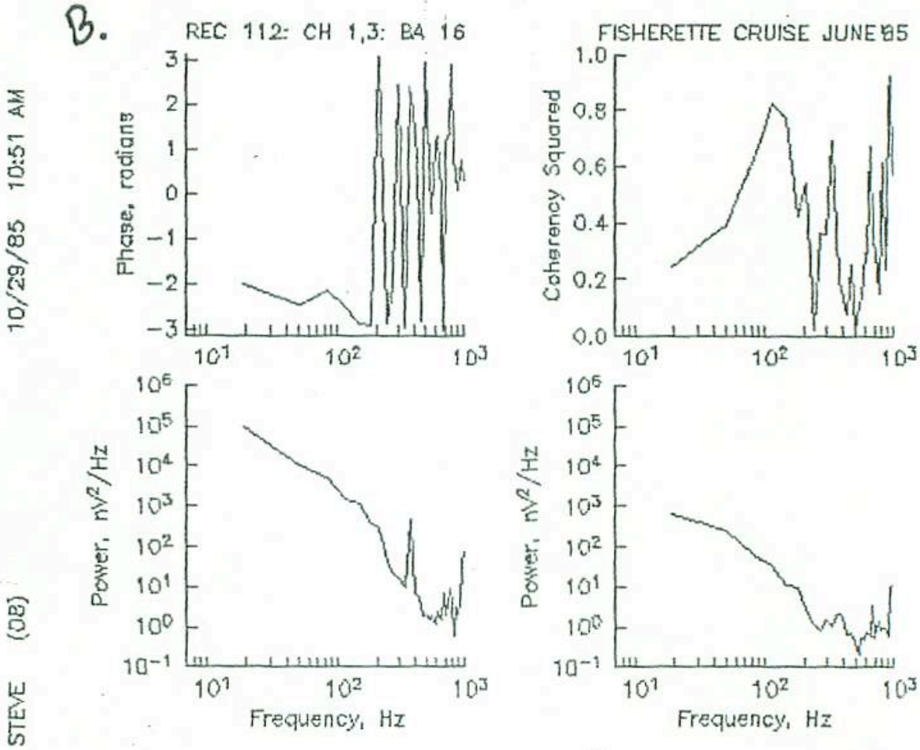
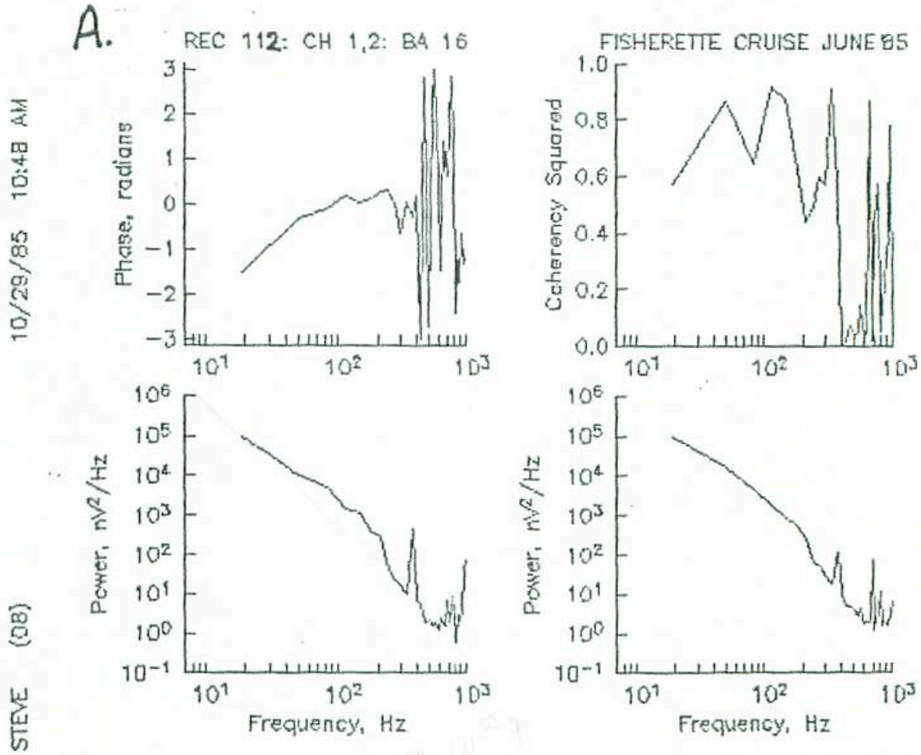


A.

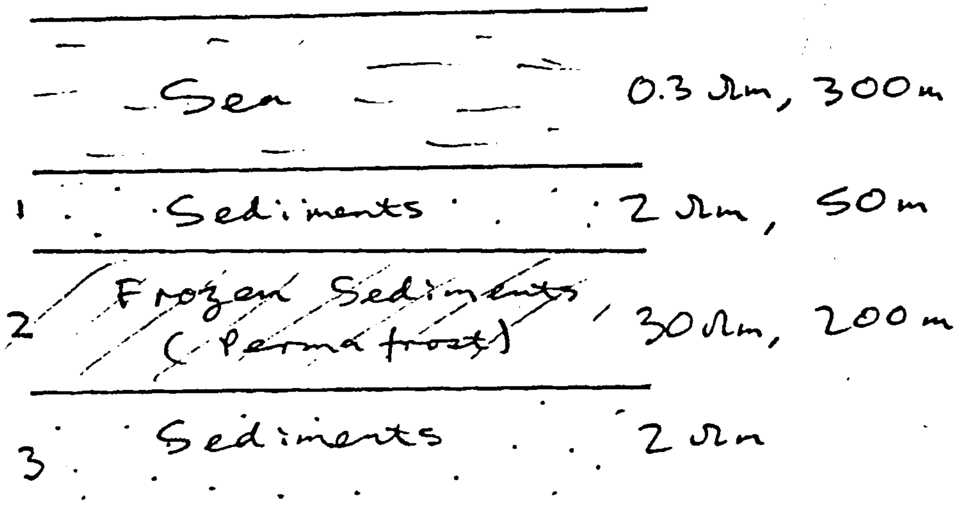


10^8 nV²/√Hz @ 1 Hz
amplitude.
10^4 nV/√
10^2 nV/m
.1 μV/m

10 min

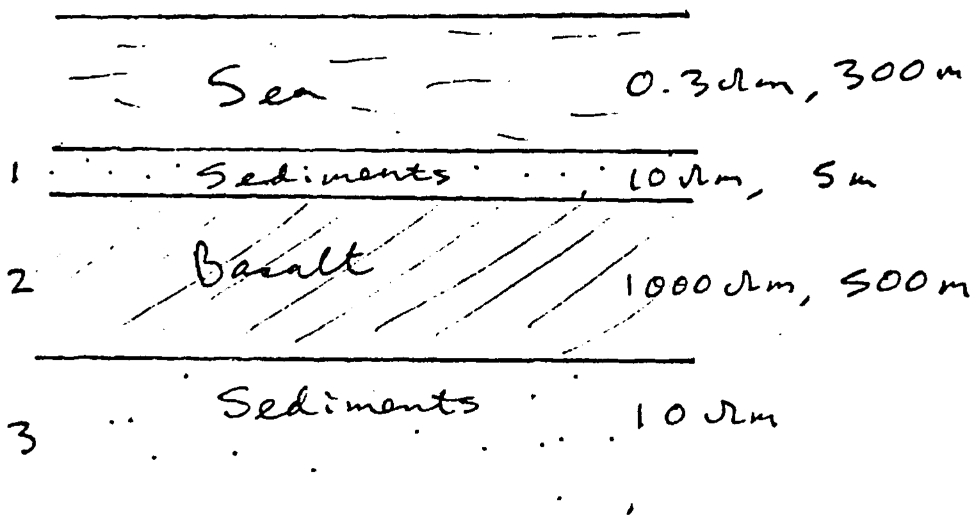
100 m by 10^4 our divide
$10\,f^{-3}$ V²/Hz
$= f^{-3}$ V²/Hz
$10^{-4} f^{-3}$ V²/m²/Hz
10^{-7} @ 1 Hz
10^{-13} @ 1 kHz

A

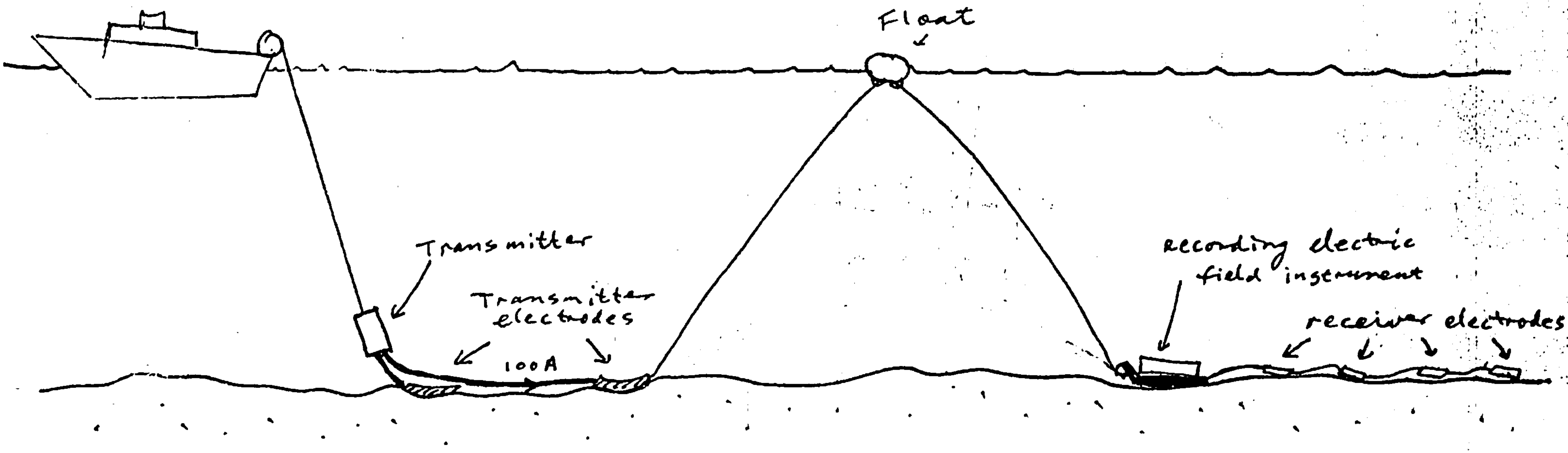


Sea
0.3 Ωm, 300m
1
Sediments
2 Ωm, 50m
2
Frozen Sediments
(Permafrost)
30 Ωm, 200m
3
Sediments
2 Ωm

B



Sea
0.3 Ωm, 300m
1
Sediments
10 Ωm, 5m
2
Basalt
1000 Ωm, 500m
3
Sediments
10 Ωm


Float
Transmitter
Transmitter electrodes
100A
recording electric field instrument
receiver electrodes