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SIMULTANEOUS GEOMAGNETIC MEASUREMENTS ON AN ICE ISLAND SURFACE AND 1000 FEET BELOW

by
J. R. Heirtzler

Technical Report No. 2
CU-2-63 Geology
Contract Nonr-266 [82]

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ABSTRACT

For a few weeks in the fall of 1962 the total geomagnetic field intensity was measured simultaneously on an ice island surface and approximately 1000 feet below. The magnetic gradient as indicated by the difference between the two readings varied as the station passed over geologic bodies. A statistical analysis of the time variations during two time intervals revealed an attenuation and phase shift of the lower head reading with respect to the surface head reading. The analysis was made between 70 and 400 seconds period. There are indications of an anomalous attenuation at the lower period end of this band although the experiment was not such that accurate determinations could be made.

I. INTRODUCTION

In the spring of 1962 the U. S. Naval Ordnance Laboratory, White Oak, entered discussions with Lamont's Arctic Geophysics and Geomagnetism Departments concerning the feasibility of underwater measurements of the time variations of the geomagnetic field intensity from an ice island. It was jointly decided that the easiest and most orderly approach to such an investigation would be the measurement of the total geomagnetic field intensity with a proton precession magnetometer simultaneously on the ice island surface and at a depth of 1000 feet below the surface.

It was clearly recognized that the sensitivity and frequency response limitations of this type instrument would allow only very gross attenuations and phase shifts to be detected and such gross effects would probably not be found. Never-the-less it was felt that this first step should be taken before more refined studies of the attenuation by sea water were undertaken. This work should lay to rest any notions of gross changes in the fluctuations of the magnetic field intensity near the sea subsurface. An ice island is unique as a stable platform from which to make magnetic measurements on the deep ocean surface and at depth at the same time. The difficulties in making such simultaneous measurements on other platforms in the open ocean are known to persons who have attempted to make measurements of this kind. Two ice islands were occupied by the Arctic Geophysics group. Because of its larger base installation T-3 (Fletcher's Ice Island) was chosen for these measurements.

II. FIELD OPERATION

The magnetometer used was a modification of the Varian Associates Modular V-4931 Proton Precession Station Magnetometer.

This basic magnetometer is nearly identical to many other proton precession magnetometers in common use. A hydrogen-rich sample in the sensor is polarized by applying a relatively strong magnetic field by current through turns of a solenoid surrounding it. After polarization, the proton procession signal is induced through these same turns. The frequency of the signal is determined by allowing a predetermined number of signal cycles to gate the output of a clock pulse generator of known repetition rate. The number of clock pulses that get through the gate is recorded on a digital counter. This reading, then, divided by the number of preset cycles is the period of the signal. The counter records the five low order digits of the output of the pulse generator. The last two decimal digits are converted to an analogue voltage and recorded on a strip chart recorder. After the reading has been recorded the sample is again polarized, then the signal read, etc., in a cyclic fashion. The precession frequency is directly related to the total geomagnetic field strength through an accurately known constant.

The instrument used in the present work had the following special features:

1) There were two sensors. Each sensor was polarized, then read, then idle while the other sensor was polarized, and read. For each sensor the polarize time was one second, the readout time one second and the idle time two seconds giving an overall

cycle time of four seconds. A dual pen recorder was used with each pen being activated with its sensor. The instrument operation is shown in the block diagram of Figure 1.

2) The clock pulse generator of the counter was changed from 100 kcps, as normally supplied, to a 200 kcps clock to get more sensitivity (± 0.7 gammas). The full scale span of the strip chart recorder was 70 gammas. On occasion the sensitivity was degenerated because of noise but for the major part of the recording period a sensitivity of 0.7 gammas was obtained.

3) A kerosene-heptane mixture was used as a sample so that the sample would not freeze at the subzero temperatures encountered.

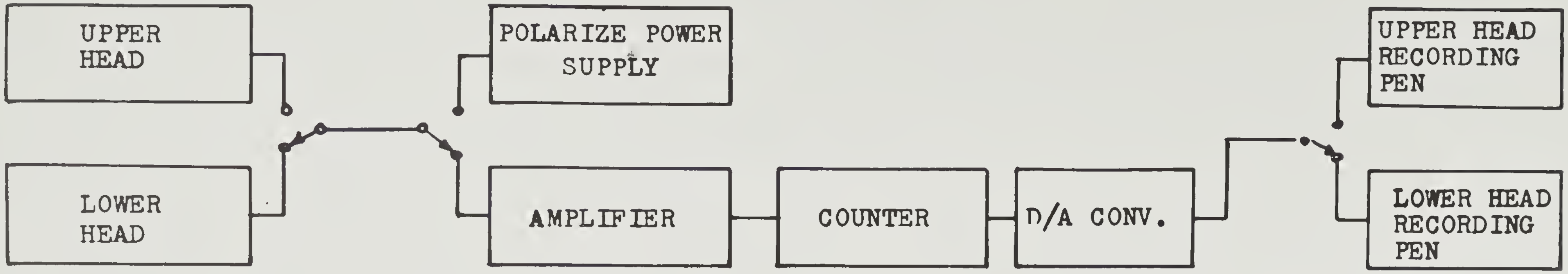
4) The surface sensor was attached by a 100 foot nonmagnetic cable containing a type 310 stainless steel braid stress member. The lower sensor was attached by a 1050 foot cable. The fifty feet nearest the head contained type 310 stainless braid and should introduce no more than two gammas constant error in the magnetic readings. The remaining part of the cable utilized type 304 stainless which is more magnetic but did not introduce errors in the readings.

5) The housing of the lower sensor had pressure equalizing diaphrams to reduce the detrimental effects of the hydrostatic pressure at the operating depth.

The physical arrangement of the special field installation is shown in the sketch of Figure 2 and in Plate 1. The facilities were established at a location near the island edge and isolated from the main camp. Except for one occasion when ice rafted onto the island, this location proved satisfactory.

PLATE 1

PHOTOGRAPH OF UPPER SENSOR (IN THE DISTANCE)
AND THE HOLE THROUGH THE ICE FOR ENTRY
OF THE LOWER SENSOR (IN FORE GROUND)



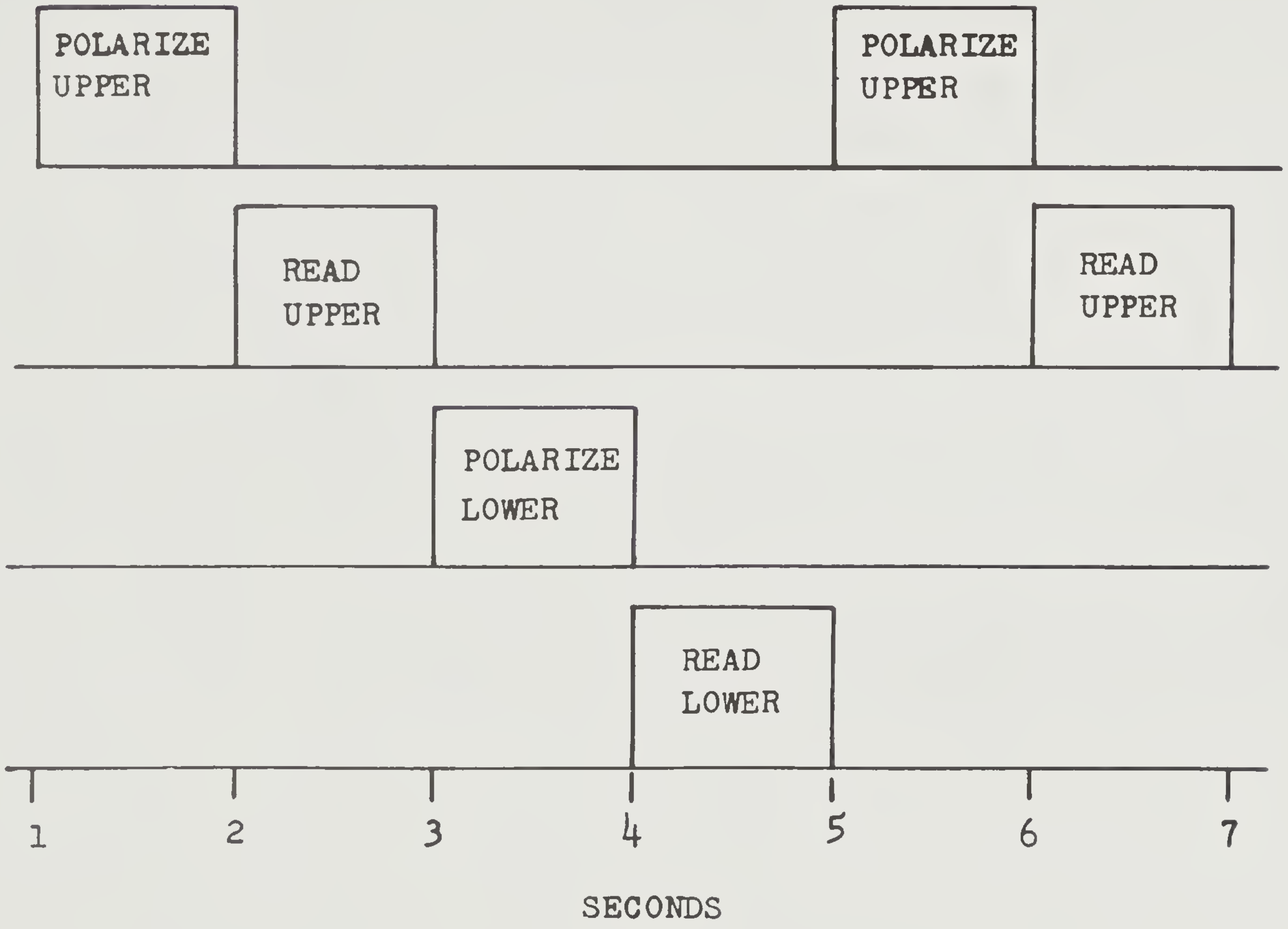


FIGURE 1

BLOCK DIAGRAM
OF INSTRUMENT

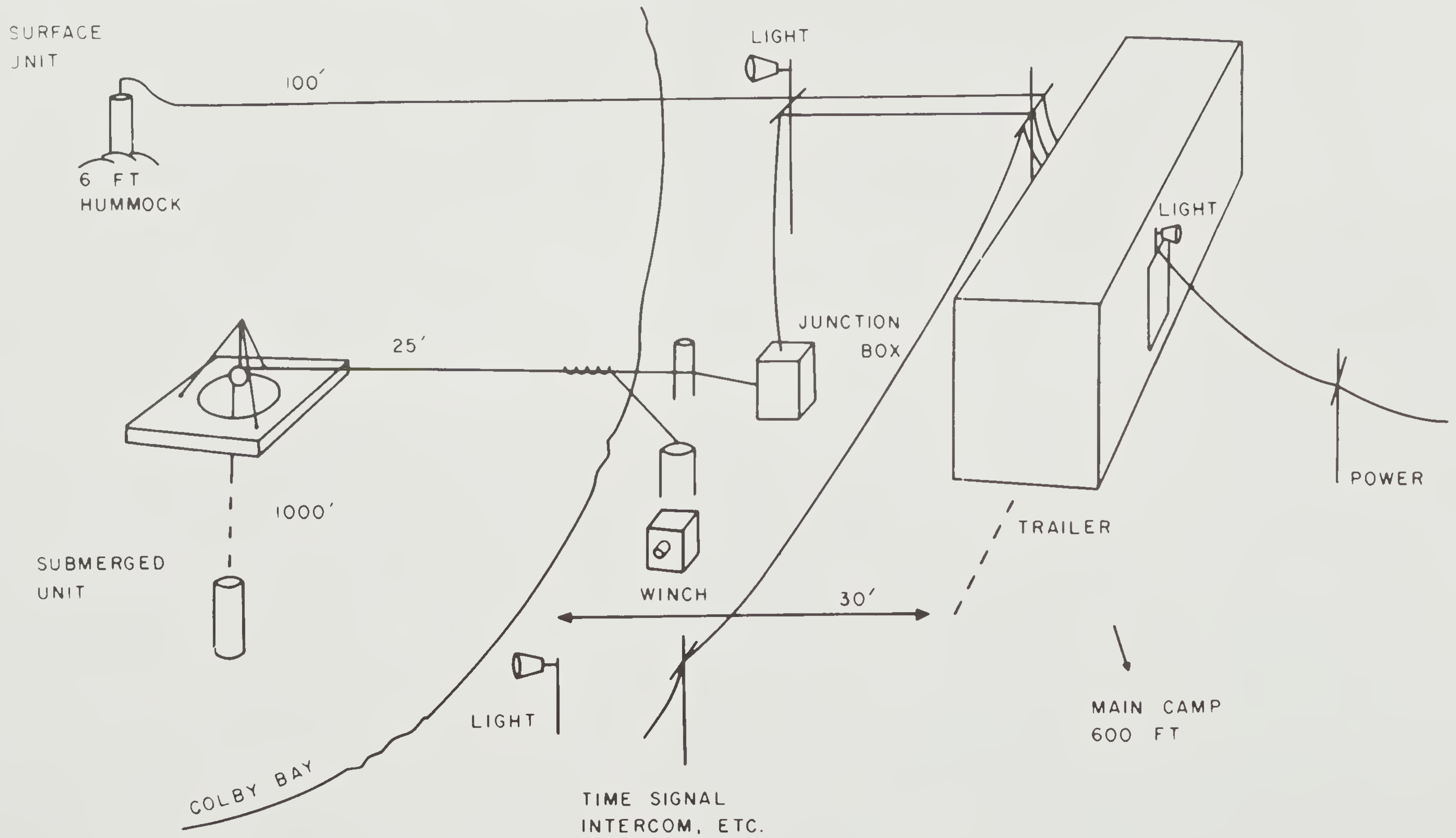


FIGURE 2

MAGNETOMETER STATION ON T-3

OCTOBER 1962

At that time prompt removal of the sensors prevented any damage. The lower sensor was placed by a pulley over a hole through thin ice. The hole was kept from refreezing by placing an electrical heater wire in it. The major impedment to the operation was a twenty day failure of the camp's electrical generators when spare parts could not be readily obtained. There were other logistic and electronic troubles which are inherent in an operation of this kind.

The installation began operation 14 October 1962. Except for the twenty day period mentioned above it was possible to record fairly regularly on the paper strip chart record. Random and selected times were recorded on magnetic tape by the use of retransmitting slidewires attached to the pen recorder. On 26 November 1962, recording with two sensors had to be temporarily abandoned due to equipment failure. Records and tape recorder were returned to Lamont at that time. Electronic parts have since been sent to T-3 and the two sensor, strip chart recordings have been resumed. This report covers the period from 14 October to 26 November 1962.

Fixes (weather permitting) and soundings were taken once a day. The movement of the island between fixes is somewhat questionable, but the fixes with straight line interpolations between them is shown in Figures 3A and 3B.

III. GENERAL DESCRIPTION OF RESULTS

Although the ice land was north of the auroral zone it

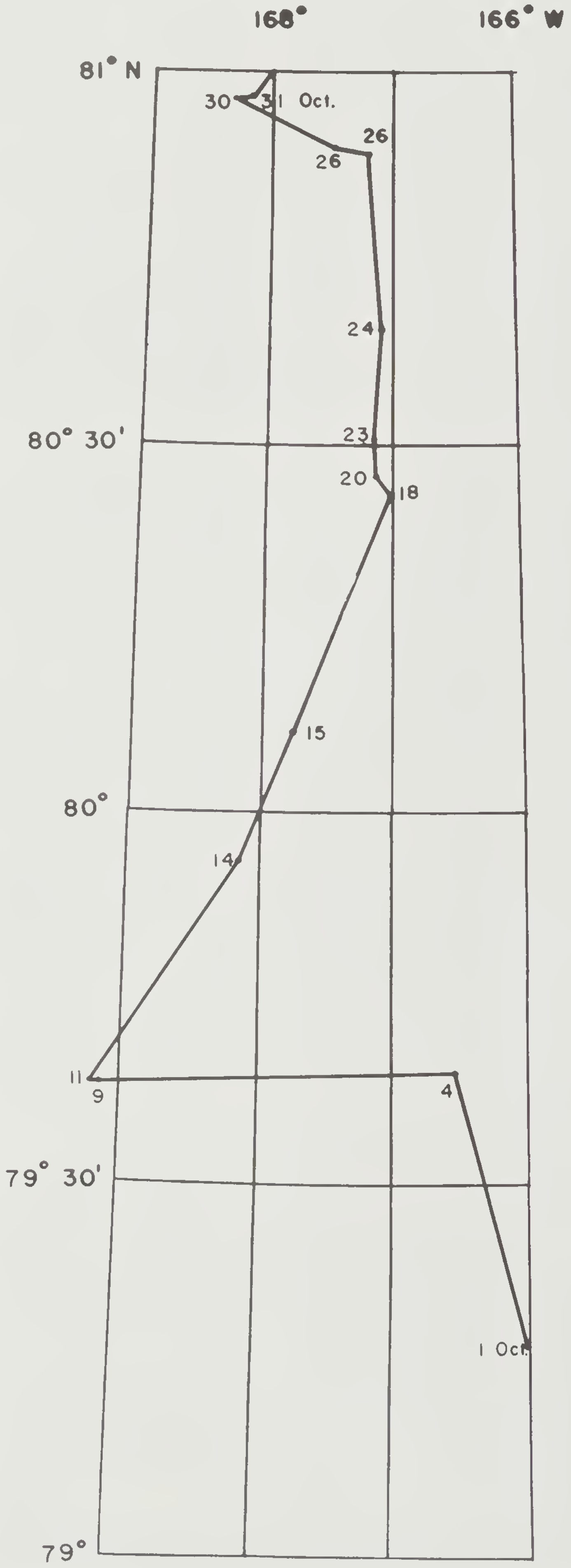


FIG. 3A
POSITIONS OF T-3
1 - 31 OCT. 1962


SIZE OF T-3 (FEB. 1962)
TO SAME SCALE
AS ADJACENT FIGURE

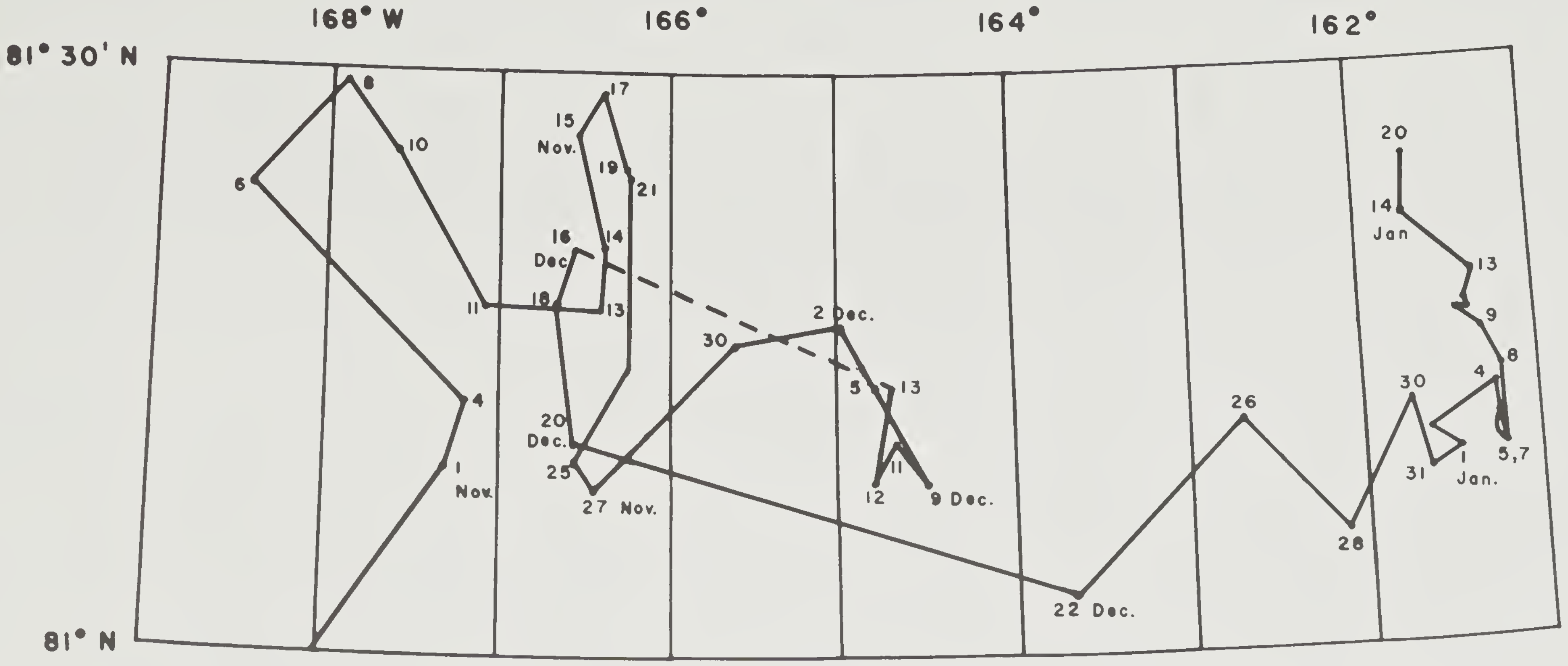


FIG. 3B - POSITIONS OF T-3 31 OCT. - 20 JAN., 1962 was located in a geographic area where intense time variations of geomagnetic field are common. There were aurorae visible and magnetic fluctuations accompanied them. Figure 4 shows the magnetometer traces during one such interval. There were other periods of several hours when the magnetometer traces were nearly straight.

Hall (1962) has calculated signal frequency variations that are to be expected if the sensing head of a proton precession magnetometer is in rotation about an arbitary axis. On several occasions the lower sensing head showed a rapid cyclic change in signal frequency that was not evident on the upper. See Figures 5 and 6. Calculations showed that these variations could be accounted for by a slow rotation of the lower head about a vertical axis. Subsequently, an intentional rotation of the upper head about a vertical axis gave a similar result. A single fin was attached to the lower head in an attempt to prevent motion of this type, but the resulting drag raised the head to such an extent that it was not deemed wise to use the fin. Rotation of the lower head occurred on such infrequent occasions that it did not interfere with general observations.

Appendix I shows how the effect of drag, caused by differential motion between the ice and sea water, can be estimated. In a typical case the lower head may be only 890 feet below the surface when 1000 feet of cable is in the water.

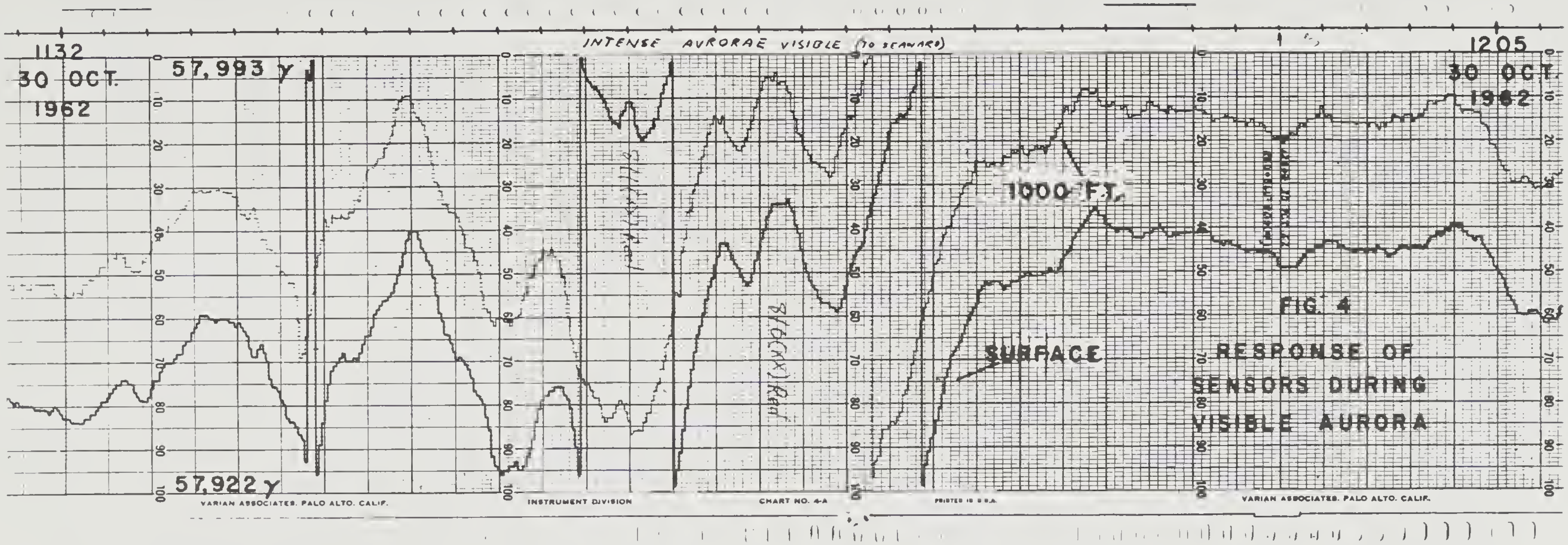


FIG. 4
RESPONSE OF SENSORS DURING VISIBLE AURORA

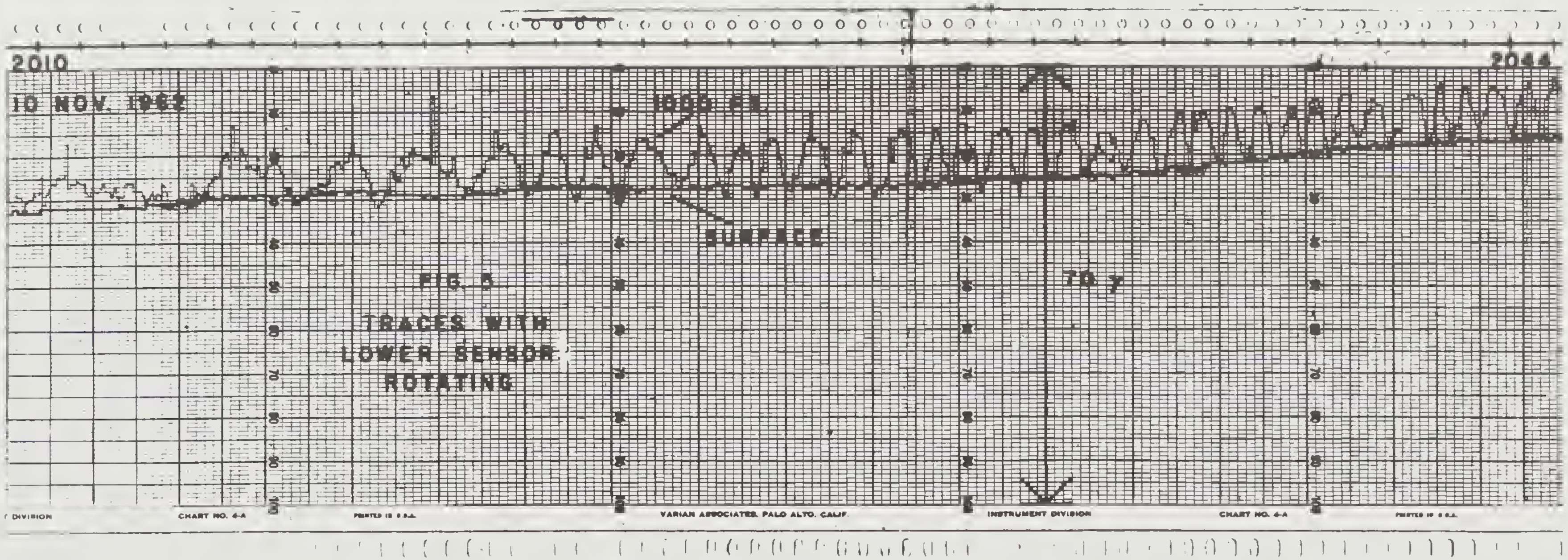


FIG. 5

TRACES WITH LOWER SENSOR ROTATING

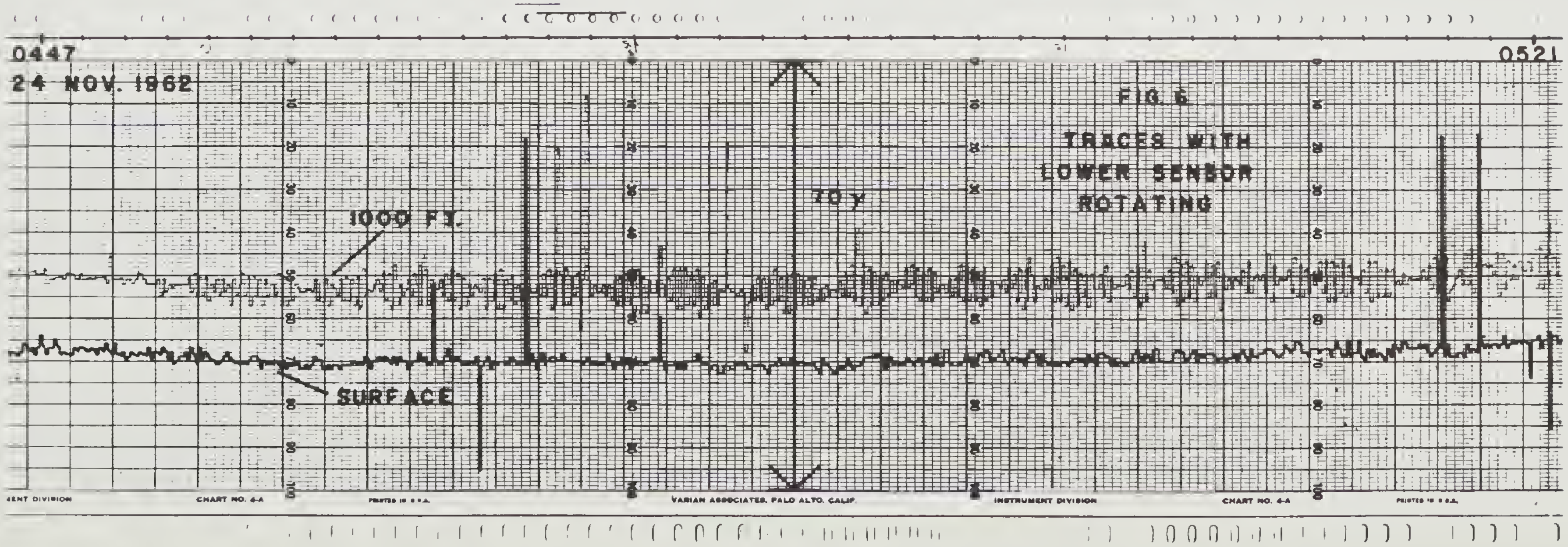


FIG. 6

TRACES WITH LOWER SENSOR ROTATING

IV. TIME VARIATIONS

The instrument recorded the total intensity of the magnetic field. The total field strength, F, is related to the horizontal field strength, H, and the vertical field strength, Z, by:

$$F = \left[H^2 + Z^2\right]^{1/2}$$

and small changes in these quantities are interrelated by the equation:

$$F + \Delta F = \left[(H + \Delta H)^2 + (Z + \Delta Z)^2\right]^{1/2}$$

so that to a good approximation:

$$\Delta F = \left(\frac{H}{F}\right)\Delta H + \left(\frac{Z}{F}\right)\Delta Z$$

$$= (\cos D)\Delta H + (\sin D)\Delta Z$$

where D is the dip. At the recording site the dip was approximately 87 degrees so that:

$$\Delta F = (.052)\Delta H + (.998)\Delta Z.$$

It is clear that it would take a very large time fluctuation in the horizontal intensity, ΔH, to alter the total field intensity to a measurable extent. It was the vertical component of time fluctuations that was recorded.

The calculation of attenuations and phase shifts expected in the vertical component with depth must embody the geometry of the source and the curvature of earth structures. Such a development is beyond the scope of the present report, although it is understood that such a development is in progress elsewhere (A. T. Price, personal communication).

The assumption of plane electromagnetic waves normally incident on the sea surface is unsatisfactory because such a wave is not permitted, by Maxwell's equations, to have a vertical time varying component (for example see Panofsky and Phillips, 1955). The assumption of a non-normal plane electromagnetic wave or the assumption of a hydromagnetic wave would introduce an unwarrented degree of freedom to the calculation.

Two relatively short time intervals (approximately thirty minutes each) of the records were subjected to auto and cross power spectral analyses. The first section of record analyzed is shown in Figure 7 (between the arrows) and its spectra in Figures 8 and 9. The second section is shown in Figure 10 and its spectra in Figures 11 and 12. Figures 9 and 12 include the ratio of the power densities as a function of frequency.

Although an attempt was made to digitize the records from the analogue magnetic tape recordings the similarity of the two records and the limited dynamic range of the tape recorder prohibited an adequate digitization. Accordingly, the sections of record were scaled by hand for a 1.25 second digitization interval. As Figures 8 and 11 show, the rapid decrease in spectral amplitudes with frequency causes digitization noise to become important for the shorter period activity. Those figures show the part of the spectrum that can be considered free of such noise, very conservatively estimated. Since each section of the

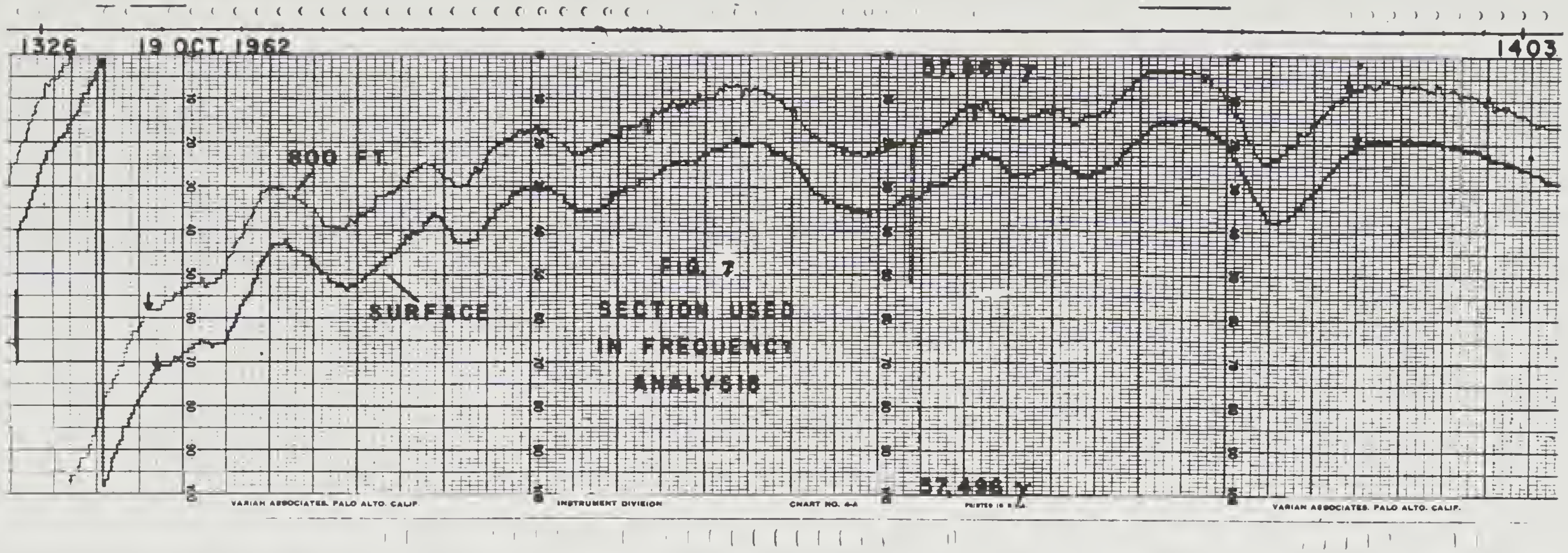


FIG. 7
SECTION USED
IN FREQUENCY
ANALYSIS

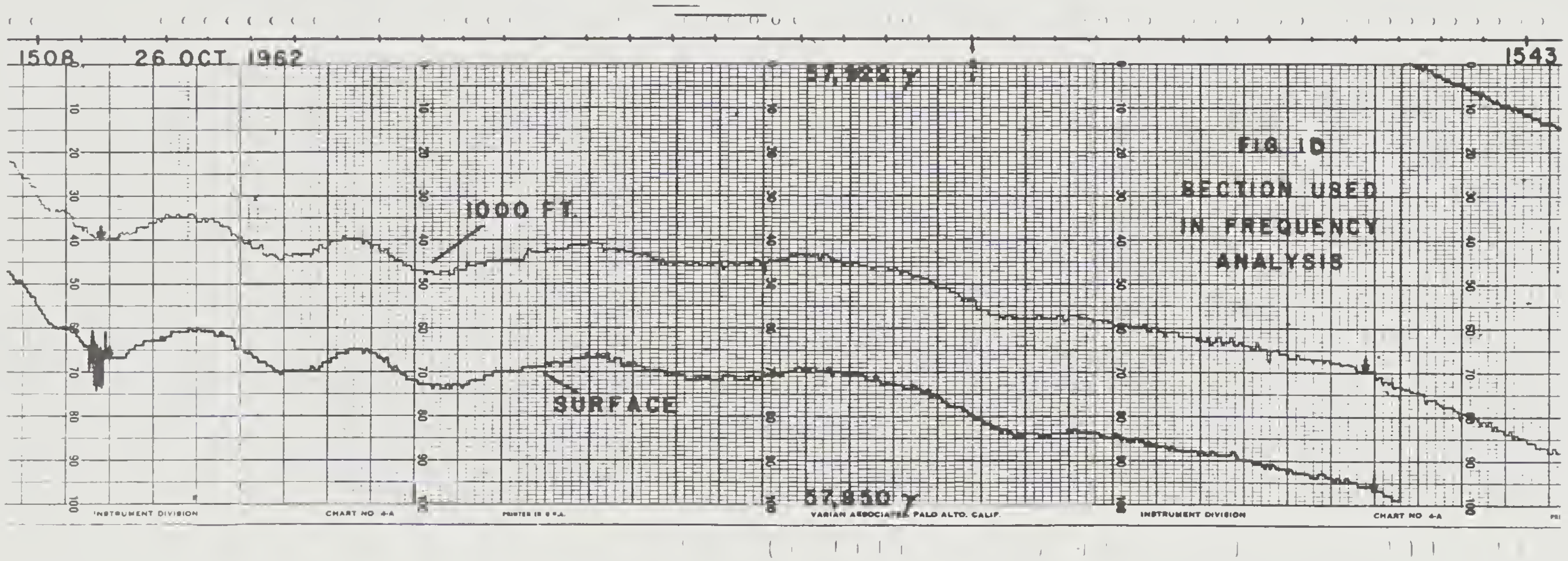


FIG. 10
SECTION USED
IN FREQUENCY
ANALYSIS

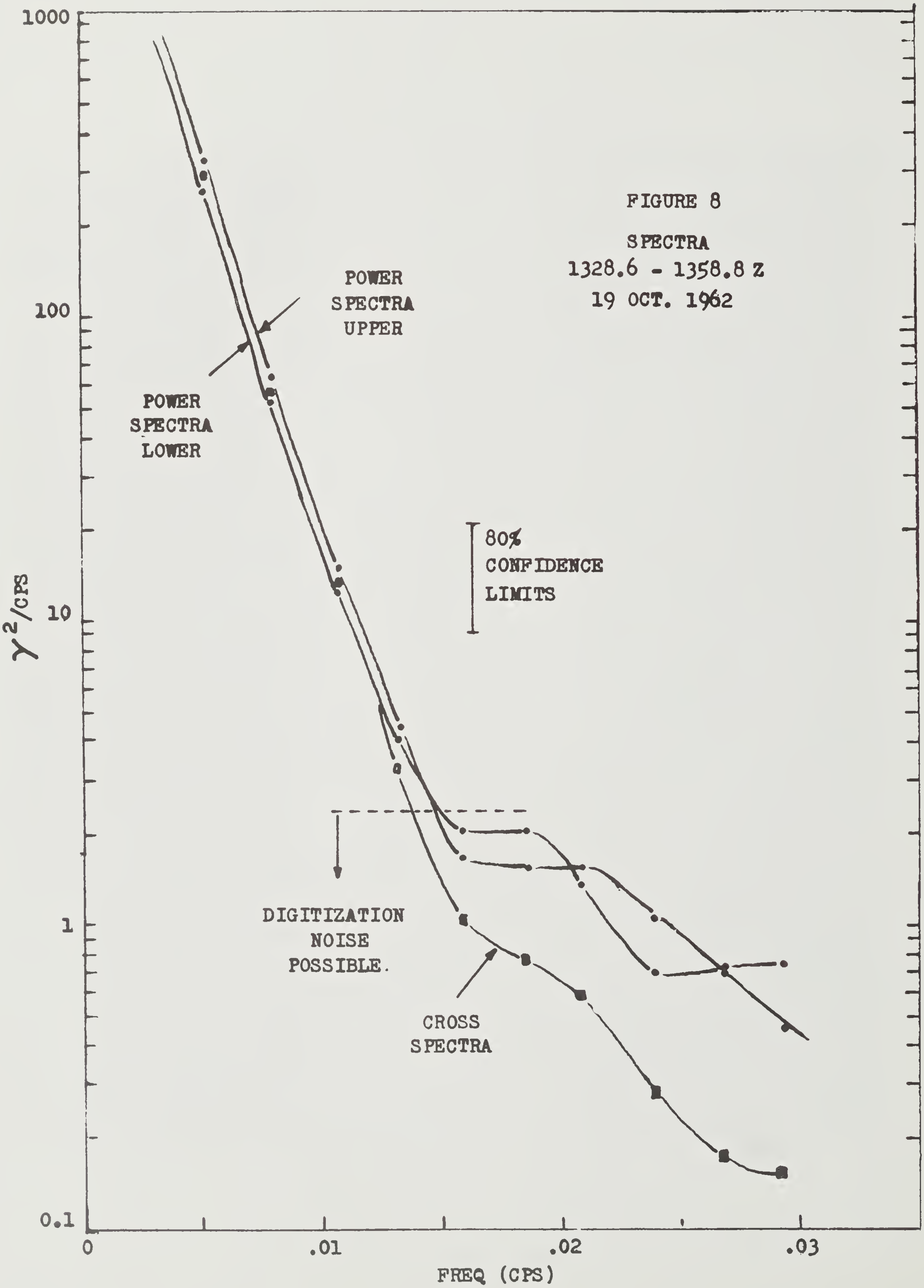


FIGURE 8

SPECTRA
1328.6 - 1358.8 Z
19 OCT. 1962

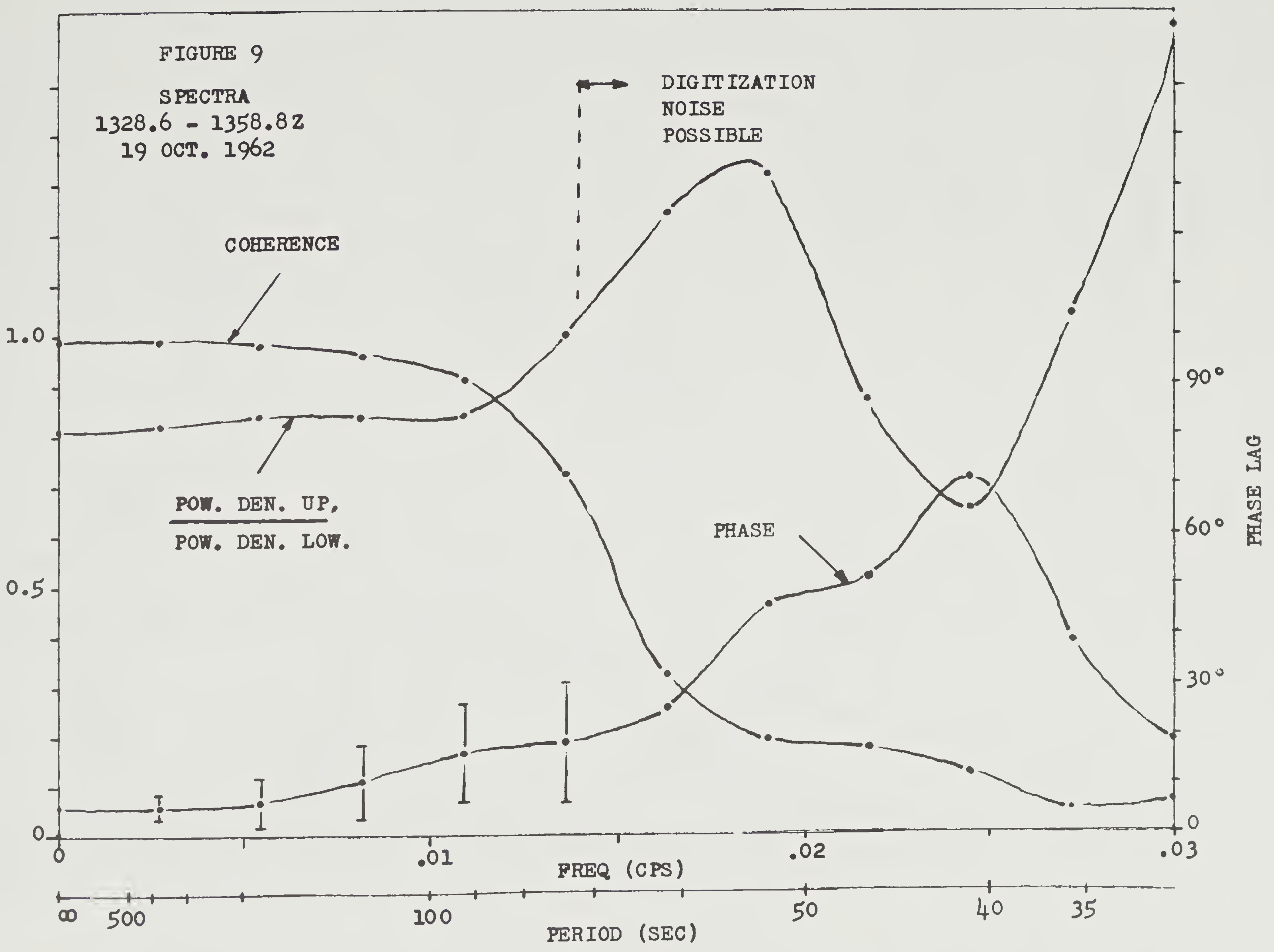


FIGURE 9

SPECTRA
1328.6 - 1358.8Z
19 OCT. 1962

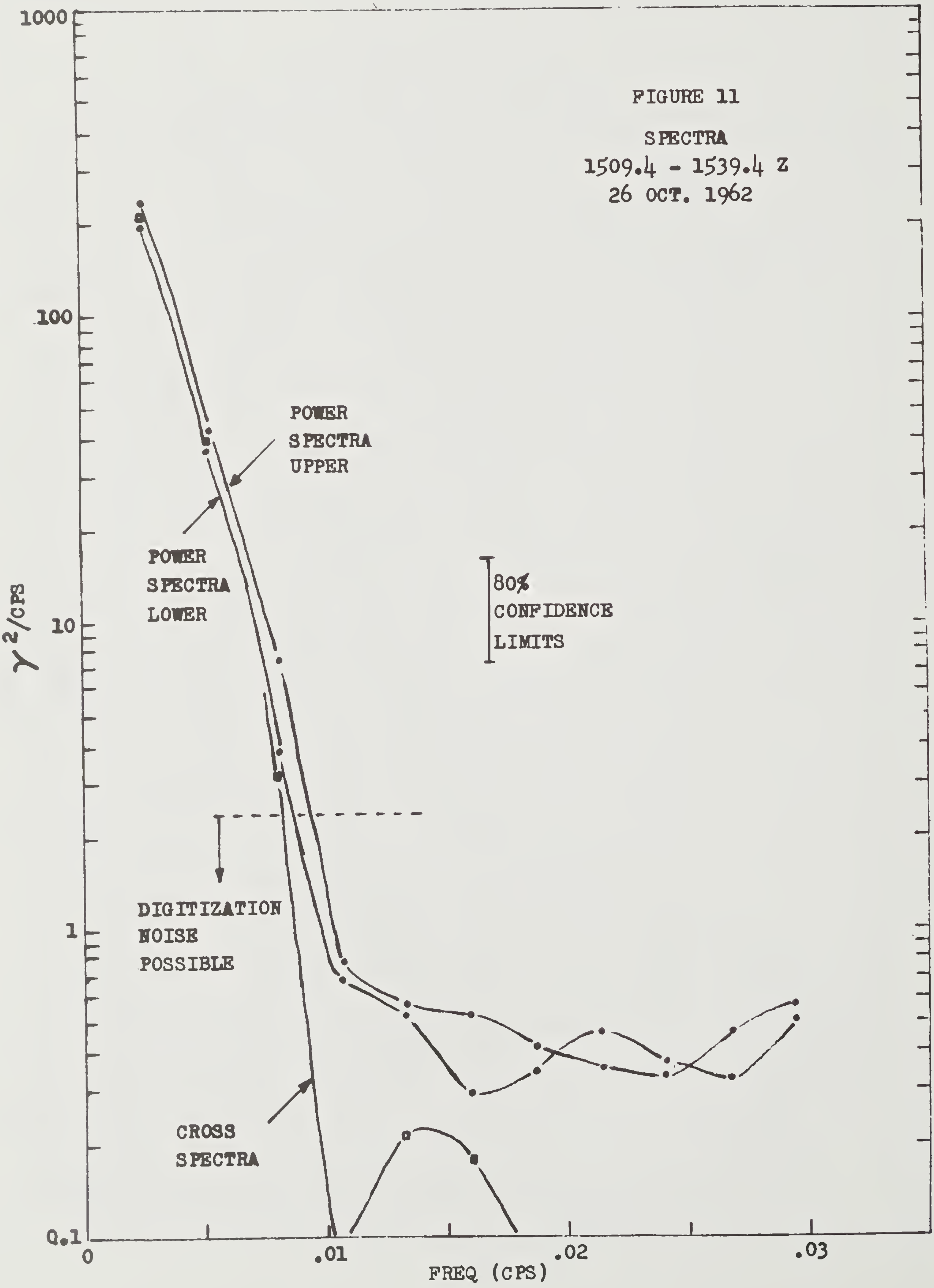


FIGURE 11
SPECTRA
1509.4 - 1539.4 Z
26 OCT. 1962
1000
100
10
1
0.1
γ^2/CPS
0
.01
.02
.03
FREQ (CPS)
POWER SPECTRA UPPER
POWER SPECTRA LOWER
80% CONFIDENCE LIMITS
DIGITIZATION NOISE POSSIBLE
CROSS SPECTRA

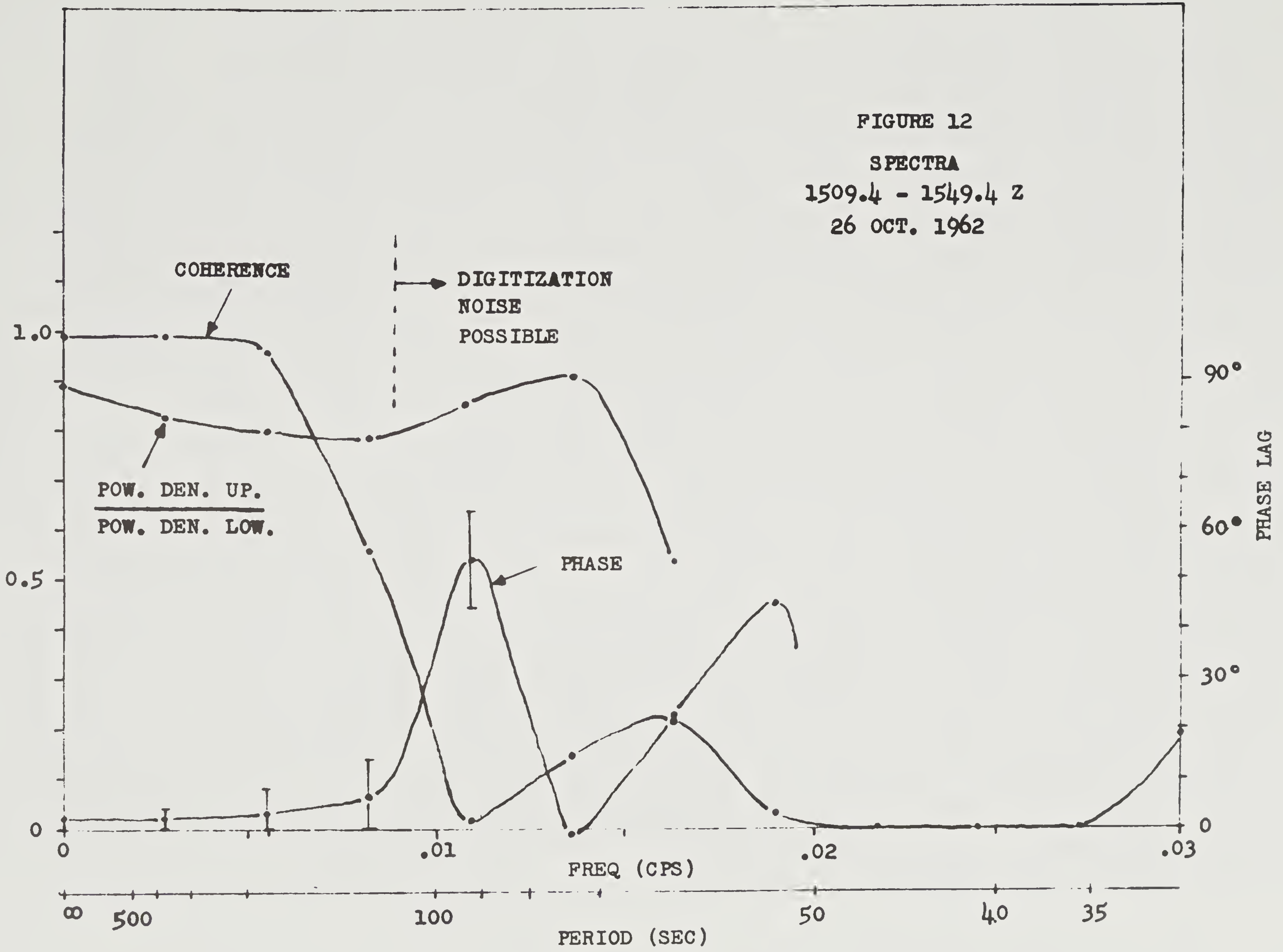


FIGURE 12

SPECTRA
1509.4 - 1549.4 Z
26 OCT. 1962

chart was digitized twice (for upper and lower heads) there was some possibility of a relative time displacement in the digitized data. This would be manifest as an error in the phase spectra. In Figures 9 and 12 the vertical lines with bars indicate the phase error that would be so introduced, again very conservatively estimated.

The spectral determinations were made on an electronic digital computer utilizing the general procedures of the auto-covariance method (Blackman and Tukey, 1958). The individual steps of the procedure were:

a) convert digital units to gammas
b) remove mean value: remove linear trend by using average of first third and average of last third of data
c) filter to produce a nearly white spectra and to eliminate alaising by periods of less than ten seconds
d) compute lagged products; series lagged 10% (20 degrees of freedom)
e) compute power spectra, coherency, phase
f) "ham" (smooth) the spectra
g) remove effect of filter

Between the periods of 70 and 400 seconds the spectra indicate:

a) for the longer of these periods the amplitudes of the lower head are attenuated. While the limitations of the instrument and analysis do not give a clear indication of the amount of attenuation as a function of the wave period there is evidence for reduced attenuation or possible enhancement of the lower head intensity for periods shorter than about 90 seconds

b) an increase in phase shift with frequency.

V. SPATIAL VARIATIONS

It is of some interest to determine the magnitude of the gradient of the total magnetic intensity due to the earth's main field. The magnitude of the geomagnetic field intensity can be obtained from the expression for the magnetic potential. Including only first order terms the expression for the magnetic potential is:

$$V = \left(\frac{r}{R}\right)^{-2} \left[g_1^0 \sin A + (g_1^1 \cos B + h_1^1 \sin B) \cos A \right]$$

r is the distance from the center of the earth to the point of observation, R the radius of the earth, A the latitude, B the longitude, and g_0^1, g_1^1, and h_1^1 are constants. Since the constants g_1^1 and h_1^1 are no more than 20% of g_0^1 and since the experiment was made at a high latitude (therefore $\cos A$ small) only the first term in this expression need be retained. This is equivalent to assuming that the earth's magnetic field is due to a dipole. For this case we use the common expression for the total geomagnetic field intensity as a function of radial distance and latitude

$$F = F_0 \left(\frac{R}{r}\right)^3 \sqrt{4 \cos^2 A + \sin^2 A}$$

where F_0 is the equatorial surface field value.

At the surface of the field installation r = R and

$$F = F_1 = F_0 \sqrt{4 \cos^2 A + \sin^2 A}$$

and at any point below the surface of the installation

$$F = \left(\frac{R}{r}\right)^3 F_1$$

At a depth d below the surface $r = R - d$ and

$$F = \left(\frac{R}{R-d}\right)^3 F_1 \approx \left(1 + \frac{3d}{R}\right) F_1 .$$

The difference between the lower and upper field strengths is:

$$\Delta F = F - F_1 = F_1 \left(\frac{3d}{R}\right)$$

Taking $d = 1000$ ft, $R = 2.1 \times 10^7$ ft and $F_1 = 57{,}500$ gammas

$\Delta F = 8.3$ gammas

In addition to the earth's main field there are magnetic gradients caused by geologic bodies at or beneath the ocean floor. These bodies may have a remanent or induced magnetization. The amount of remanent magnetization present is determined by the structure's magnetic history and cannot be calculated. However, the gradient of the total field anomaly due to induced magnetization can be calculated for an assumed body geometry. This was done on an electronic digital computer for several two dimensional structures following the method of Heirtzler, et al. (1962). The results of one calculation (a fault with upper surface on the ocean bottom) are shown in Figure 13. The magnetic susceptibility of 0.006 used in this calculation yielded an anomaly gradient of the type observed on 18 November 1962 (see Figure 15). This value of susceptibility is approximately the same as that required by Hunkins, et al. (1962) in accounting

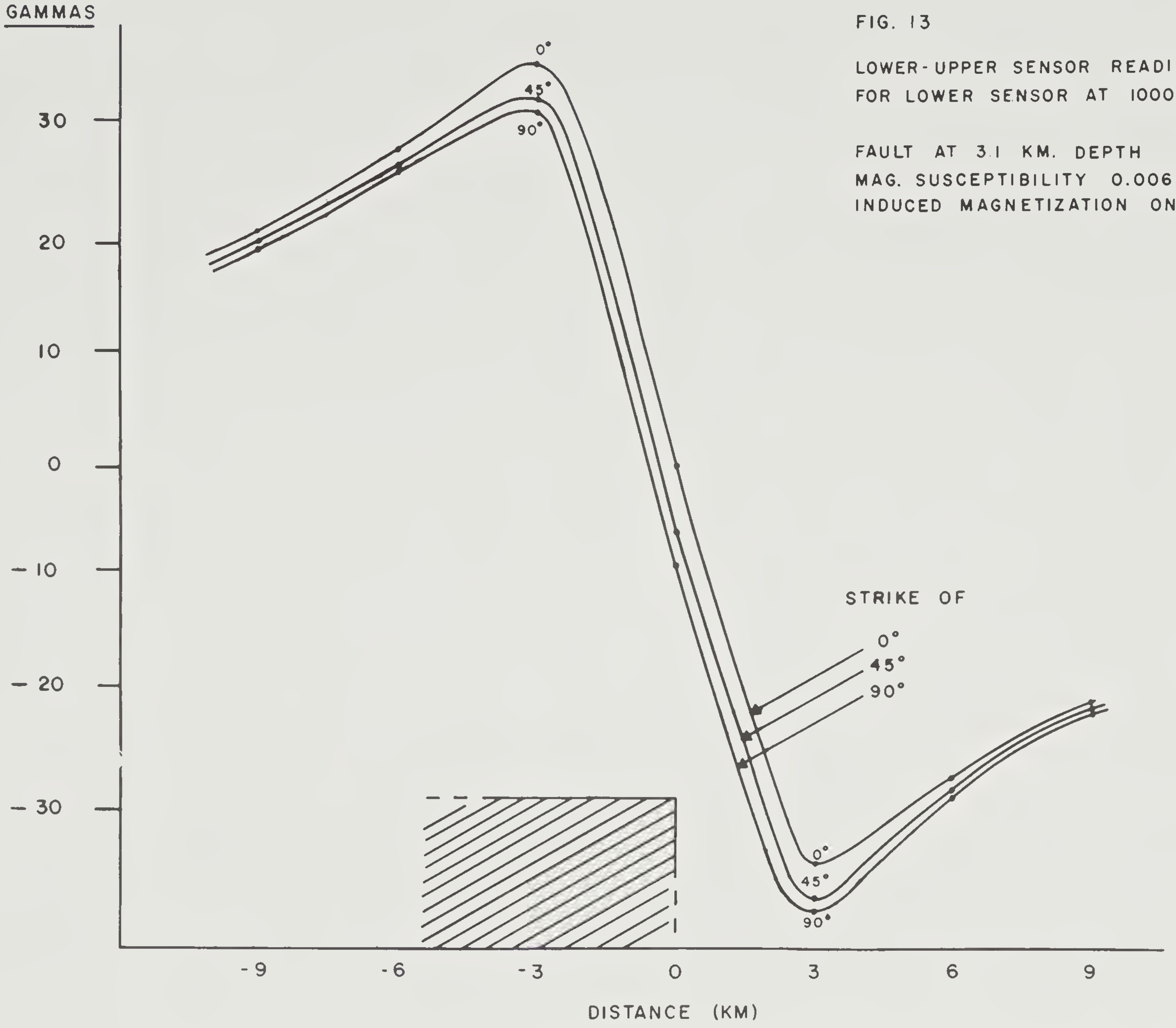


FIG. 13

LOWER-UPPER SENSOR READING
FOR LOWER SENSOR AT 1000 FEET

FAULT AT 3.1 KM. DEPTH
MAG. SUSCEPTIBILITY 0.006 EMU
INDUCED MAGNETIZATION ONLY

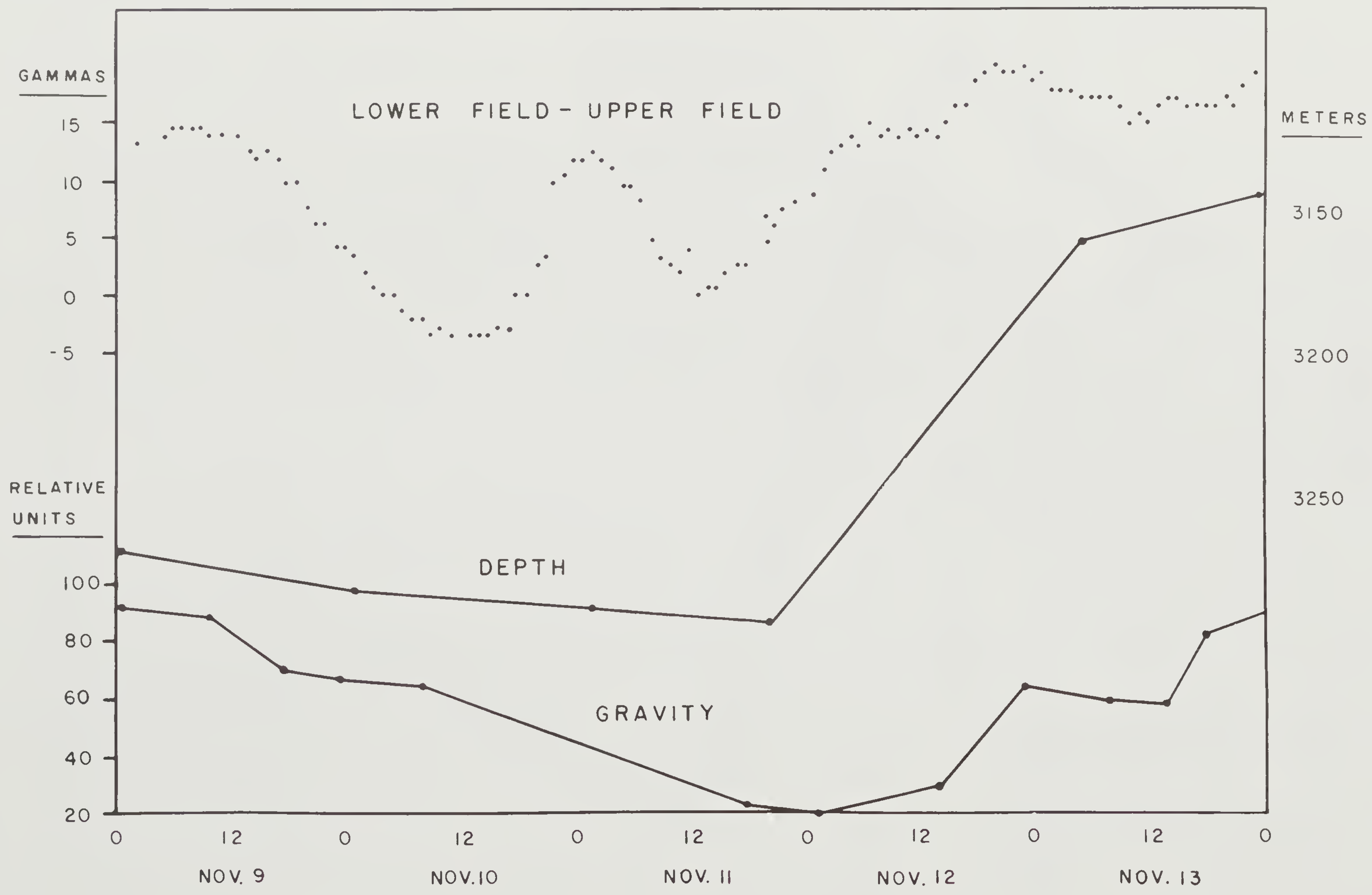


FIG. 14- MAGNETIC GRADIENT, DEPTH AND GRAVITY ANOMALY PROFILES

for an anomaly over the Chukchi Cap.

The magnetic effects of geological bodies dominated the effects of the main field as far as the magnetic gradients are concerned. There were a number of occasions where the field was of greater magnitude on the surface than at depth. If the earth's main field alone had been operative, the lower head would always have given a higher field intensity. Figure 14 shows the magnetic gradient, depth and gravity anomalies observed over a sample period of five days. Due to the irregular track of the island and shortage of good determinations of position, it was not possible to produce reasonable contour plots of the data. Figure 15 shows one of the more successful attempts to contour depths and magnetic gradient.

VI. CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

With the instrument and recording technique employed it was possible to measure the changes in vertical gradient as the ice island drifted over geological bodies and to get general estimates of attenuation and phase shifts of the vertical component of time variations between 70 and 400 seconds period. There may be anomalous attenuations near 90 seconds period. However, no gross attenuations were found.

For the future study of time variations beneath the sea surface the sensitivity of the instrument needs to be improved by (a) increasing the repetation rate of the clock pulse generator and (b) by fixing the instrument in place on the bottom so that no rotational effects are operative. At the present time a self-contained bottom instrument with digital acoustic telemetry is under construction at Lamont as an in-house effort.

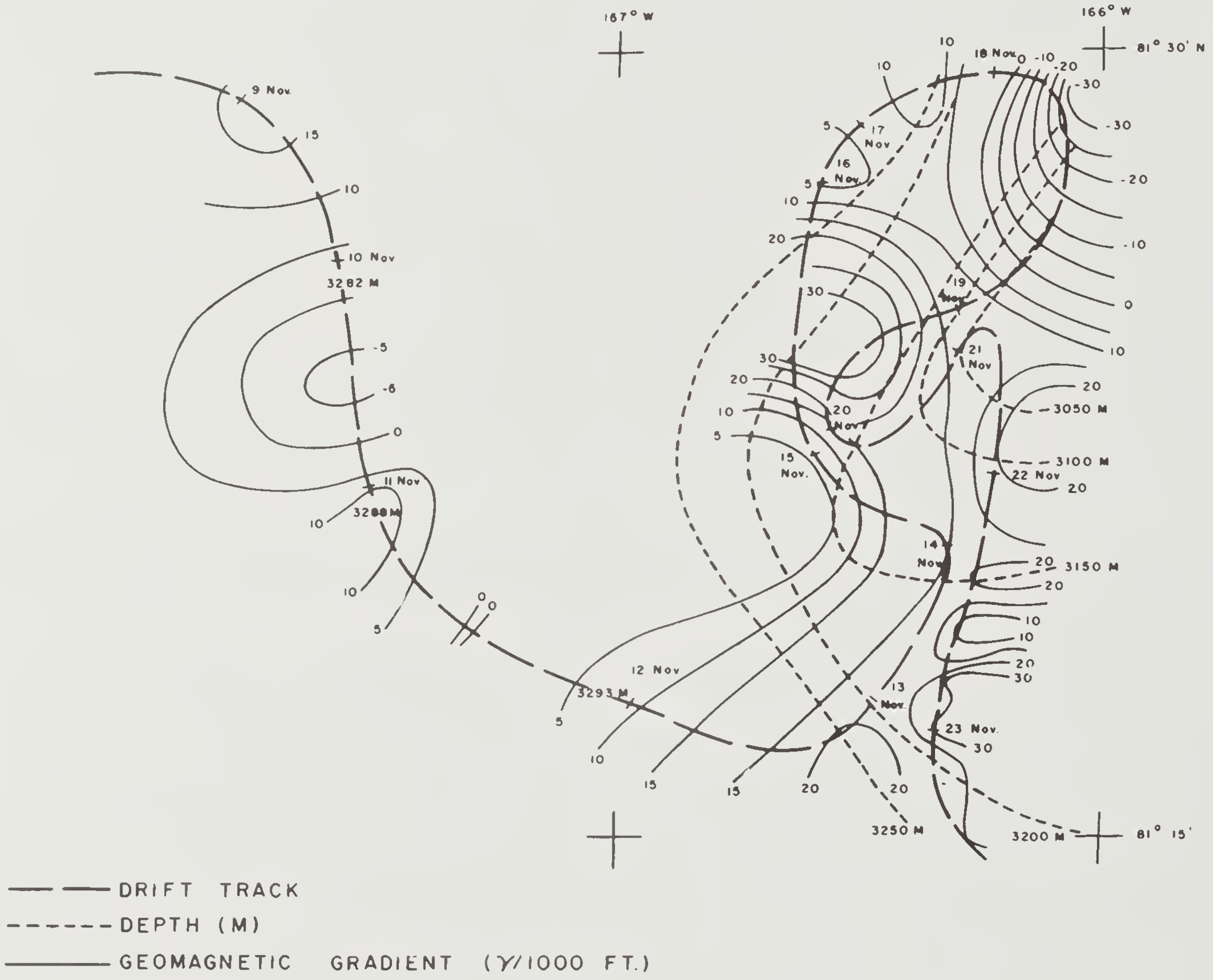


FIG. 15 - CONTOURS OF DEPTH AND MAGNETIC GRADIENT, 9 - 23 NOVEMBER

This instrument uses a one megacycle clock pulse generator and will have an accuracy of ± 0.1 gamma if the counter is recorded digitally. With this increased sensitivity and with the increased depth of the lower head attenuations and phase shifts will be more definitely known and the spectrum can be examined to somewhat shorter periods.

In high latitudes it will be advantageous to operate this new instrument, part-time, with a magnetic bias field to cancel part of the vertical d.c. field component. By this means the horizontal component of time variations will play a more dominant role and the two components of time variations can be studied independently. The entire vertical field cannot be eliminated since the resulting field would be too low to measure with this type instrument.

At lower latitudes, however, one could cancel the entire vertical component and study the horizontal time fluctuations exclusively.

APPENDIX I

Configuration of Cable Due to Drag of Water

Calculations were made to find the configuration of the cable and sensor under conditions of uniform ice drift over an ocean without other currents. Current measurements from previous ice stations have shown that most of the change in relative velocity between the ice and water occurs in a fairly thin boundary layer just beneath the ice. The assumption of ice moving over a motionless ocean is, therefore, valid as a first approximation.

The problem was solved according to the technique outlined by L. Pode in Report 687 of The David Taylor Model Basin, "Tables for Computing the Equilibrium Configuration of a Flexible Cable in a Uniform Stream". Pode tabulates certain "cable functions" which are the numerical solutions of the differential equation of the cable hanging in equilibrium under the influence of a uniform current. It is assumed that the hydrodynamic force which acts on an element of cable depends only on the angle that the element makes with the stream and is not affected by such matters as the curvature of the cable or the flow at neighboring elements. This assumption is considered to be valid in this application.

The sensor was considered to be a cylinder 20" long and 5" in diameter weighing 36 lbs. in water. The cable was considered to be a cylinder with weight of 0.193 lbs/ft. For a current velocity of 1/4 ft/sec., hydrodynamic drag on the sensor and cable were calculated from the formula,

$$\text{Drag} = \frac{C_D A \rho V^2}{2}$$

where C_D = drag coefficient

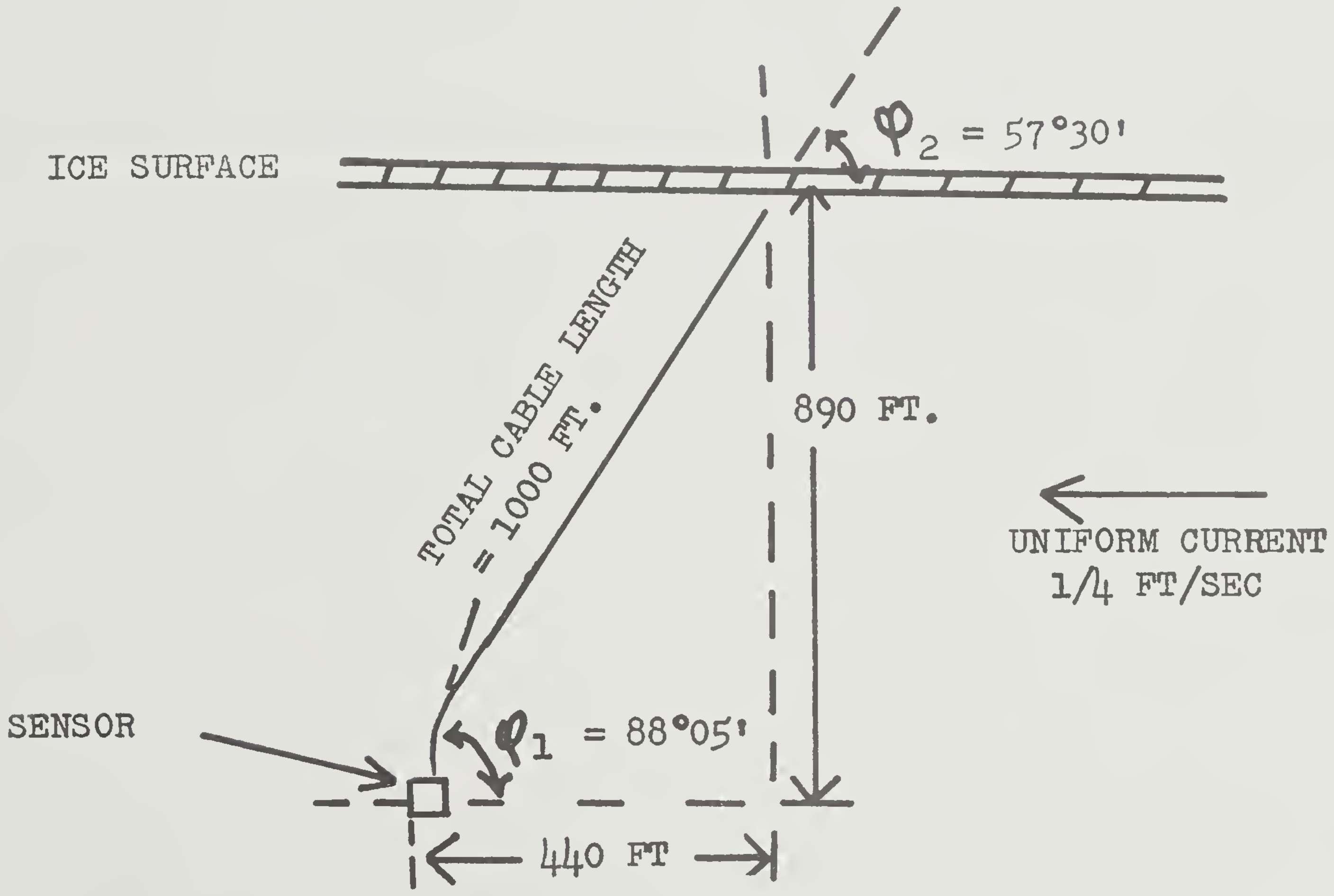
A = cross-sectional area

ρ = water density

V = current velocity

For the sensor, drag was 1.18 lbs. and for the cable it was 0.122 lbs/ft.

Entry into Pode's tables gave the depth of the sensor as 890 ft. and the horizontal displacement of the sensor as 440 ft. for a cable length of 1000 ft. The accompanying diagram illustrates the configuration. The diagram is not to scale.



ACKNOWLEDGMENTS

Dr. Kenneth Hunkins, head of Arctic Geophysics Department of Lamont Geological Observatory, devoted a considerable amount of time to the management of this project and to resolving the technical problems that arose. Mr. James F. Cottone, of the Geomagnetism Department, was responsible for seeing that all aspects of the instrumentation system were technically sound and met specifications. He installed and operated the instrument during the three month field trip required to obtain the data. Mr. Arthur Jokela materially assisted in the operation of the instrument, obtained other geophysical data mentioned in this report, and analyzed the results to determine the effects of geological structures. Mr. M. J. Davidson provided computer programs for the statistical analysis.

The Arctic Research Laboratory at Barrow, Alaska, provided the logistic support north of Alaska.

The project received financial support from the Naval Ordnance Laboratory, Silver Spring, Maryland, through the Office of Naval Research, Contract Nonr 266(82).

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