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# 30-DAY OCEAN-BOTTOM SEISMOGRAPH

## MODIFICATION AND TESTING OF NINETEEN OCEAN-BOTTOM SEISMOGRAPHS

By

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# ABSTRACT

Dallas modifications and tests, Albuquerque land tests, shallow and deep water tests off the coast of California, and antenna tests were run to prove that the Ocean-Bottom Seismograph is a practical seismograph.

Dallas modifications included pressure switches added to the radio transmitter and the beacon light. A new high-precision motor was added to the tape recorder. Pressure transducer sensitivity was increased by approximately 20 db. The trigger board was redesigned for sonar recall. The U-joint, battery boxes, bottom and side plugs, and secondary release were also modified, and an input filter was added.

Albuquerque land tests showed almost exact duplication between OBS data and that from adjacent reference seismometers.

Shallow and deep water tests showed that the unit was basically reliable, but showed a resonance problem. The consequent antenna tests resulted in a switch to wrap around antennas to solve the ocean current-induced resonance.

Clock tests were run to test the accuracy of the clocks at 3° C and 25° C and to measure the thermal time lag.

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The following scientists or engineers contributed to the research reported on in this report:

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# SECTION I

# INTRODUCTION

This report discusses results of the testing program performed on the Ocean Bottom Seismograph systems. The program consisted of three phases:

- Laboratory and field tests conducted in Dallas
- Final checkout of the system on land at Albuquerque
- A series of shallow and deep water tests off the coast of California

The water tests led to a fourth phase to determine the effect of the antenna during operation on the ocean bottom.

After a brief summary of the thirty-day Ocean-Bottom Seismograph project, which was prior to the testing program (Section II), the four phases are discussed in Sections III through VI. Section VII summarizes the outcome of the testing program and lists the modifications that resulted.

## SECTION II

## SUMMARY OF 30-DAY OCEAN-BOTTOM SEISMOGRAPH PROJECT

After successful construction and operation of the first generation ocean-bottom system [Air Force Contract AF 19(604)-8368] Texas Instruments was awarded a contract in March, 1964 to build a second generation system.* Twelve units were built and dropped in the Gulf of Mexico, and in the areas around the Aleutian Islands and Kurile Islands. Analysis of data from recovered units was reported in the Final Report.** These data revealed two systems problems: (1) low sensitivity of the pressure transducer and (2) mechanical crosscoupling between the vertical and horizontal seismometers. These problems were rectified by redesigning the pressure transducer and by adding bottom viscous coupling to the gimballed seismometer package.

In addition, several modifications were made to improve recovery reliability. These included:

- Addition of a backup release clock
- Addition of a beacon light
- Painting the spheres orange for better visibility
- Increasing the "life" of the radio transmitter

Twelve additional units which incorporated the above modifications were then built (making a total of 19 units, including the 7 modified units remaining from the first 12). To check their operational reliability at ocean-bottom temperatures, all 19 were tested in a cold chamber. After successful completion of the cold tests the units were tested to check their performance on the ocean bottom in a series of shallow and deep tests off the coast of California. These tests resulted in several additional system modifications*** and showed that some problems remained to be solved (especially the "resonance" problem). The testing program just completed was undertaken to test these modifications and resolve the remaining problems.

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*Texas Instruments, 1964: Thirty day ocean-bottom seismograph, Semi-Annual Tech. Rpt. No. 1, Jul. 20.

**Texas Instruments, 1964: Thirty day ocean-bottom seismograph, Final Rpt, Oct. 31.

***Texas Instruments, 1966: Thirty day ocean-bottom seismograph, Final Rpt. Supp., Mar. 4.

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## SECTION III

## DALLAS MODIFICATIONS

Shallow and deep water tests of the Ocean-Bottom Seismograph, conducted from 7 October to 18 December 1965, showed areas of needed improvements. Among the mechanisms modified and improved were

- U-joint
- Battery boxes
- Bottom and side plugs
- Sonar
- Radio transmitter switch
- Pressure transducer
- Beacon light
- Tape recorder unit
- Secondary release

A pressure switch for the light and a new direction finder have been added.

### A. U-JOINT

A variety of techniques were evaluated for the suspension of the 3-component seismometer assembly from the "bird cage." Two requirements were placed on the suspension system:

(1) It must allow vertical alignment of the seismometer assembly for OBS package emplacement angles up to 45° from vertical

(2) It must provide undistorted seismic coupling into the seismometer assembly.

From all the suspension systems considered, it was determined that the U-joint was the most desirable from a standpoint of reliability and coupling rigidity. Both a ballbearing U-joint and a pinned U-joint assembly were evaluated. It was determined that either design provides rigid, undistorted coupling of seismic energy into the gimballed seismometer assembly. Further tests indicated that the ballbearing U-joint was more subject to brinelling under impact than the pinned U-joint. For this reason the decision was made to modify the existing pinned U-joint assemblies. Each existing U-joint was disassembled, cleaned and a new, lighter-weight lubricating oil was added.

Additional tests were performed to ascertain that the silastic compound (silly putty) did provide rigid seismic coupling to the bottom of the sphere for the frequencies of interest.

As an additional precaution, the pan was firmly bolted to the lead weight located at the bottom of the sphere. In turn, the lead weight was firmly bolted to the bottom of the sphere.

## B. BATTERY BOXES

Holes have been drilled in the bottom of the battery boxes so that any water which leaks into the boxes will flow to the bottom of the sphere to activate the salt-water release circuits.

## C. BOTTOM AND SIDE PLUGS

Bottom plugs have been cleaned and an RTV sealant has been added to prevent corrosion. It was determined that much of the corrosion and electroplating had been due to leakage of the high voltage (540 v) used to fire the beacon light. The beacon light subsequently has been modified for internal battery operation, and the high voltage has been removed from the bottom plug.

All side plugs have been modified. The "O" ring groove has been widened to accommodate "O" ring expansion. Each plug has been pressure-tested with no leakage occurring.

## D. SONAR

The original sonar recall seemed to work satisfactorily on isolated units, but when several units were in the same area, there was trouble with units surfacing on the wrong code. The decoder had no information on signal strength. If all the pulses of a weak code were not detected, an erroneous recall might result.

In an attempt to correct this, the analog portion of the sonar receiver was redesigned. The input is to a bandpass filter which rejects all but the frequencies of interest. This is followed by six gain stages which are designed to symmetrically clip the signal. The result is a square wave at the predominate frequency of the bandpass filter output. Two narrowband filters drive a trigger circuit which feeds the decoder.

A squelch circuit was incorporated to lock the decoder in a reset condition when there was not a good signal at either of the narrowband filter frequencies. It was found during the sea tests that this scheme did not work since it was unable to detect signal conditions that were just poor enough that the trigger output did not follow all the transmitted signal pulses.

It became apparent that the most reliable way to tell whether the received signal was accurate was to see if the signal was repeatable. Accordingly, the trigger board was again redesigned to eliminate the squelch circuit and to incorporate additional digital logic which operates in conjunction with the decoder card. This latest system requires the reception of three consecutive codes of the correct number for the unit called. The reception of any code of another number resets the decoding logic. The probability of the receiver misinterpreting a code in the same way three times in a row should be very low. This has been borne out by the success of the latest tests.

## E. BEACON RADIO PRESSURE SWITCH

Original design of the beacon radio allowed radio operation only upon activation of the release relay. It was determined that this did not provide for radio operation in the event that the unit surfaced due to mechanical breakage of the release wire upon impact. For this reason, the transmitter power circuits were redesigned so that the holding current for the transmitter power relay was forced to flow through the radio antenna with circuit completion through sea water. This allowed the radio to transmit when the unit surfaced, regardless of the reason for surfacing. Subsequent operation revealed that rather severe corrosion and electroplating of the antenna tip was occurring. This resulted in intermittent operation of the radio transmitter at times when the units were recording seismic data on the ocean bottom. Operation of the radio transmitter resulted in complete corruption of the seismic data.

In order to overcome this difficulty, a pressure switch has been incorporated. This switch was designed to be mounted in place of one of the two side plugs. The switch turns off the radio transmitter at approximately 275 ft while descending and turns it on at 200 ft while ascending.

## F. PRESSURE TRANSDUCER

The sensitivity of the pressure transducer has been further increased by ≈ 20 db for a total sensitivity of 90 db below one V/microbar.

Changes in the transducer housing have been made to accommodate the larger crystals necessary to effect this increase in sensitivity. Each unit was pressure-tested prior to installation (Figure III-1).

Figure III-1. Pressure Transducer

## G. BEACON LIGHT

The beacon light has been redesigned to allow inclusion of internal operating batteries in the lamp package. A pressure switch is incorporated which energizes the beacon light as the unit surfaces. The pressure switch is the same design used on the radio transmitter and operates at approximately the same depth. The flash rate has been reduced to one flash every 2 to 3 sec in order to extend the useful life of the beacon light to more than 3 weeks.

## H. TAPE RECORDER UNIT

The major improvement in the tape recorder system has been the change to a high precision, brushless Sperry motor. This motor is more reliable, has a longer life (10,000 hr) and less vibration than the previous motor. In addition, a voltage regulator has been added to provide speed regulation for the motor. See Appendix A for specifications of this motor.

Additional modifications have been made to the tape transport. A new flywheel plate has been incorporated. This plate is spring-loaded to maintain even pressure on the drive train in all operating positions. In addition, travel-limiting screws have been added to prevent denting the drive wheels on severe impact. New bearings mounted in silicone rubber have been added to form double-ended support for the secondary drive disc. All drive wheels were remade using hardened stainless steel. Mounting brackets within the sphere have been reworked to allow more clearance and easier mounting of the transport.

## I. BUOYANCY

Modification of the light and battery housing made rearrangement of the batteries necessary in order to keep the OBS balanced.

## J. BEACON PULSE DIRECTION FINDER

The original loop antenna used to receive the signal from the surfaced OBS gave an 180° ambiguity in the direction of the OBS unit. As was reported in the Final Report Supplemen under Contract AF19(628)-4075, this problem has been eliminated by use of the Beacon Pulse Direction Finder Unit (D. F. Unit). The D. F. Unit consists of two radio receivers and three vertical whip antennas. Operation of this system depends upon the different travel times from a given transmitter to two receiving antennas a known distance apart. Directional ambiguity has thus been eliminated.

## K. SECONDARY RELEASE

It was determined that a secondary release to provide a backup for the fuse wire would be a highly desirable addition to the OBS. Many systems were investigated, eg., explosive bolt, guillotine. It was determined that a reliable and economical solution was to use a double-sectional fuse wire so situated that a burn pulse through either section would effect the release. A pictorial representation is shown in Figure III-2 below.

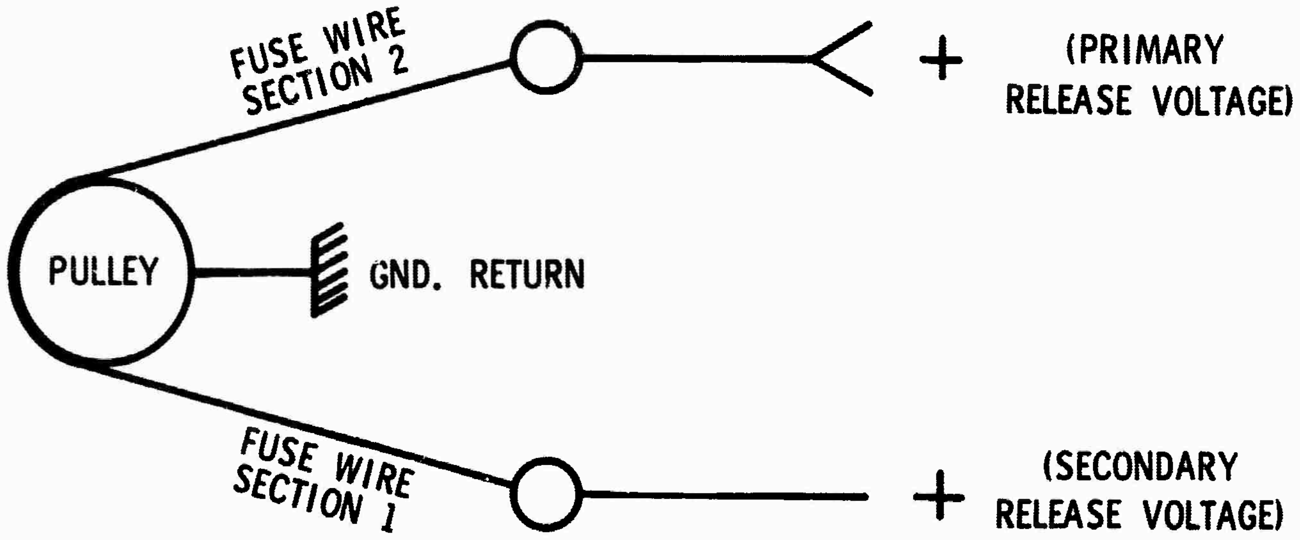

Figure III-2. Secondary Release Mechanism

The secondary release is under control of the Bulova backup clock.

## L. INPUT FILTER

During early phases of the Dallas-based test program, it was determined that the seismometers used in the OBS were very sensitive to high frequency seismic energy. Under conditions of relatively high seismic background noise, the higher frequencies completely obscured the lower frequencies of interest, i.e., 1 to 10 cps. The amplifier electronics were designed to bandpass filter the seismometer outputs over the 1 to 10 cps band. However, the active filters were placed after the preamplifier section (voltage gain of 1000) in order not to degrade the low equivalent input noise voltage of the parametric preamplifier. The preamplifier thus served to amplify the high frequency output of the seismometer by a factor of 1000. It was determined that the high frequency was of such amplitude under certain conditions to cause the filter circuits to overload.

It was determined that the higher frequencies could be attenuated to a level sufficient to prevent filter overload by the inclusion of a 6 db/octave high-cut filter incorporated at the input to the preamplifier. The circuit is shown in Figure III-3.

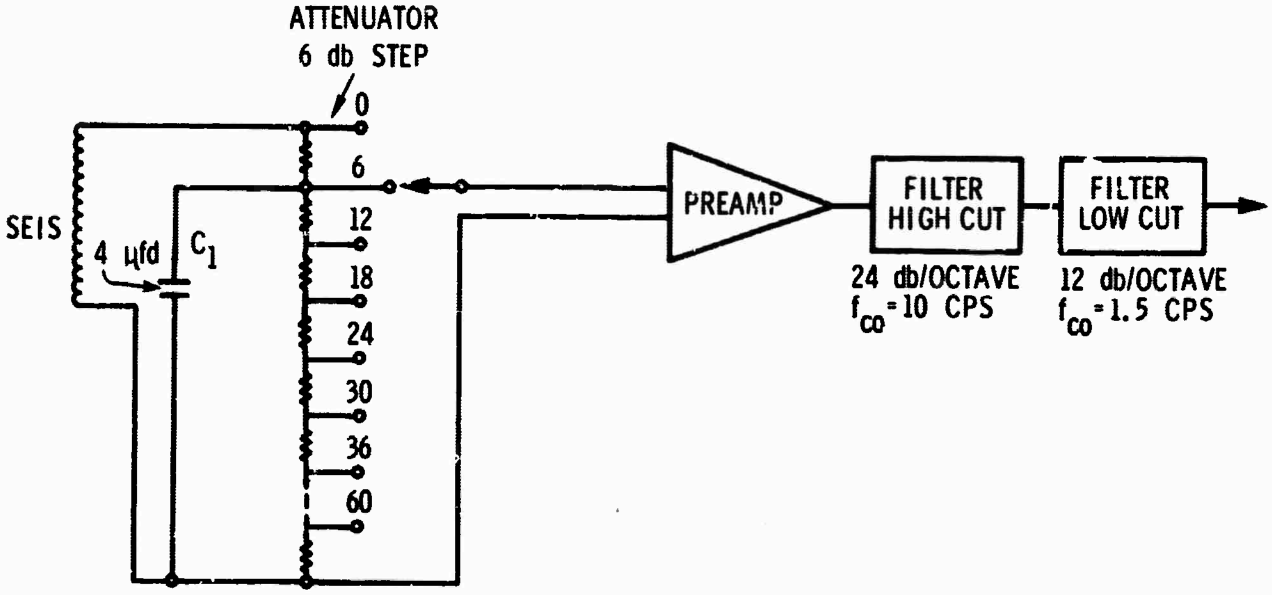

Figure III-3. Circuit Diagram of Input Filter

$C_1$ and the seismometer damping resistors form a high-cut filter of 6 db/ octave with a corner frequency of 8 cps.

The pressure channel was likewise connected to provide identical response.

## M. CLOCK TESTS

Tests were conducted on all clocks to ascertain timing accuracy at normal ocean-bottom temperatures and clock error caused by normal temperature gradients (ocean bottom vs shipboard). Table III-1 depicts clock errors in parts/$10^8$ at 25°C and at 3°C before any oscillator frequency adjustments were made. Note that the maximum clock error at 3°C was 19 parts/$10^8$. This corresponds to a time error of approximately 0.5 sec over a 30 day time cycle. All clocks were set to the correct frequency at 3°C after approximately 48 hr of stabilization.

Additional tests were conducted to determine the thermal time lag at the clock crystal location as the OBS goes from a warm outside air temperature to ocean bottom temperatures. These tests indicate a time lag of approximately 3.5 hr in going from an outside air temperature of 27°C to an ocean-bottom temperature of 2°C. The reverse process (from 2°C to 27°C) showed a time lag of approximately 9.5 hr. Table III-2 depicts clock errors as a function of temperature over the range from 3°C to 26°C.

## N. TESTS FOR SYSTEM RESONANCE

At the time the laboratory tests were conducted the ocean-bottom resonance problem was not resolved, so tests were run to determine whether some system component was causing it.

Two basic tests were run. The first systematically removed mechanical components from the OBS package and compared the OBS outputs (or, if the seismometer assembly was removed, a standard was placed in the OBS package) with standard EV-17 seismometers placed on the floor next to the unit. It was determined that no resonance phenomenon was associated with the following:

- The "birdcage" from which the seismometer assembly hangs
- The kickspring which secures the sphere to the base
- The aluminum pan inside the unit which holds the silicon compound used for bottom damping
- The three pads which couple the sphere to the base
- The base itself

The second test placed the base and then the entire unit on a pier and drove the pier with an external horizontal force at frequencies

Table III-1

CLOCK TIMING ERROR IN PARTS / $10^8$ AT 25°C AND 3°C BEFORE OSCILLATOR ADJUSTMENTS WERE MADE WHERE + EQUALS FAST AND - EQUALS SLOW

| Clock No. | 25°C(Parts/$10^8$) | 3°C (Parts/$10^8$) |
|---|---|---|
| 1 | -46 | +4 |
| 2 | -38 | +6 |
| 3 | -88 | -2 |
| 7 | -37 | -3 |
| 10 | -01 | +14 |
| 11 | -77 | +1 |
| 12 | -32 | +1 |
| 13 | -51 | -1 |
| 14 | -03 | +13 |
| 15 | -107 | -7 |
| 16 | -50 | +10 |
| 19 | -87 | 0 |
| 20 | +24 | +19 |
| 21 | -83 | +1 |
| 22 | -90 | -2 |
| 23 | -112 | -5 |
| 24 | -40 | +10 |

## Table III-2

## CLOCK TIME ERROR IN PARTS/$10^8$ vs TEMPERATURES

| Clock No. | 3°C | 4°C | 8°C | 10°C | 12°C | 15°C | 18°C | 20°C | 23°C | 26°C |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | -1 | 0 | -1 | -7 | -12 | -19 | -29 | -36 | -47 | -62 |
| 2 | 0 | 0 | -2 | -5 | -9 | -15 | -22 | -28 | -37 | -50 |
| 3 | 0 | -3 | -8 | -16 | -25 | -33 | -44 | -56 | -76 | -99 |
| 7 | 0 | +3 | +6 | +9 | +10 | +7 | -1 | -10 | -24 | -38 |
| 10 | 0 | +5 | +8 | +11 | +10 | +8 | +3 | -2 | -10 | -21 |
| 11 | -2 | -3 | -7 | -13 | -19 | -29 | -41 | -52 | -70 | -88 |
| 12 | 0 | +5 | +7 | +7 | +4 | -1 | -8 | -15 | -28 | -40 |
| 13 | 0 | +1 | +1 | -2 | -6 | -12 | -20 | -30 | -45 | -59 |
| 14 | +1 | +4 | +7 | +9 | +8 | +7 | +2 | -3 | -14 | -26 |
| 15 | 0 | -5 | -13 | -25 | -35 | -46 | -59 | -72 | -93 | -114 |
| 16 | 0 | +1 | 0 | -4 | -9 | -16 | -25 | -36 | -51 | -68 |
| 19 | 0 | -4 | -8 | -19 | -24 | -34 | -46 | -58 | -65 | -98 |
| 20 | +1 | +6 | +13 | +16 | +17 | +17 | +15 | +14 | +12 | +3 |
| 21 | +1 | -2 | -5 | -14 | -20 | -29 | -42 | -54 | -74 | -96 |
| 22 | 0 | -2 | -5 | -13 | -19 | -29 | -43 | -55 | -76 | -97 |
| 23 | -1 | -3 | -11 | -18 | -29 | -41 | -54 | -69 | -94 | -116 |

0 to 350 cps at 5 cps increments. The responses of the base and unit were determined by measuring the seismometer outputs, and the transfer function was obtained. No indication of resonance was observed from this test.

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# SECTION IV

# ALBUQUERQUE TESTS

The purpose of the Albuquerque tests was to show that the OBS recorded valid seismic data on land. This was done by comparing the OBS data with that from seismometers on the ground adjacent to the package (hereafter called reference seismometers) and by comparing data from two adjacent OBS systems. Comparisons were made visually and by computing coherences between the OBS and reference seismometers. The coherence is given by:

$$C(f) = \frac{\Phi_{OBS,R}(f) \quad \Phi_{OBS,R}^{*}(f)}{\Phi_{OBS}(f) \cdot \Phi_{R}(f)}$$

where

$\Phi_{OBS,R}(f)$ is the crosspower density spectrum between the OBS and reference seismometer

$\Phi_{OBS}(f)$, $\Phi_{R}(f)$ are the autopower density spectrum of the OBS and reference seismometers

and

$$0 \leq C(f) \leq 1$$

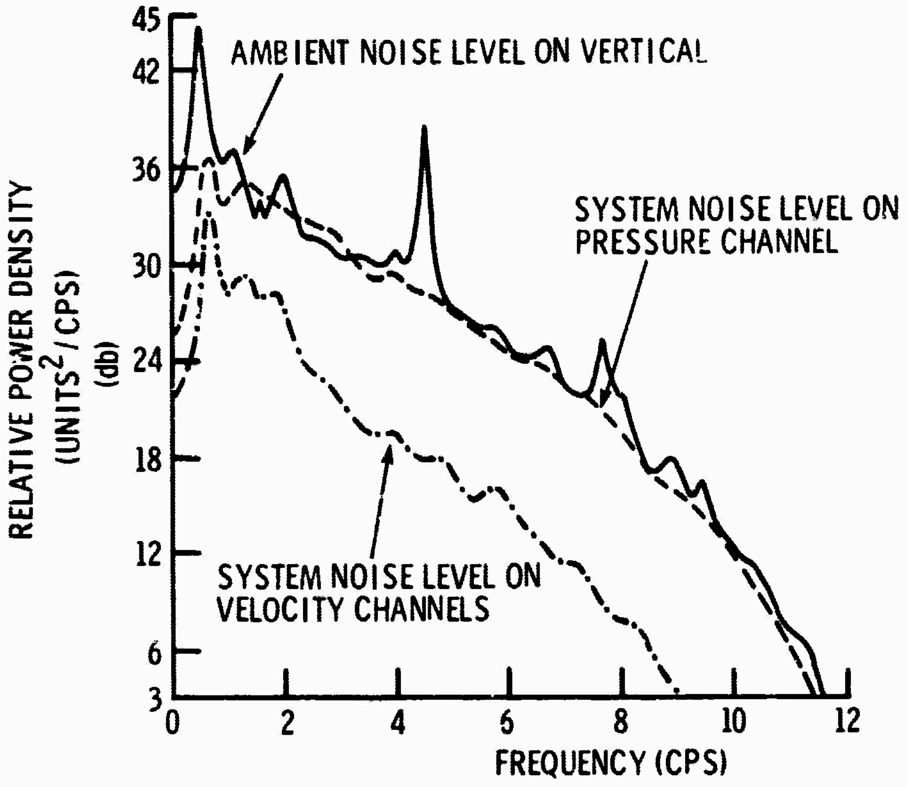
Since the OBS and reference seismometers were sampling essentially the same point in space, it would be expected that $C(f) \sim 1$ if the OBS recorded valid seismic data.

Units 13, 14 and 16 were sent to Albuquerque. Unit 16 was placed in a vault at the United States Coast and Geodetic Survey Seismological Laboratory; Units 13 and 14 were placed in a nearby vault on Sandia Base. Units 13 and 14 were first run in the same trace configuration (3-component OBS and a reference vertical on the pressure transducer channel). Unit 13 was then used to compare the OBS and reference horizontals: the N-S OBS component (recorded on channel 3) was compared with a N-S Benioff (recorded on the pressure channel-channel 1), the E-W OBS component (recorded on channel 4) was compared with an E-W EV-17 (recorded on channel 2). Unit 14 was used to compare the vertical OBS component with a vertical Benioff (recorded on the pressure channel). Unit 16 compared the vertical OBS component with a vertical EV-17 (recorded on the pressure channel). Both units 14 and 16 recorded the two OBS horizontals in channels 3 and 4. All three systems had tape recorders with the old Barber-Coleman motors, and a passive 6 db/octave high-cut filter (cut-off frequency of 8 cps) was placed ahead of the preamplifiers.

It was originally intended to use ambient noise data to compare the OBS and reference seismometers. However, it was found that the ambient noise at this quiet site was not much above system noise level (especially in the pressure channel which has a 10-db higher system noise level due to thermal noise of the 6 megohm input resistor). Figure IV-1 compares the ambient noise level on both the vertical and horizontal components with the system noise level on the pressure and velocity channels and shows that, except for spectral peaks, the ambient noise was about at system noise on the pressure channel and about 10 db above it on the velocity channels.

Figures IV-2 and IV-3 show noise coherences between the OBS NS and Benioff NS, the OBS E-W and EV-17 EW, the OBS and Benioff V, and the OBS-V and EV-17 V, respectively. It can be seen that the coherences were low (except at spectral peaks) which would be expected because system noise is uncorrelated between units. The E-W coherence was best because the pressure channel was not involved and the ambient noise was somewhat above system noise. Because of the low ambient-to-system noise ratio, the performance of the OBS system could not be determined by using ambient noise data.

It should be emphasized that the system noise level will not be a problem for ocean bottom noise analysis. At Albuquerque, the ambient noise was so low-level that the x100 channels were used in the analysis; whereas for ocean-bottom data the x10 or x1 channels have been used. While the attenuaters at Albuquerque were set at 6 db, signal input attenuators are normally set to 18 db. The ambient noise will be 30 to 50 db above the system noise level. In other words, while the seismometer sensitivity was not sufficient for the Albuquerque site it will be sufficient for ocean-bottom recording.



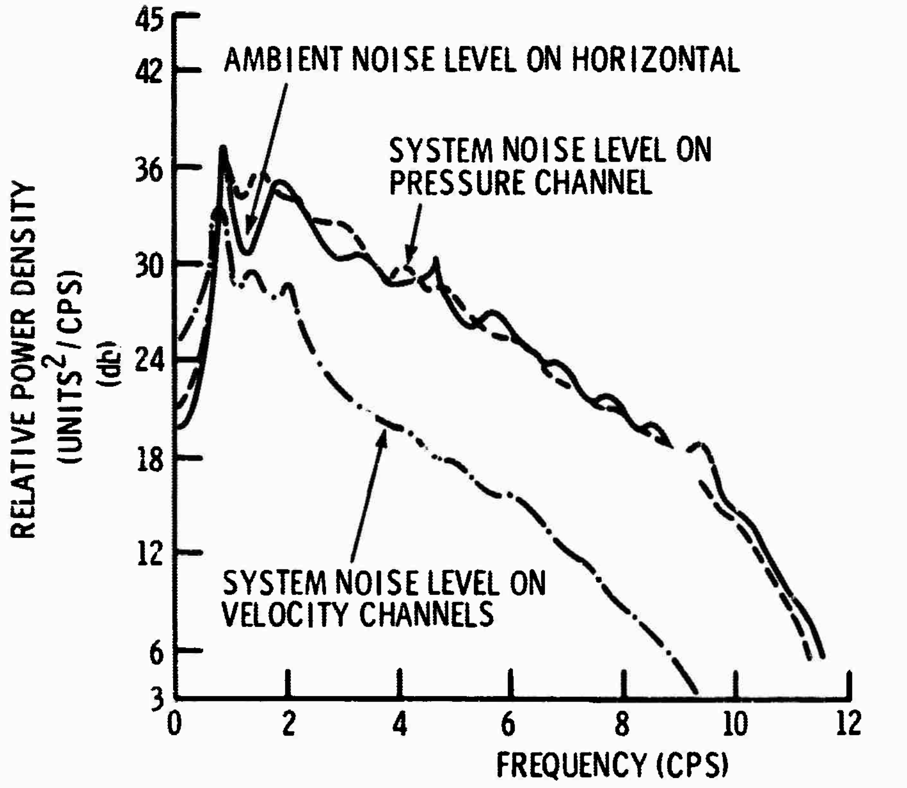


Figure IV-1. Comparison of Ambient and System Noise Levels

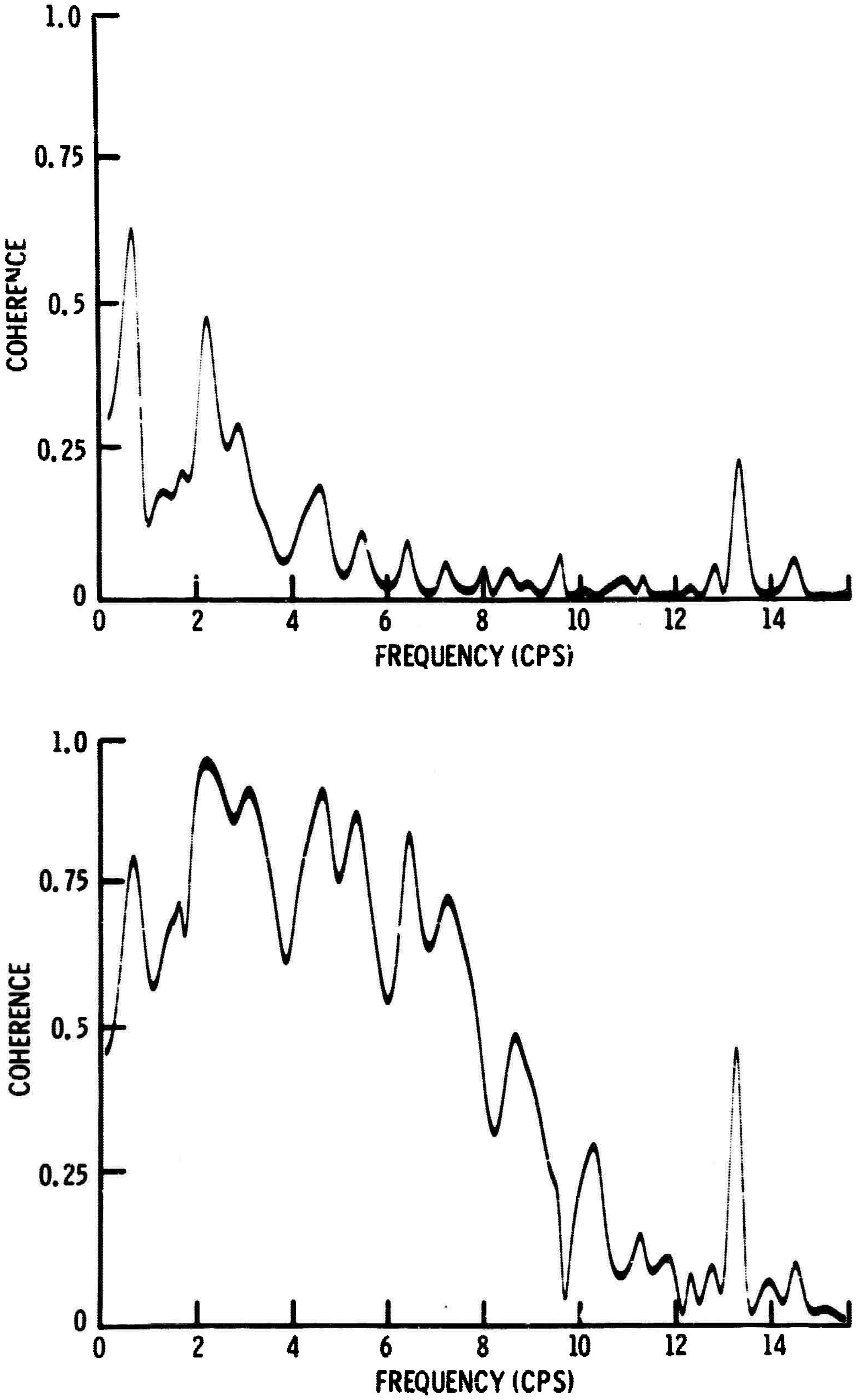


Figure IV-2. Ambient Noise Coherences Between OBS NS and Benoiff NS and OBS EW and EV-17 EW

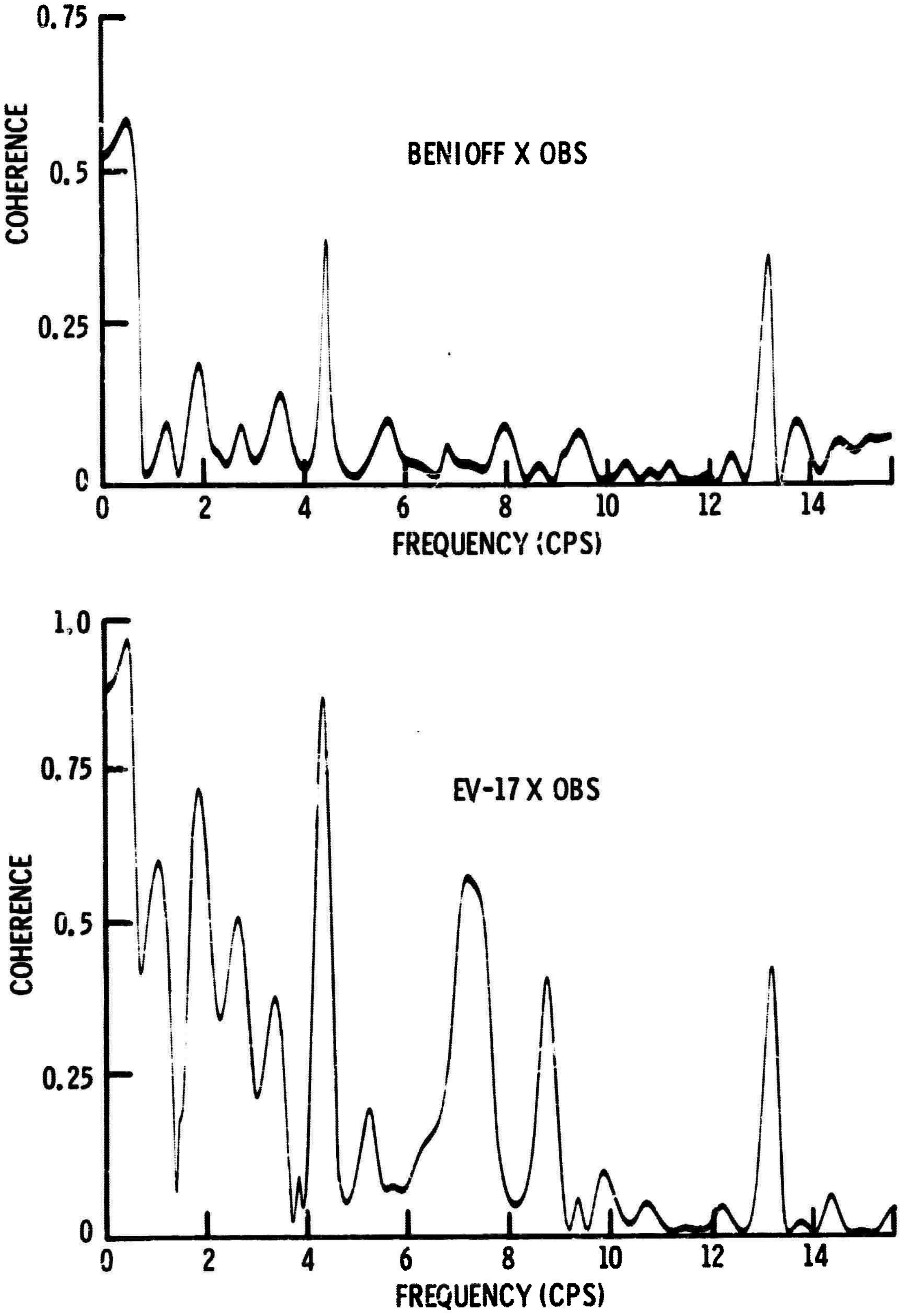


Figure IV-3. Ambient Noise Coherences Between OBS V and Benioff V, and OBS EW and EV-17 EW

Because of the low ambient noise, large signals had to be used to determine the performance of the OBS system. For large signals the output from two adjacent OBS systems would be expected to be essentially identical if the units were performing correctly. Also, in the frequency band where signal-to-noise ratios were high, high coherences would be expected. Consequently one near-regional event was visually compared between two OBS units, and one teleseism and one local event from each event were used to compute coherences between the OBS and reference components.

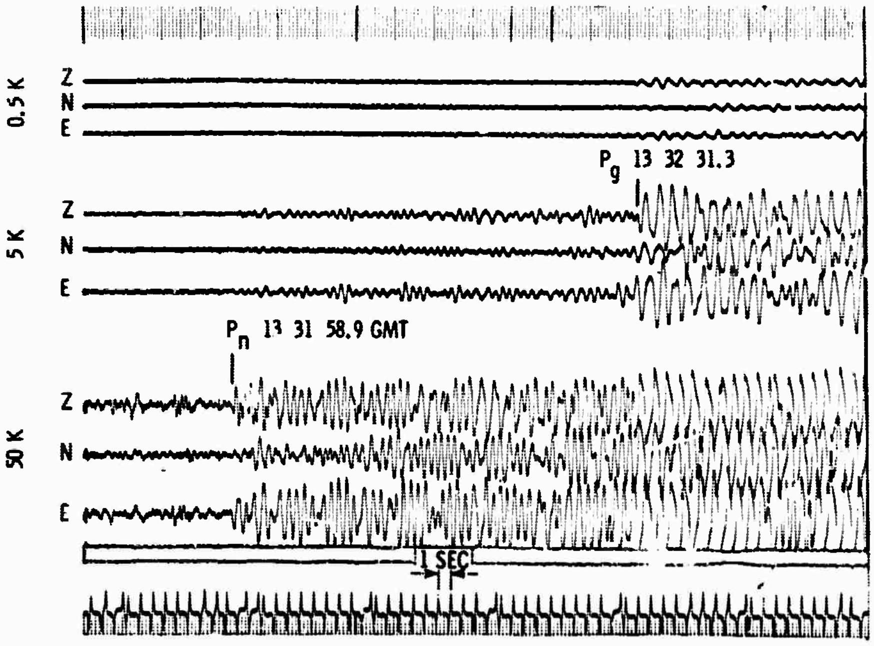
Figure IV-4 shows the near-regional event as recorded by Units 13 and 14. It can be seen that the two units, which were a few feet apart, had essentially identical outputs; showing that the OBS systems will duplicate in the recording of seismic data at the same point in space.

Figure IV-5 shows a teleseism recorded on the two OBS and outside horizontals (Unit 13) and a second teleseism recorded on the OBS components and on an outside vertical (Unit 14). It can be seen that, except for gain differences (due to the difference in sensitivity of the OBS and Benioff Seismometer), the OBS components duplicated the reference mometers almost exactly. Coherences (Figure IV-6) were good over the narrow-band (0.5 to 3 cps) region of high signal-to-instrument noise ratios.

Figure IV-7 shows two local events recorded on Units 13 and 14, respectively. Again, the OBS components duplicated the reference seismometer almost exactly. These events had broadband spectra so that the signal-to-noise ratios were high over essentially the whole 0 to 10 cps frequency band. Figure IV-8 shows the coherences, and it can be seen that the OBS-reference coherences were excellent over the whole band. Note that the N-S coherence was not as good as the E-W coherence because the reference component was recorded on the pressure channel which had a higher system noise level. Also, the vertical coherence was not as good as the horizontal coherences because of the lower signal-to-noise for the event used. These data verify that the OBS records valid seismic data on land.

The low coherence between the OBS and reference verticals at 1.4 cps was due to vibration induced by the tape recorder flywheel rotating in a vertical plane at this frequency. Figure IV-9 shows the power spectra for the OBS and EV-17 verticals. The spectra were similar except for the 1.4 cps peak seen on the OBS vertical, but not the EV-17 vertical; hence the low coherence. To reduce this effect, the shock mounting of the tape recorder has since been improved. In addition, seismic signals are much higher in an ocean bottom environment.

OBS, UNIT 13
13 MAY 1966
ALBUQUERQUE



OBS, UNIT 14
13 MAY 1966
ALBUQUERQUE

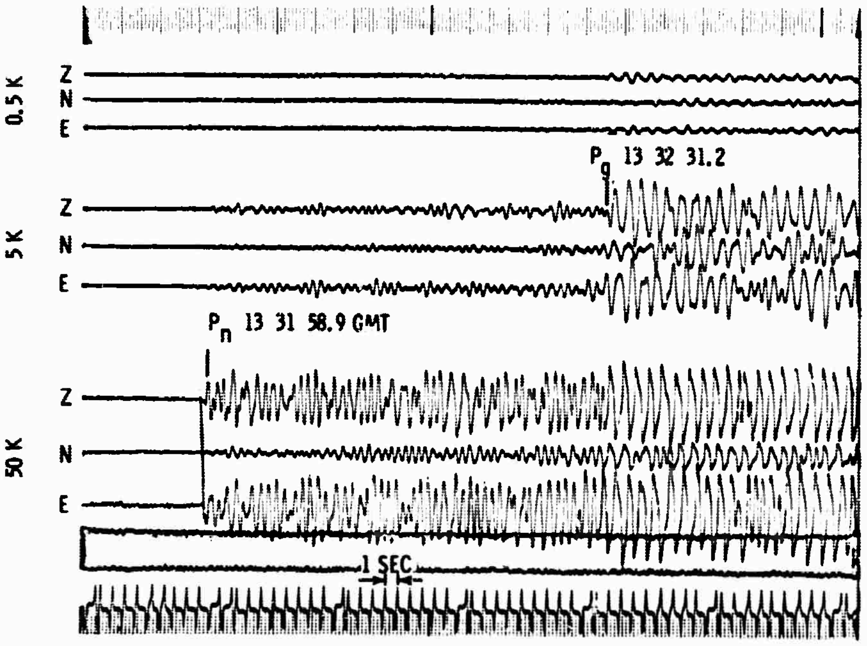


Figure IV-4. Recording of Regional Event on Units 13 and 14.

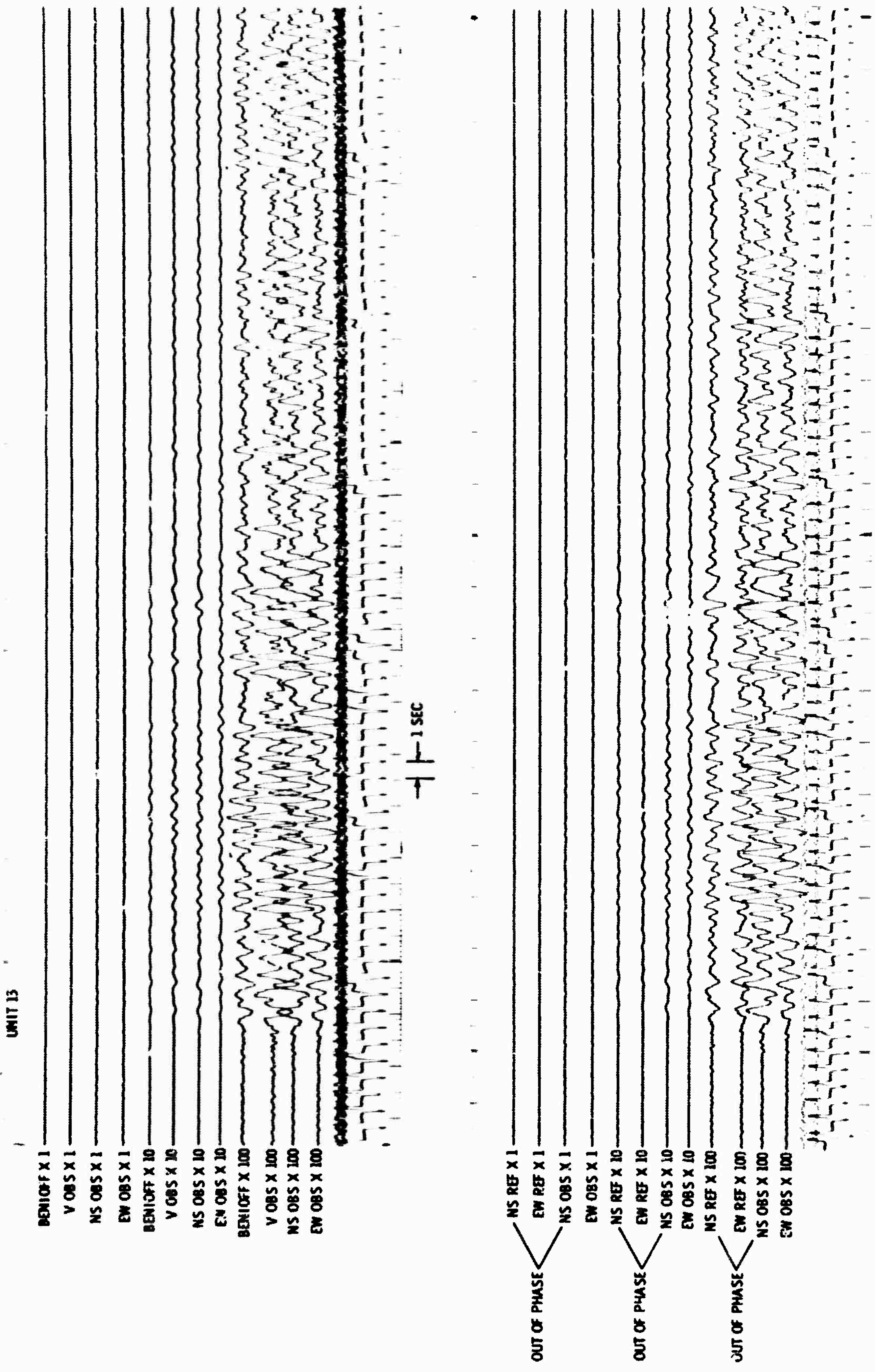


Figure IV-5. Comparison of Teleseisms Recorded on OBS and Reference Seismometers

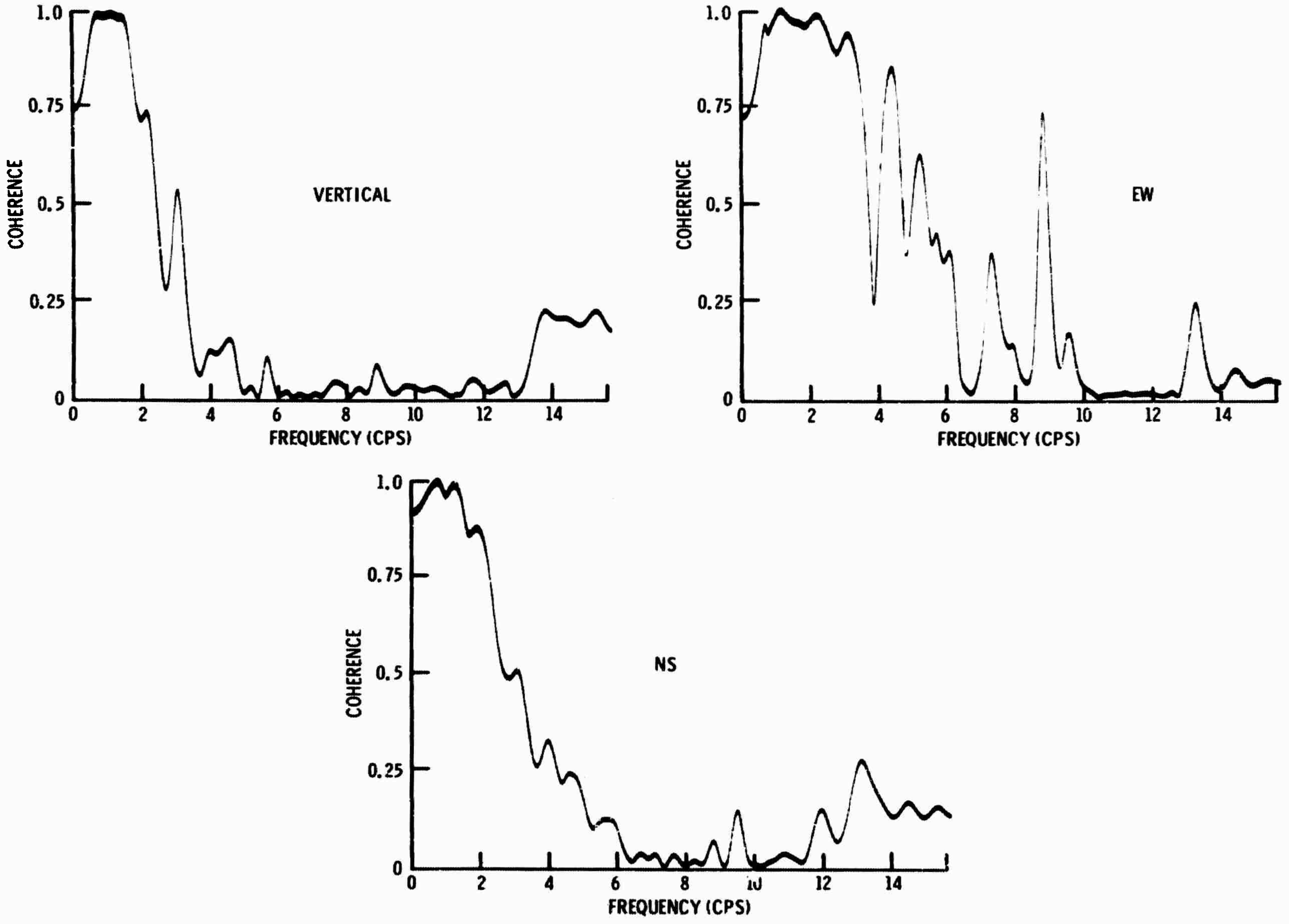


Figure IV-6. Coherences Between OBS and Reference Seismometers for a Teleseism

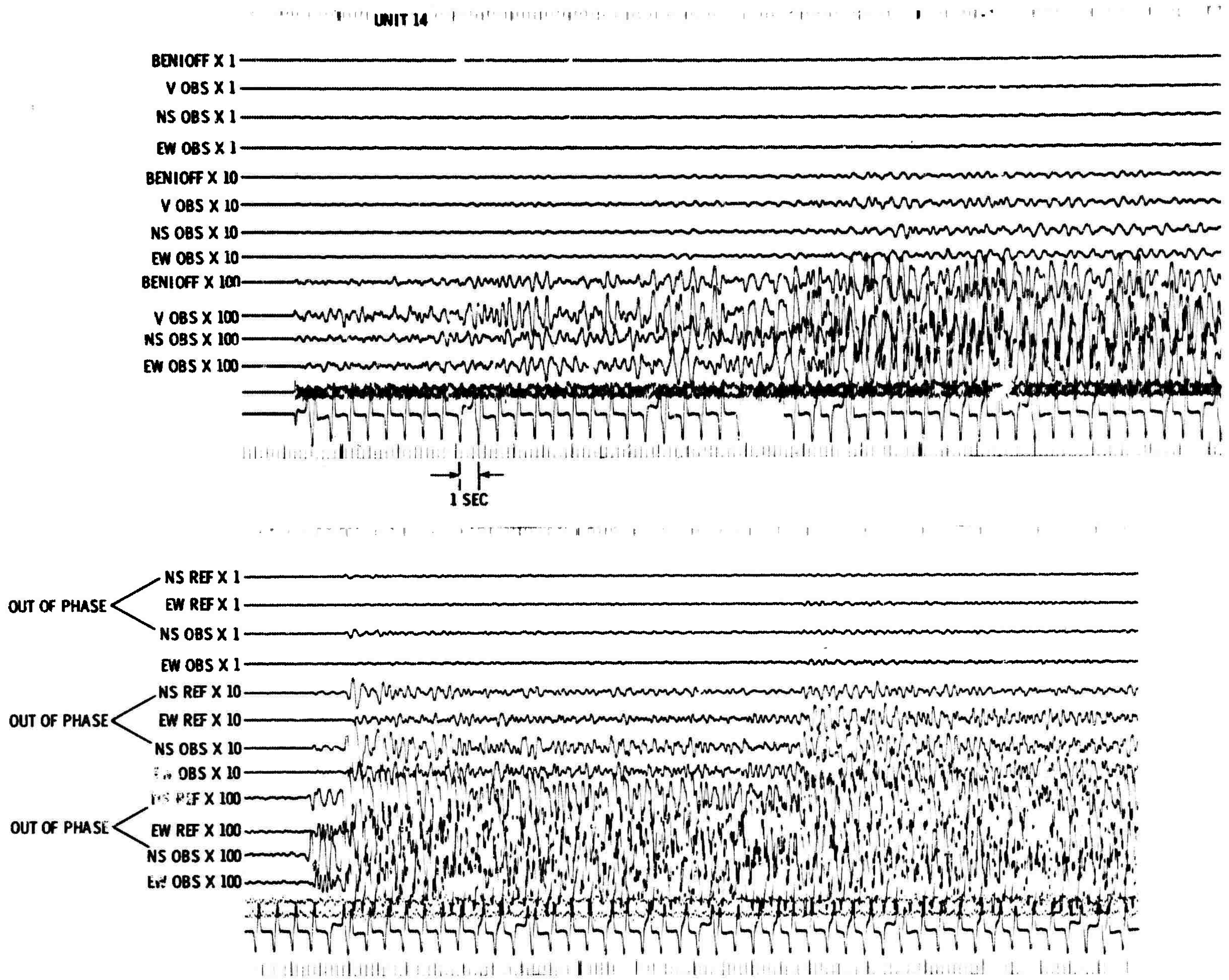


Figure IV-7. Comparison of Local Events Recorded on OBS and Reference Seismometers

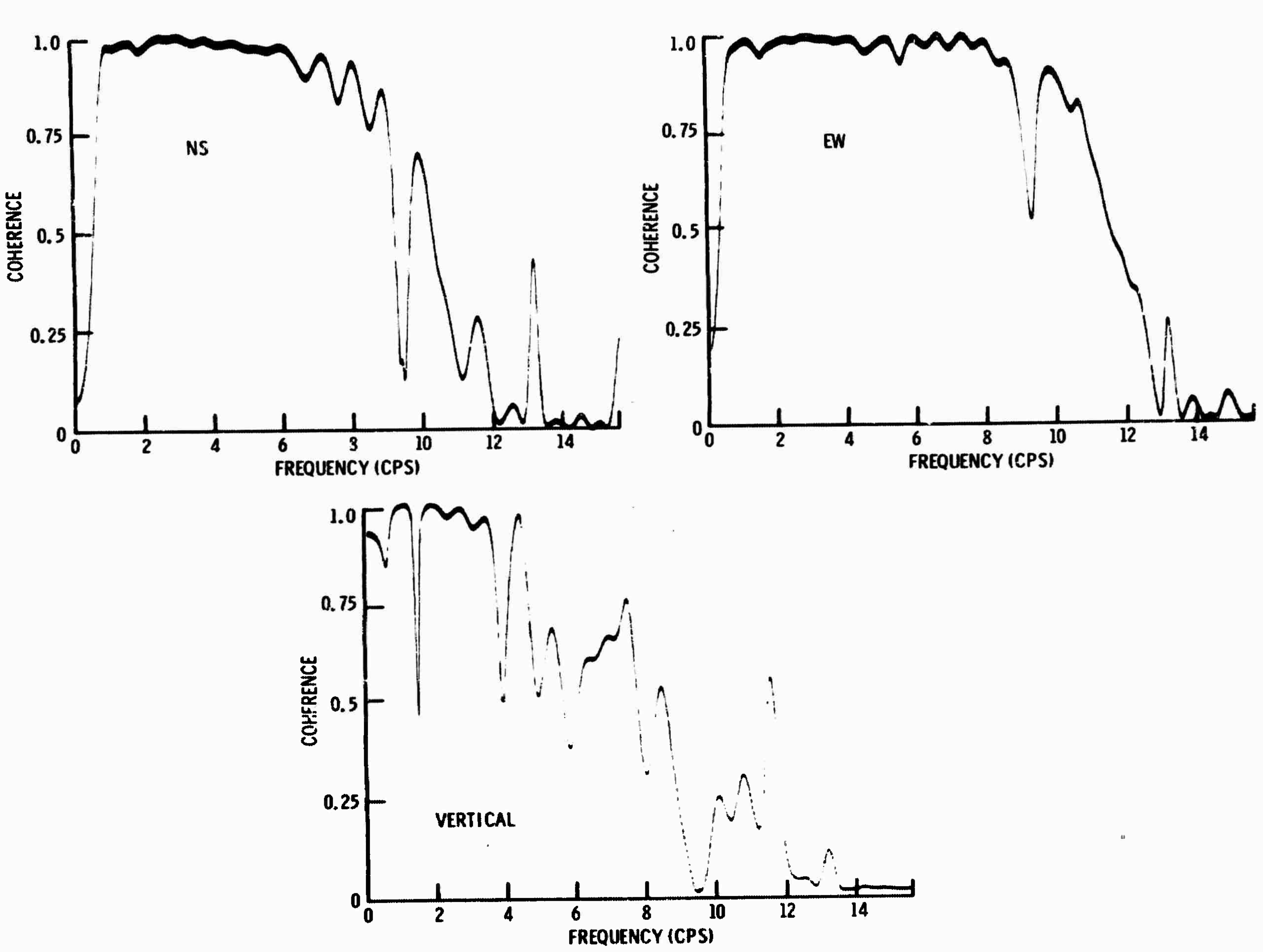


Figure IV-8. Coherences Between OBS and Reference Seismometers for Strong Local Events

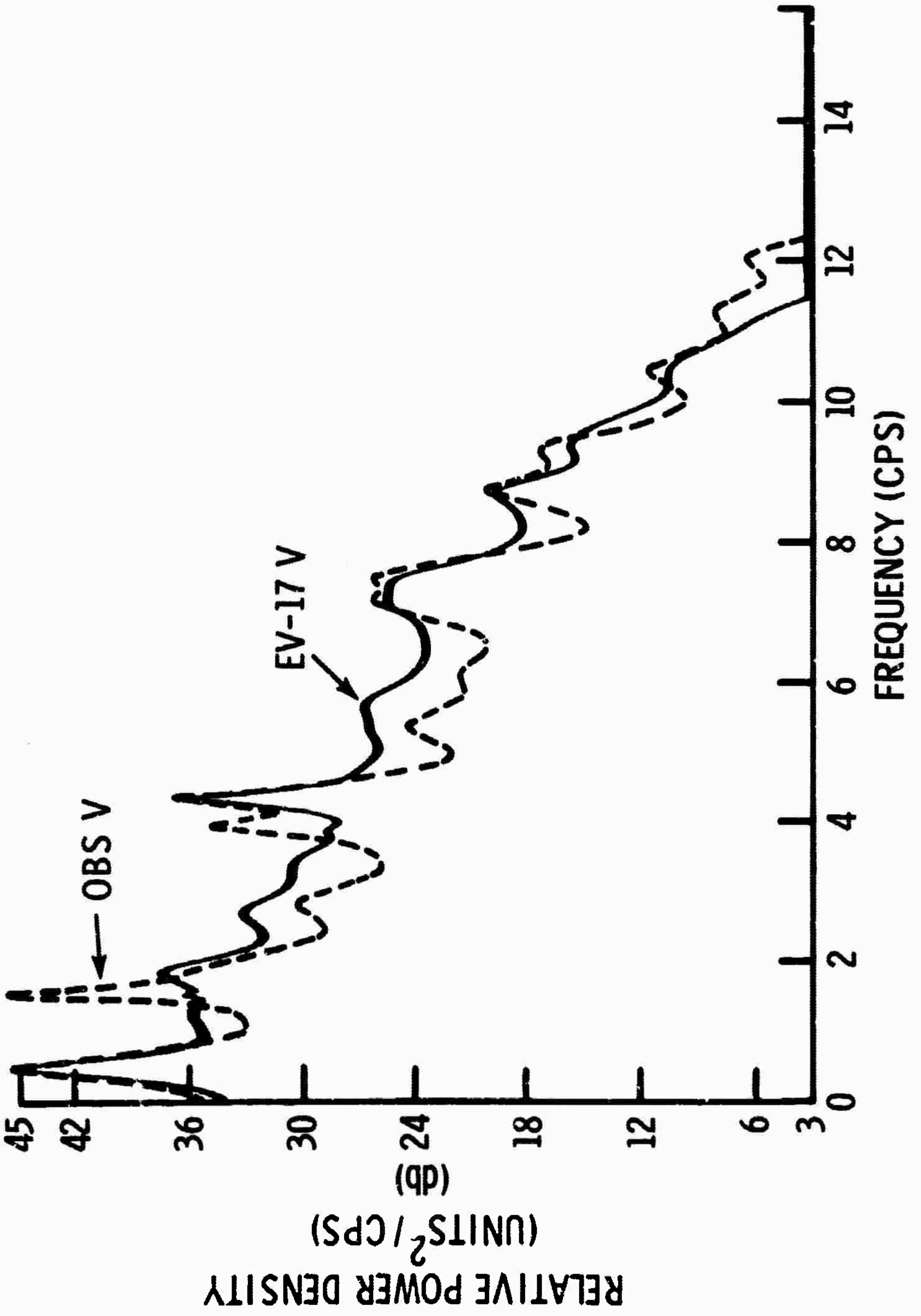


Figure IV-9. A Comparison of EV-17 V and OBS V Power Density Spectra, Showing the Effect of Tape Recorder Vibration

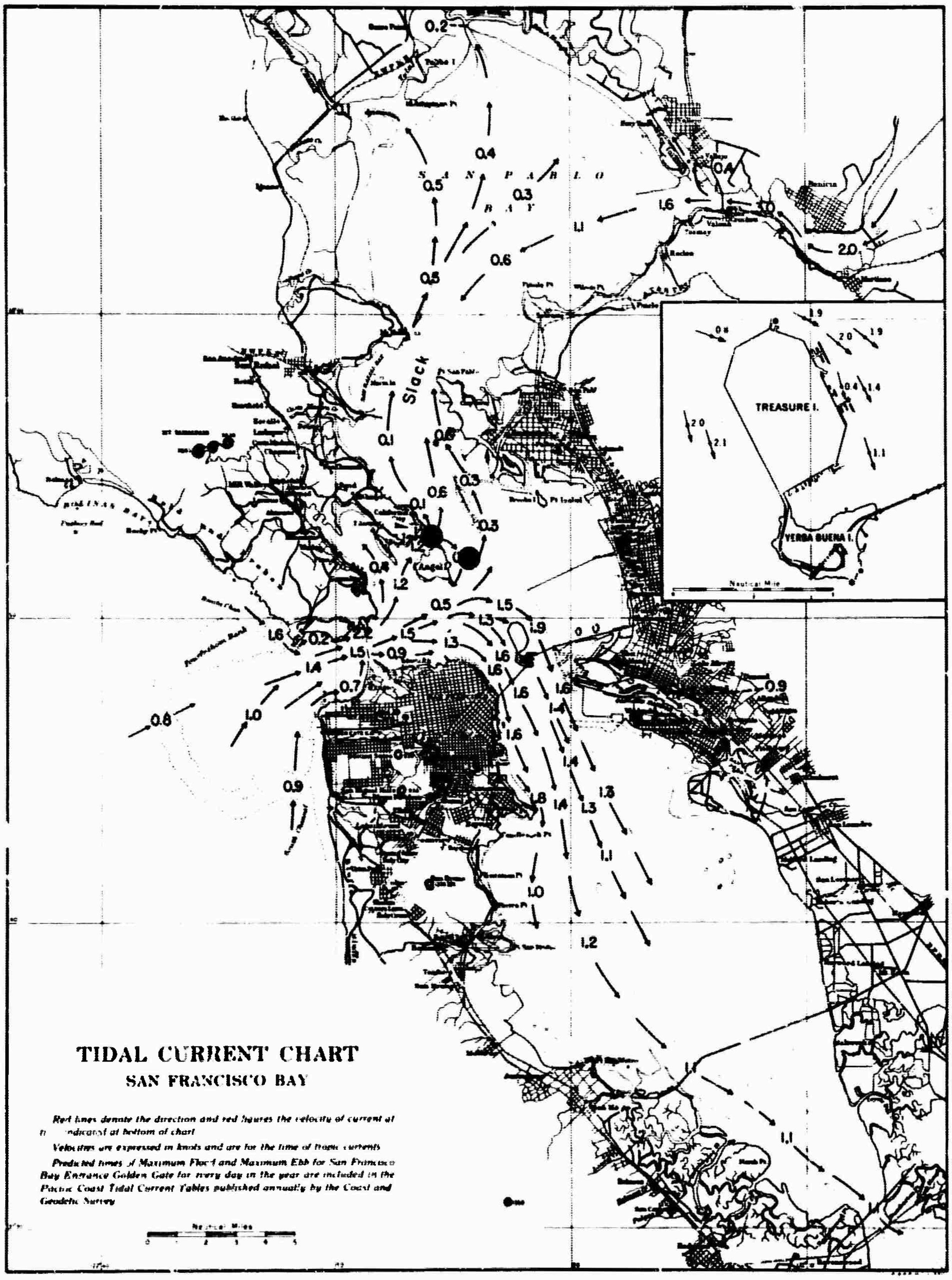
## SECTION V

## SHALLOW AND DEEP WATER TESTS

After completion of the Albuquerque tests, Units 15, 17, 20, 22, and 24 were sent to California for shallow and deep water testing. All five units had the new tape recorder motors. The units were first dropped in about 8[illegible] ft of water in San Francisco Bay (Figure V-1) for a 24-hr period (June 24-25) to check the sonar, tape recorder operation, any leakage problems, and to compare various base configurations. Table V-1 lists the problems that were observed. It was found that recall by sonar was very difficult and apparently was not possible until the sonar transmitter was right over the unit. Examination of the recently added threshold circuit revealed that some redesign was necessary for proper operation. This was immediately accomplished and checked out during the second series of shallow drops, which showed that the redesign was successful (Section III-D).

The failure of the pressure switch on Unit 15 (due apparently to a current overload) was most likely due to improper installation. However, the reliability of the pressure switch is being analyzed at present. Problems with the tape recorder were rectified with minor mechanical adjustments. No other problems were observed.

The second set of shallow drops were made in the same area from June 28 to July 2 to check the sonar to determine the effect of other base configurations and to check general operation. Figure V-2 shows some of the bases used on the two sets of drops and lists all that were tried. As previously stated, the sonar redesign was successful, and sonar recall was easily accomplished. Because of the high noise level in the Bay (which at times, caused even the x1 channels to be overdriven) and because of the overriding problem of the antenna (Section VI), a precise evaluation of the differences due to the various bases could not be made. However, no marked differences were observed among the units, so the standard base was used on all units for the deep tests.



TIDAL CURRENT CHART
SAN FRANCISCO BAY

Red lines denote the direction and red figures the velocity of current at t[illegible] indicated at bottom of chart

Velocities are expressed in knots and are for the time of tropic currents

Predicted times of Maximum Flood and Maximum Ebb for San Francisco Bay Entrance Golden Gate for every day in the year are included in the Pacific Coast Tidal Current Tables published annually by the Coast and Geodetic Survey

Figure V-1. Shallow Drop Areas

CIRCULAR PLATE

"SPIKE"

CIRCULAR PADS WITH WEDGE

| UNIT NO. | JUNE 24-25 | JUNE 28-JULY 2 |
|---|---|---|
| 15 | REGULAR BASE | REGULAR BASE WITH SINGLE LEG EXTENSION |
| 17 | REGULAR BASE | TRIANGULAR PADS |
| 20 | "SPIKE" | REGULAR BASE WITH DOUBLE LEG EXTENSION |
| 22 | CIRCULAR PADS | CIRCULAR PADS WITH WEDGE |
| 24 | CIRCULAR PLATE | CIRCULAR PADS WITH WEDGE |

Figure V-2. Some of the Bases Used During Shallow Testing

## Table V-1

## SUMMARY OF THE SHALLOW DROP PERFORMANCE OF EACH OBS UNIT, 24 to 25 June 1966

| Unit No. | Recovery By: | Electrical Performance | Mechanical Performance | Tape Recorder Performance |
|---|---|---|---|---|
| 15 | SONAR* | Transmitter not working (pressure switch burned) | OK | Tape did not pull (hitting transmitter box) |
| 17 | SONAR* | Transmitter not working (pressure switch burned) | OK | OK |
| 20 | SONAR*<br>DIGITAL CLOCK | OK | OK | OK |
| 22 | SONAR*<br>BULOVA CLOCK | OK | OK | OK |
| 24 | SONAR*<br>BULOVA CLOCK | OK | OK | Take-up reel rubbing transmitter box |

*Sonar recall was difficult

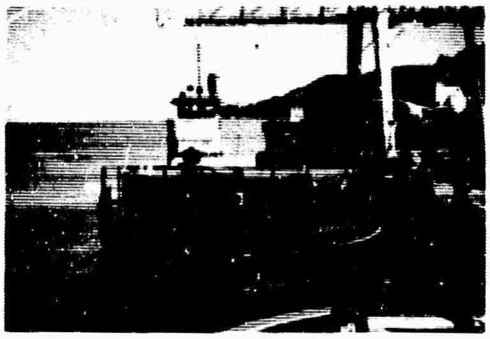
The five units were then loaded on the M/V CALCASIEU (Figure V-3) and dropped off the Farallon Islands (Figure V-4) in about 2000 ft of water. Units 15, 20 and 22 were dropped on July 10. Unit 20 surfaced shortly after it was dropped (due to a side plug leak) and was repaired and dropped with Units 17 and 24 on July 14. Shortly after the July 14 drops, 14 shots were detonated in the drop area (Table V-2). The units were then recalled on July 18; four were recovered within 20 min, but Unit 17 was not found. The ship returned to location at the times that Unit 17 should have surfaced for both the Digital and Bulova clock presets, but the unit was not seen. Thus, Unit 17 either failed to surface or surfaced but was not found.

The data for the four units which were recovered was transcribed to film and analyzed. No electrical or mechancial problems were observed and the tape recorders operated properly in all four units.

Figure V-5 shows that Shot 5 was recorded on all four units. It can be seen that the vertical and pressure channels duplicated very well among units. Note that the pressure channel had good sensitivity. The horizontals apparently resonated at about 5 cps; this was probably related to the antenna resonance problem. All 14 shots were recorded by the four units, and all had characteristics similar to those of Shot 5.

The background noise varied between periods of "normal" ambient noise and periods when the "2 cps" resonance was present (mainly on the horizontals). Figures V-6 and V-7 shows typical data from each period. Spectral analysis showed that the resonant frequencies were slightly different from unit to unit (Table V-3), and also that they changed on a given unit as a function of time (apparently due to changes in frequency of the driving forces).

Also, Figure V-8 shows that there was some (but not exact) correlation between times that the "2 cps" was present on two units. Measurement of the current on the bottom showed it was a fairly substantial 1/2 knot. In the light of the above data and subsequent antenna tests (Section VI), the observed reasonance phenomenon was probably due to current-induced antenna resonance.



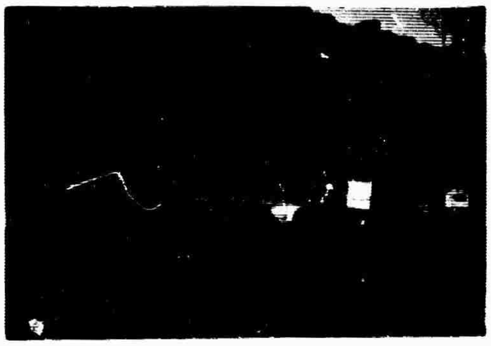


Figure V-3. M/V Calcasieu Used for Deep Drops

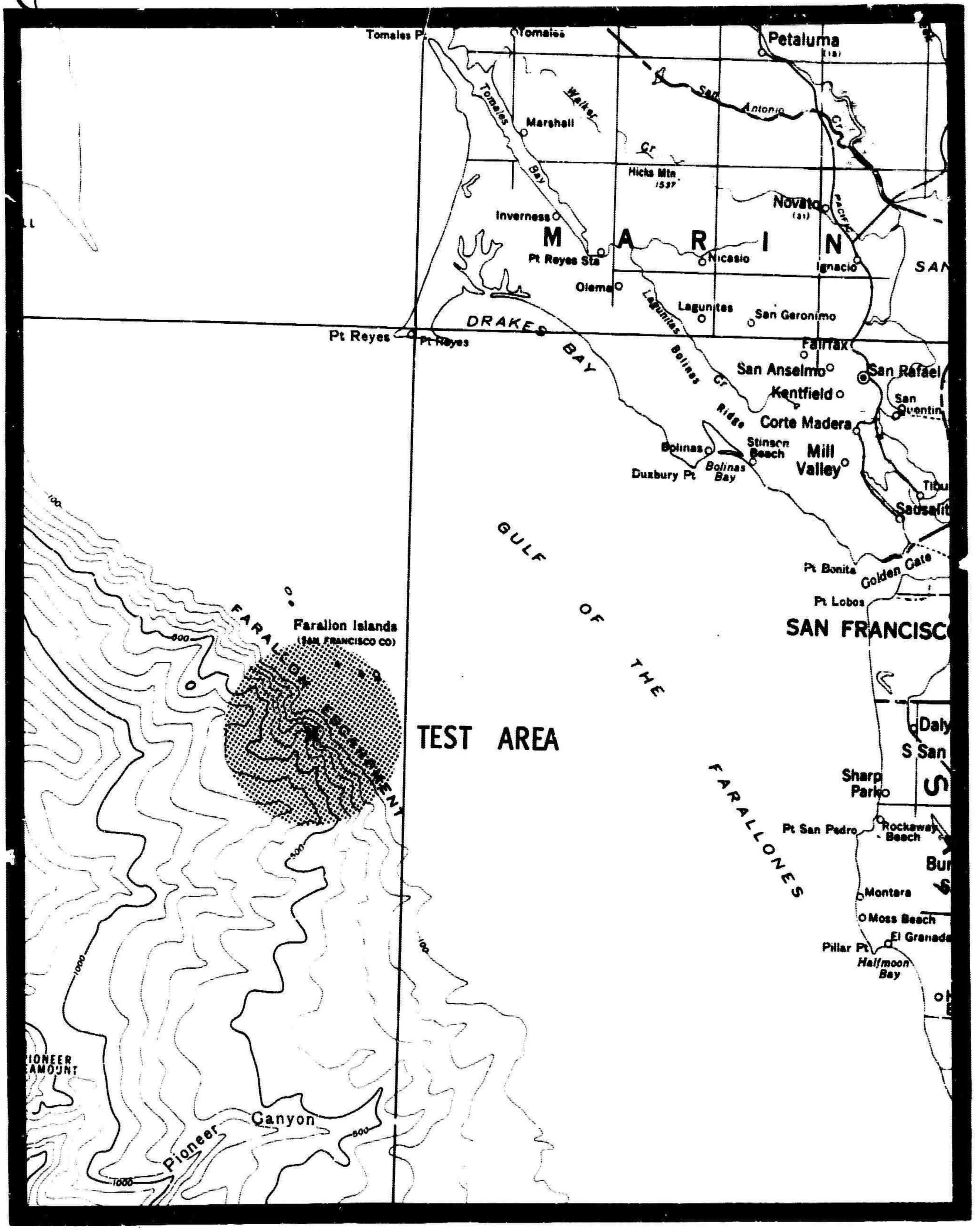


Figure V-4. Location of Deep Drops

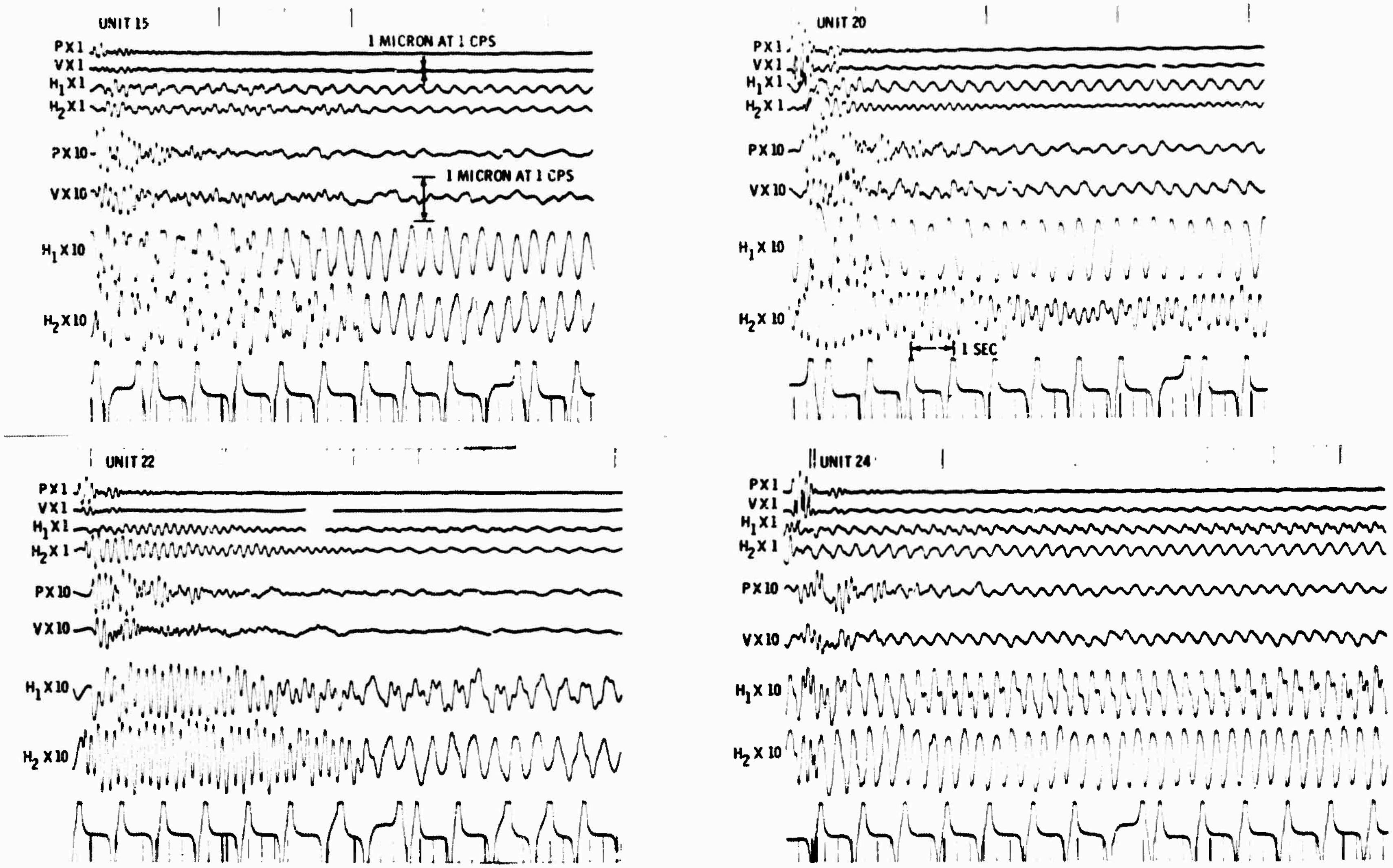


Figure V-5. Shot 5 as Recorded by all Four Units, Deep Drops

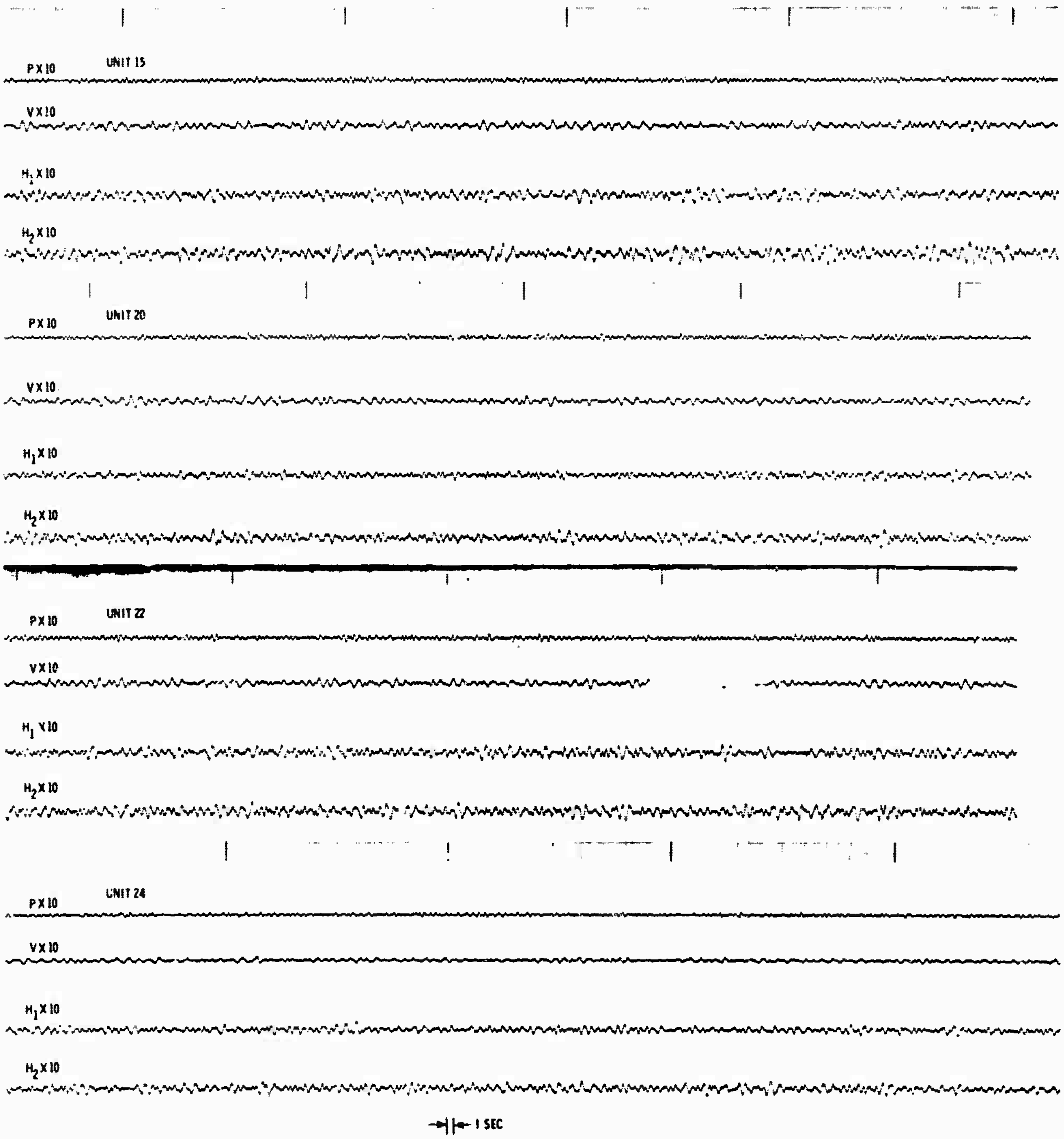


Figure V-6. Simultaneous Noise Samples During a Period of "Normal" Ambient Noise

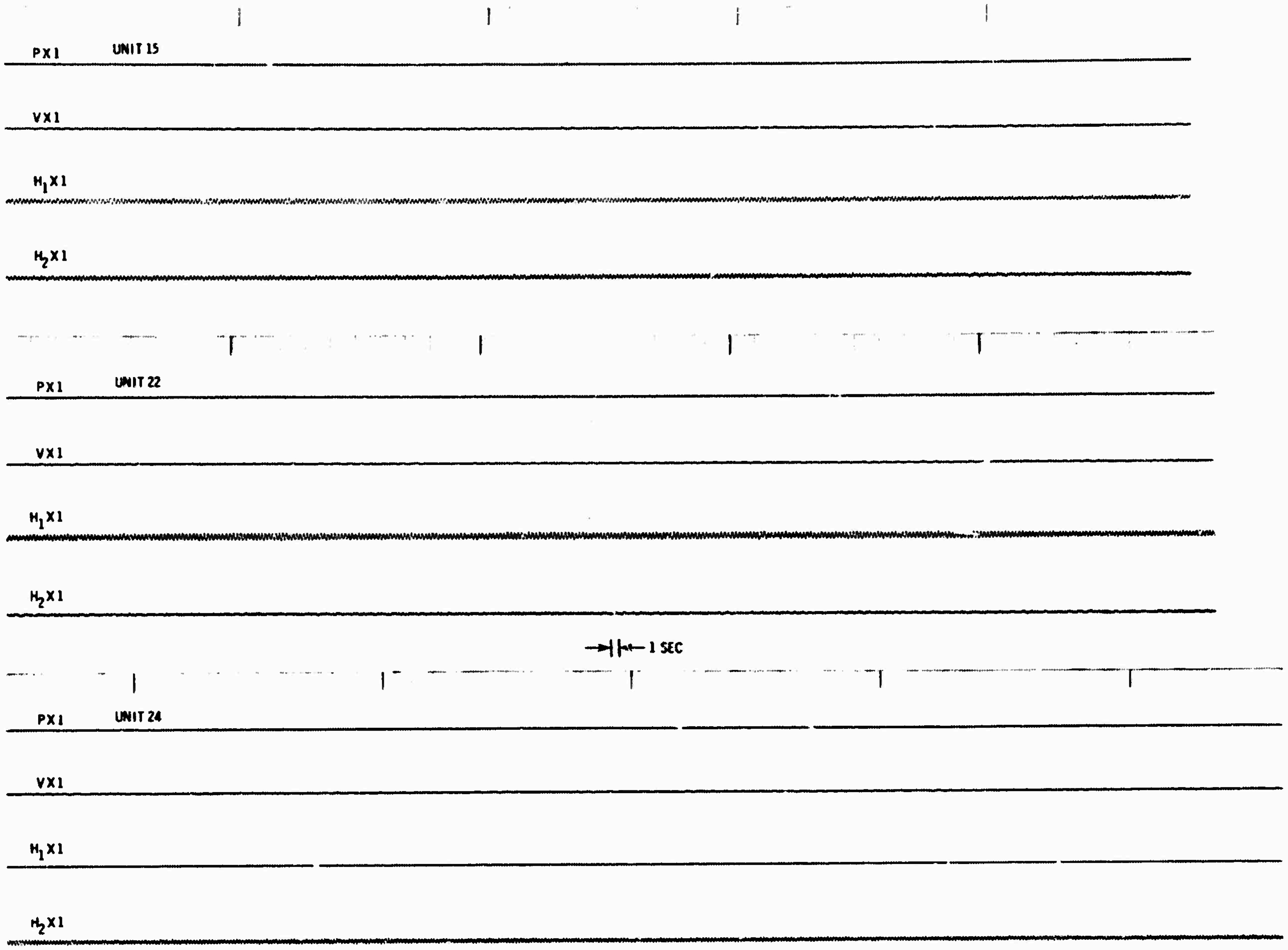


Figure V-7. Simultaneous Noise Samples on Units 22, 15 and 24 During Period When Resonance was Present.

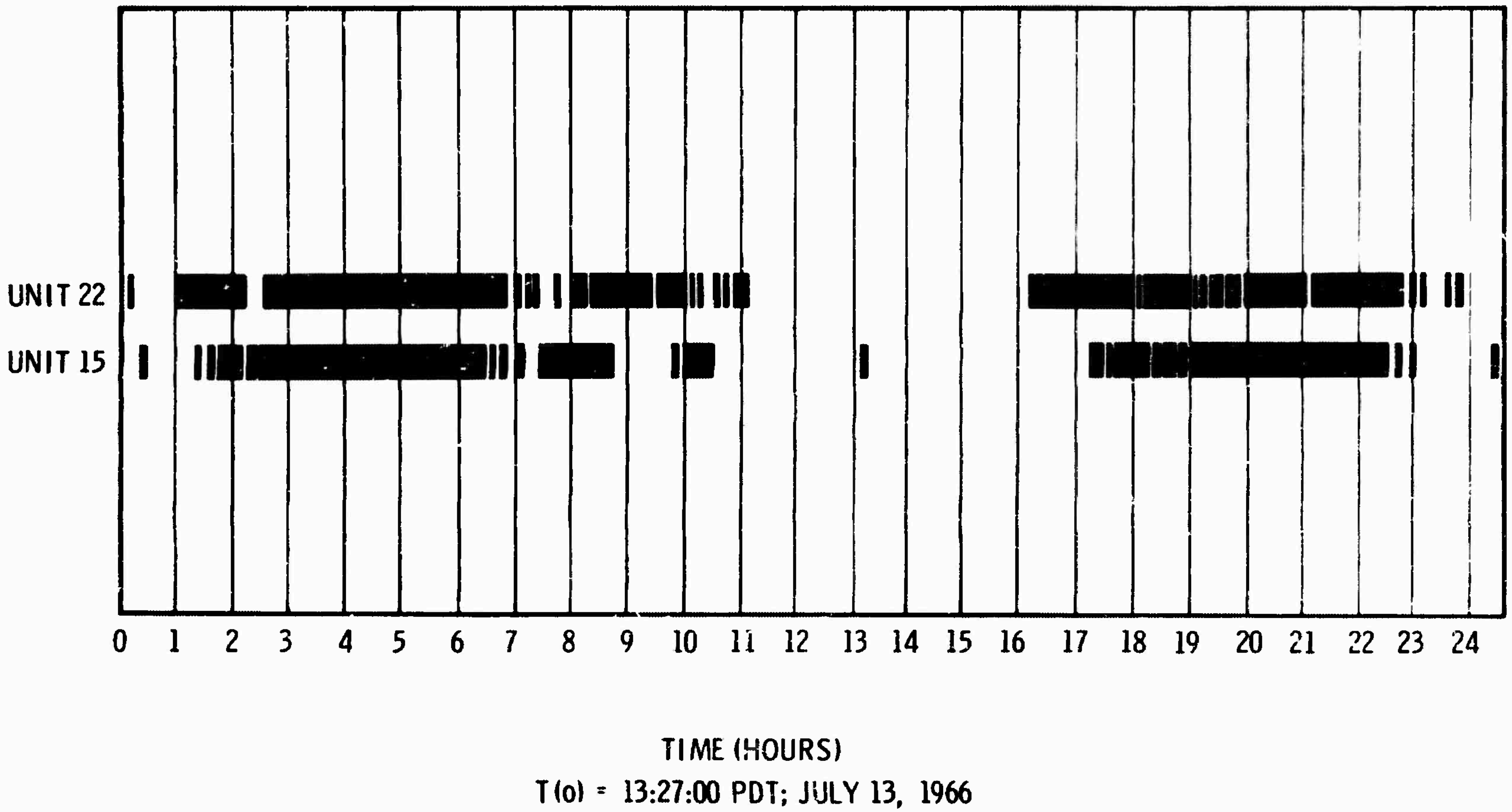


Figure V-8. Correlation of Horizontal 2 cps on Two Units

## Table V-2

## SHOTS DETONATED DURING THE DEEP DROPS

| SHOT NO. | TIME (PDT) ON JULY 14 | SIZE (lb) | LOCATION |
|---|---|---|---|
| 1 | 11:20 | 1 | Overhead |
| 2 | 11:27 | 3 | Overhead |
| 3 | 11:34 | 5 | Overhead |
| 4 | 11:43:30 | 3 | Overhead |
| 5 | 11:52 | 1 | Overhead |
| 6 | 12:26 | 5 | 2 mi S |
| 7 | 12:42 | 10 | 4 mi S |
| 8 | 13:20 | 5 | 2 mi S |
| 9 | 13:41 | 3 | Overhead |
| 10 | 14:01 | 5 | 2 mi N |
| 11 | 14:26 | 10 | 4 mi N |
| 12 | 14:53 | 13 | 4 mi N 40°E |
| 13 | 15:27 | 15 | 6 mi N 40°E |
| 14 | 16:06 | 15 | 9 mi N 40°E |

### Table V-3

### "2 cps" RESONANT FREQUENCIES ON THE FOUR UNITS FOR THE DEEP DROPS

| Unit No. | Resonant Frequency NSA (Simultaneous) | Resonant Frequency NSB (Not Simultaneous) |
|---|---|---|
| 15 | 2.35 | 2.0 |
| 20 | - | 2.25 |
| 22 | 2.3 | - |
| 24 | 2.6 | 2.7 |

For a period of "normal" ambient noise, a 10 min sample was taken simultaneously on all units, and spectral estimates were computed for the pressure and vertical channels (Figure V-9). Both the vertical and pressure spectral were similar among units. In addition, the pressure-to-vertical power ratio was about the same for all units (Figure V-10). The cause of the very low frequency peak seen on all units has not been definitely identified.

Figure V-11 shows the coherence estimates between the pressure and vertical channels for all four units. In general, coherences were fairly high out to about 1 cps (except for the region of very low power between about 0.1 and 0.4 cps) and look fairly similar to previous estimates*. Also, a peak at about 5.75 cps can be seen on all but the Unit 20 coherence (this peak showed on the power spectra also); indicating that propagating energy existed at this frequency. Coherence data above 6 cps should be disregarded due to the low power level. The coherences and power spectra data suggest (but do not prove) that the ocean bottom noise field was space-stationary over the area covered by the units.

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* Schneider, W.A., P.J. Farrell and R.E. Brannian, 1963: Collection and Analysis of Pacific Ocean-Bottom Seismic Data, Texas Instruments Incorporated, February 27.

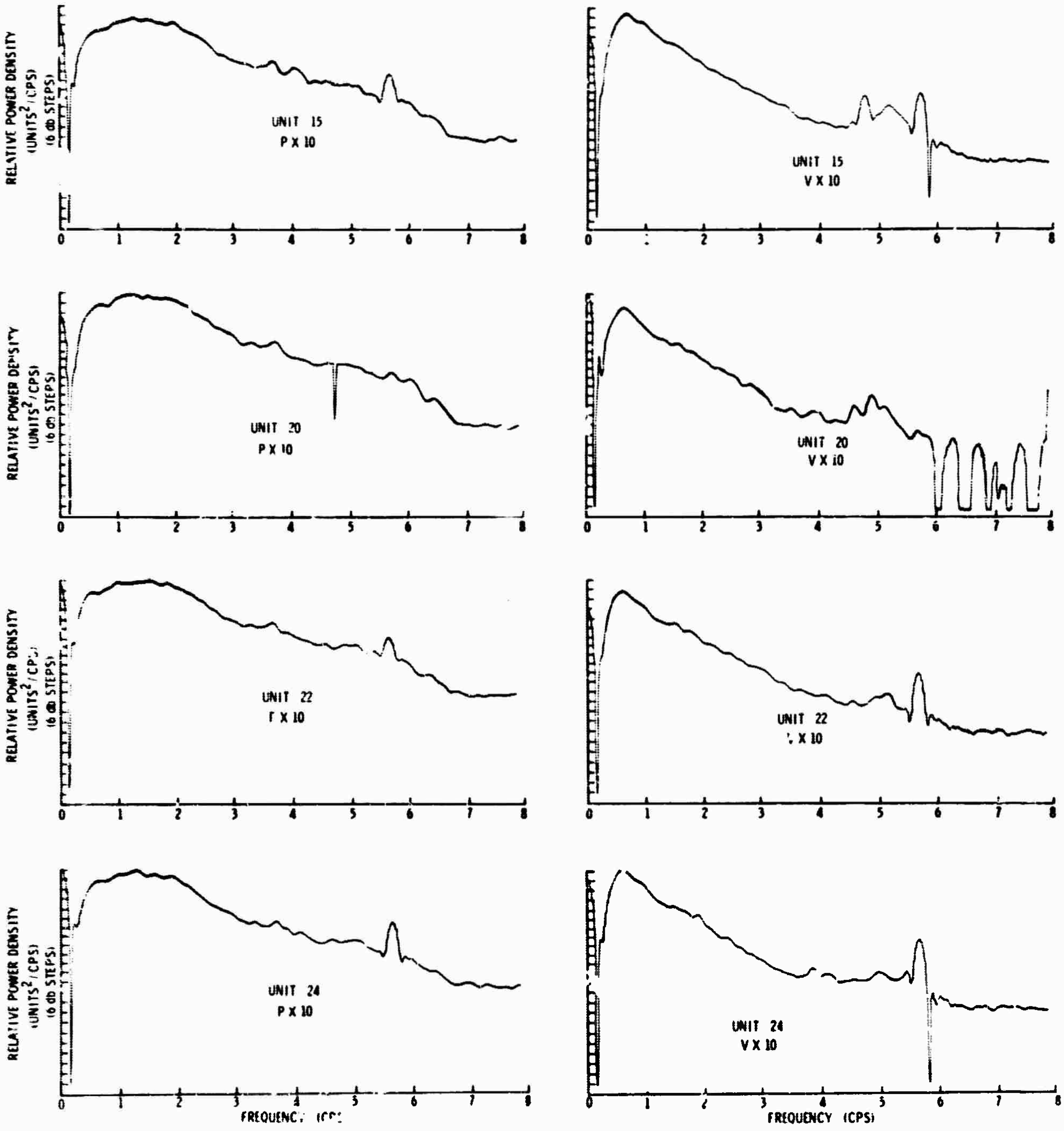

Figure V-9. Pressure and Vertical Power Density Spectra

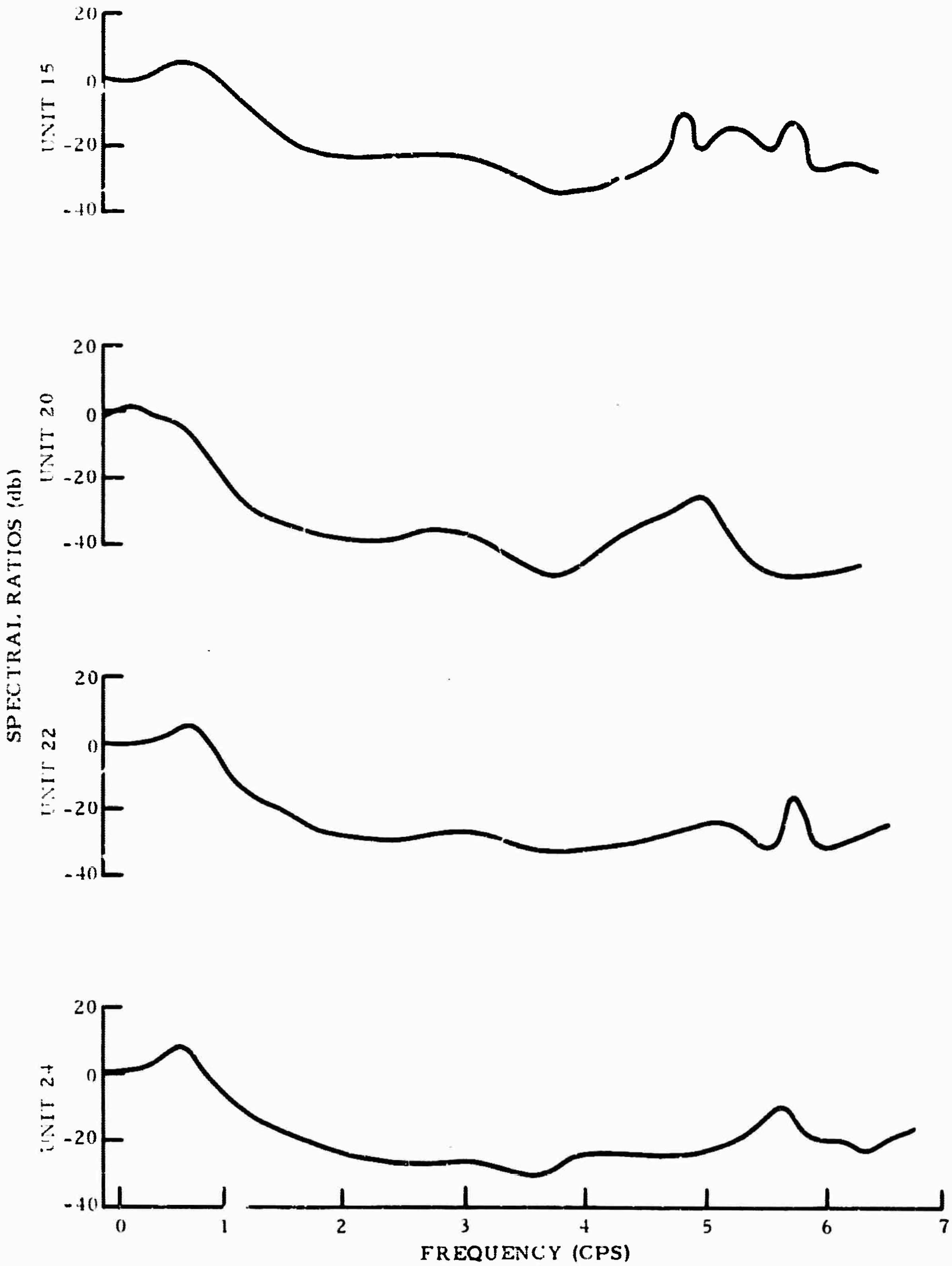

Figure V-10. Vertical-to-Pressure Spectral Ratios

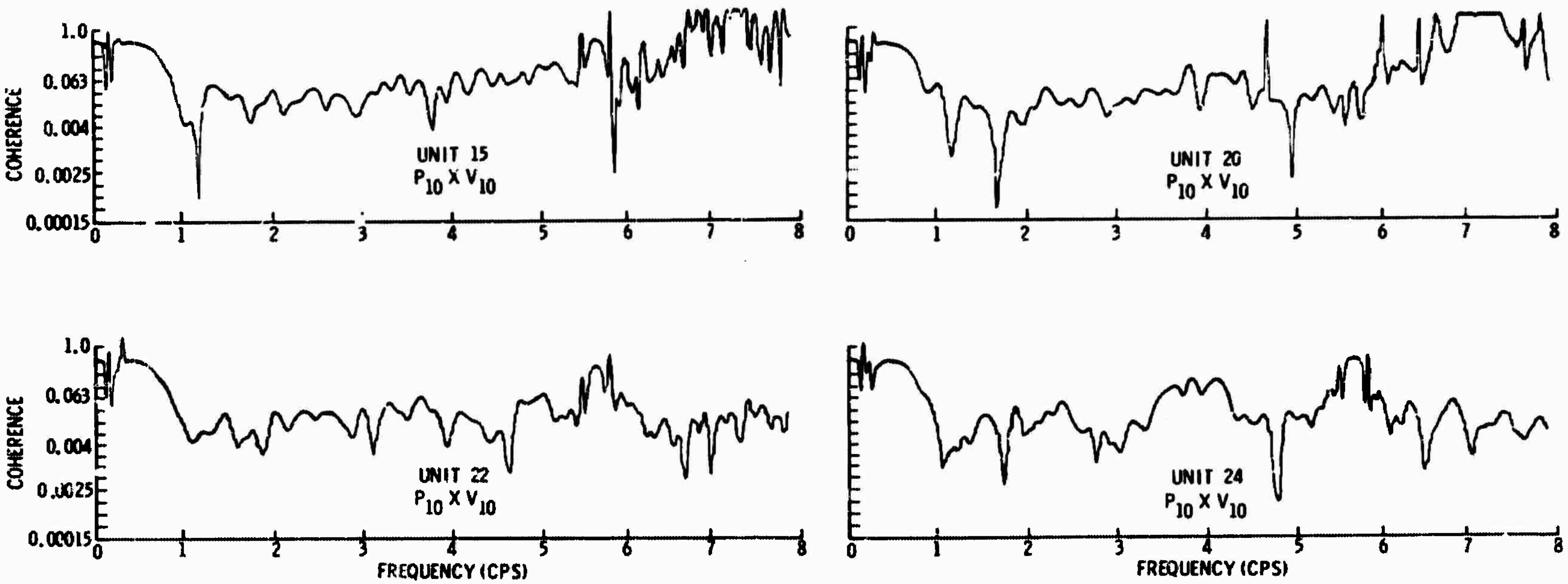

Figure V-11. Pressure-Vertical Coherences for Ambient Noise on all Four Units (Simultaneous Noise Samples)

In summary, the shallow and deep tests showed that the OBS system was basically reliable and that it recorded good data except for the "2 cps" resonance problem which was apparently a current-induced phenomenon.

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## SECTION VI

## ANTENNA TESTS

The "2 cps" resonance observed during the shallow and deep tests had several characteristics consistent with the hypothesis that the resonance was caused by current-induced antenna resonance. These were:

- It occurred primarily on the horizontal components, as would be expected for antenna resonance.
- The phase relationship between the horizontal components varied with time, implying the direction of the excitation force varied with time (which, in turn, implies an energy source external to the package).
- The resonance had a cyclic pattern, repeating on about a 24-hr period, suggesting a relationship with the tides (and tidal currents).
- There was a general, but not exact, correlation of 2-cps periods between units, which would be expected if currents were the source (i. e., the gross properties of the current--weak or strong, etc. would be the same over the area, but there would be significant variations with distance).

Consequently, it was decided to run a test to specifically determine the effect of the antenna.

Units 15, 20, 22, and 24 were used in the test. First, a different antenna was attached to each unit and the antennas' impulse responses were obtained by tapping them (Figure VI-1). The regular and modified antennas resonated strongly at 2.25 and 0.9 cps, respectively; the grey antenna had a weaker but distinct resonance at about 4 cps; the stubby antenna impulse response did not show an obvious resonance. Note also that the energy was coupled into the pressure transducers which recorded the oscillations very distinctly.

The units were then dropped just off the pier at Tiburon (See Figure V-1) on August 6. The antenna configurations, listed in Table VI-1, were changed by a diver at the times listed and recalled on August 11. The data was transcribed onto film and visually analyzed. All units operated properly; the only problems were that the H component of Unit 24 was dead and the $H_1$X10 channel of Unit 22 had a defective amplifier which caused a 12 cps "rider" to appear on the data. (the source of the 12 cps is not known).

## Table VI-1

## ANTENNA CONFIGURATION

| | UNIT 20 | UNIT 24 | UNIT 15 | UNIT 22 |
|---|---|---|---|---|
| Land Calibration Tests | Modified | Stubby | Grey | Regular |
| 0-48 hr | Regular<br>1 | Modified<br>2 | None<br>3 | None<br>4 |
| 48-72 hr | Modified<br>☐ | Regular<br>☐ | Stubby<br>☐ | None<br>☐ |
| 72-96 hr | Stubby<br>☐ | Grey<br>☐ | Stubby<br>☐ | Regular<br>☐ |
| 96-120 hr | Same as above with buoy attached directly to the bail | | | |

Figure VI-2 shows simultaneous noise samples from units with the regular and modified antennas and two units with no antennas. A strong, 2.4 cps, resonance on the horizontal components of the unit with the regular antenna can be seen. No indication of this is seen on the other units. Figure VI-2 is a typical example of a 4- to 5-hr period observed during both days that the four units had the first antenna configuration. Thus, at certain times (as was observed in the previous tests) the regular antenna resonated at 2.0+ cps and corrupted data on the horizontal components.

Figure VI-3 shows simultaneous noise samples during a period when considerable high-frequency energy was present. Here the stubby antenna resonated at about 4 cps, which apparently is its resonant frequency (although this is not obvious from the impulse response). The modified antenna resonated at about 6 cps, which is probably the first overtune of the 0.9 cps fundamental*. Although high frequency energy was recorded on both the unit with no antenna and that with the regular antenna, they had no indication of resonance. Figure VI-4 shows simultaneous noise samples during a period when the grey antenna was attached to Unit 24. Severe resonance at about 4 cps (which the impulse test indicated was the resonant frequency for this antenna) can be seen on the horizontal. Also, there appears to be less severe vertical resonance during the time. Thus, for all the antennas used, there were period when current-induced antenna resonance corrupted the data on the horizontal channels.

As a result of these tests the antenna was redesigned. Two configurations were considered: a wrap-around and a retractable model. It was decided that the wrap-around would be more reliable and so it will be used in the program now underway.

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*Morse, 1948: Vibration and Sound, McGraw-Hill, p. 153.

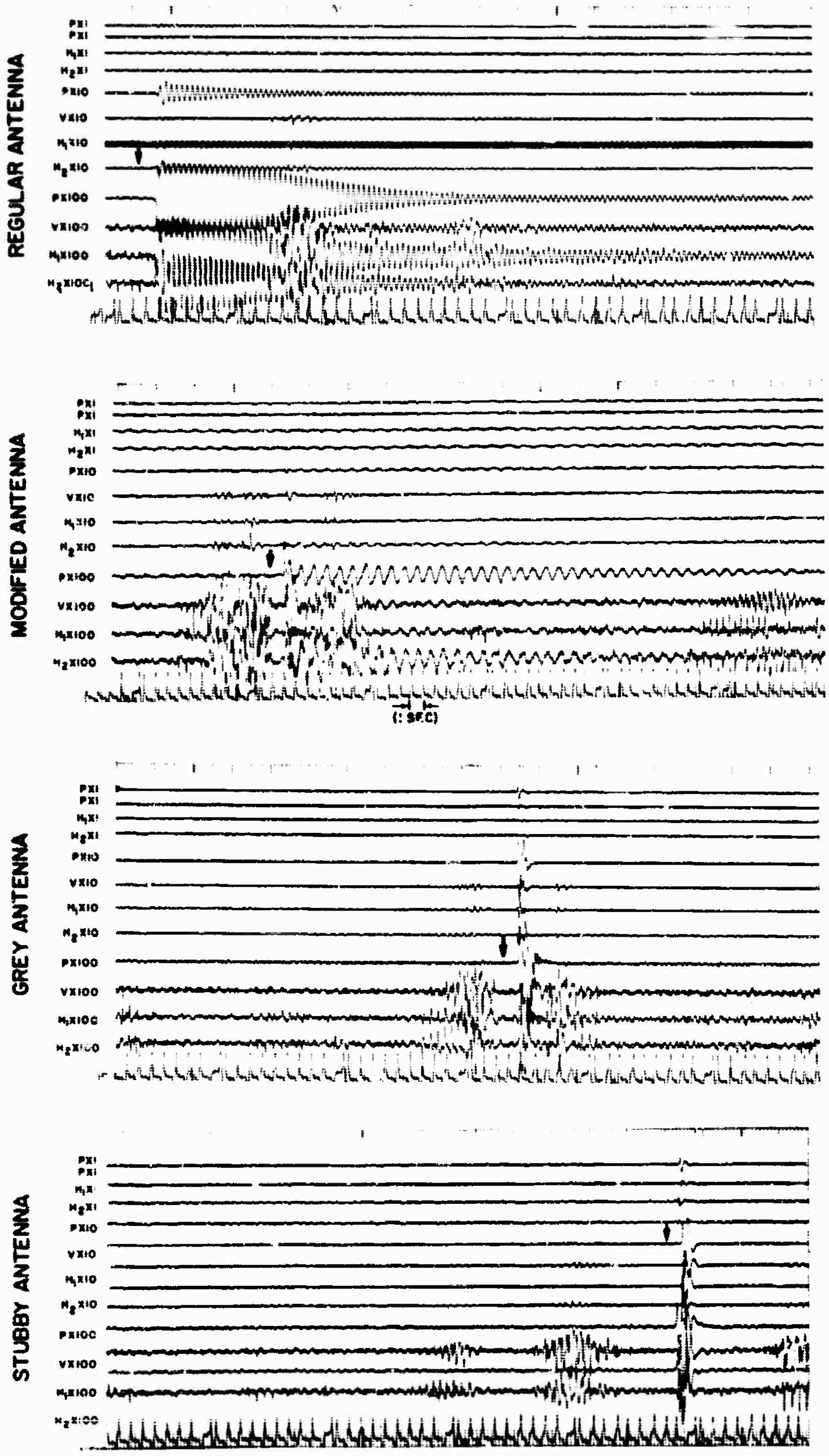
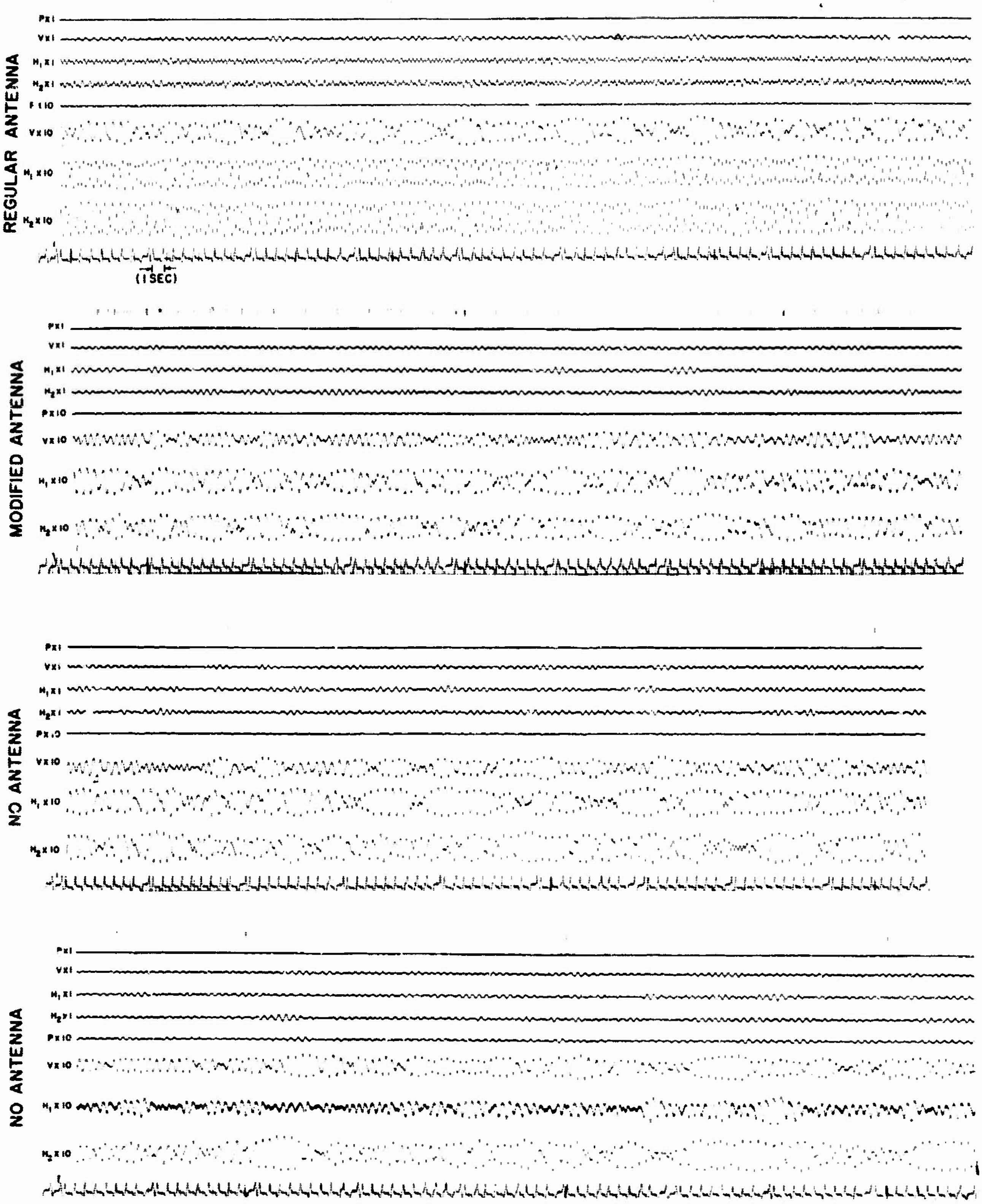


Figure VI-1. Impulse Responses of Four Different Antennas



VI-2. Simultaneous Noise Sample Showing 2.4 cps Horizontal Resonance on the Unit with a Regular Antenna

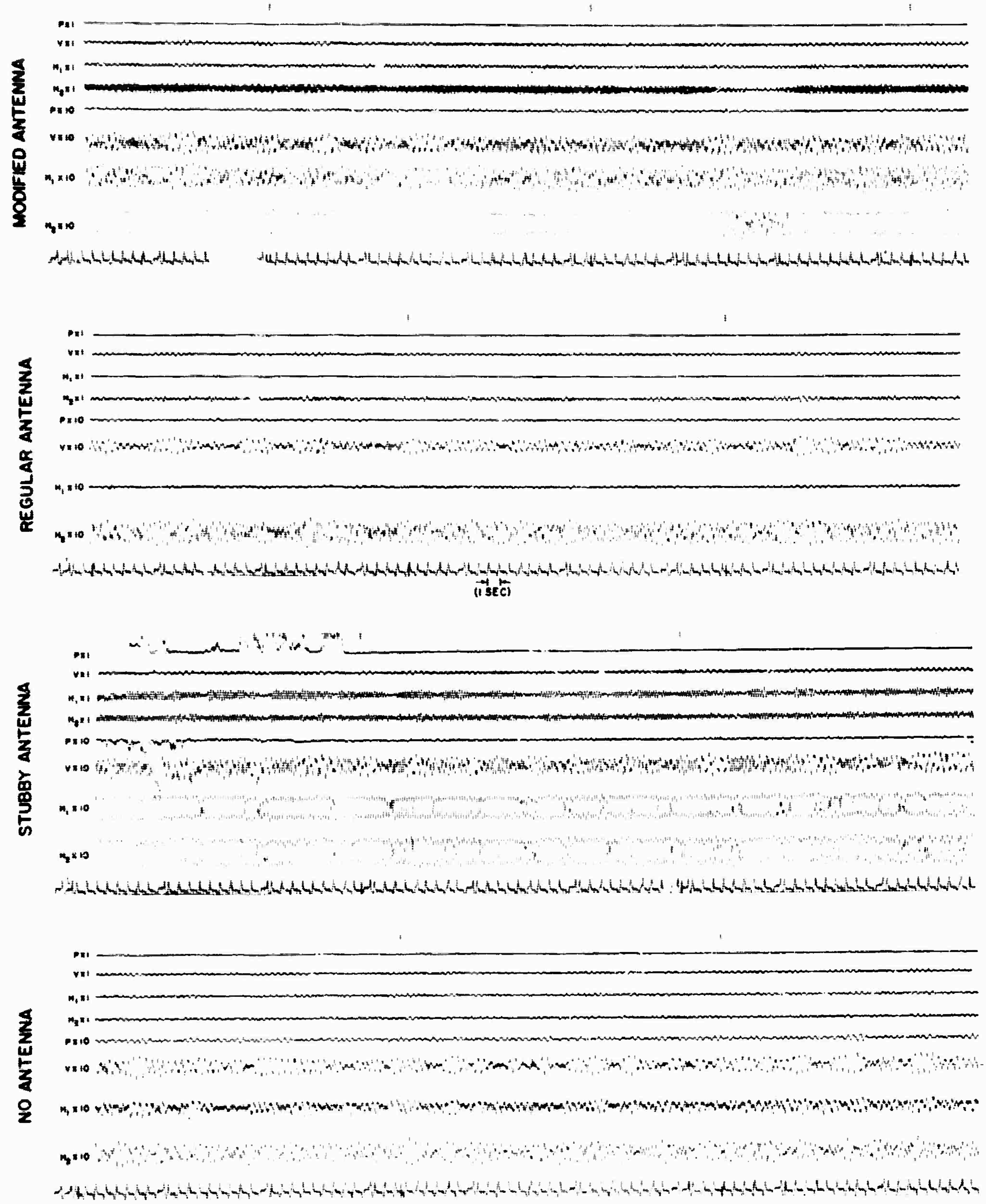


Figure VI-3. Simultaneous Noise Sample Showing Horizontal Resonances On Units With the Modified and Stubby Antennas

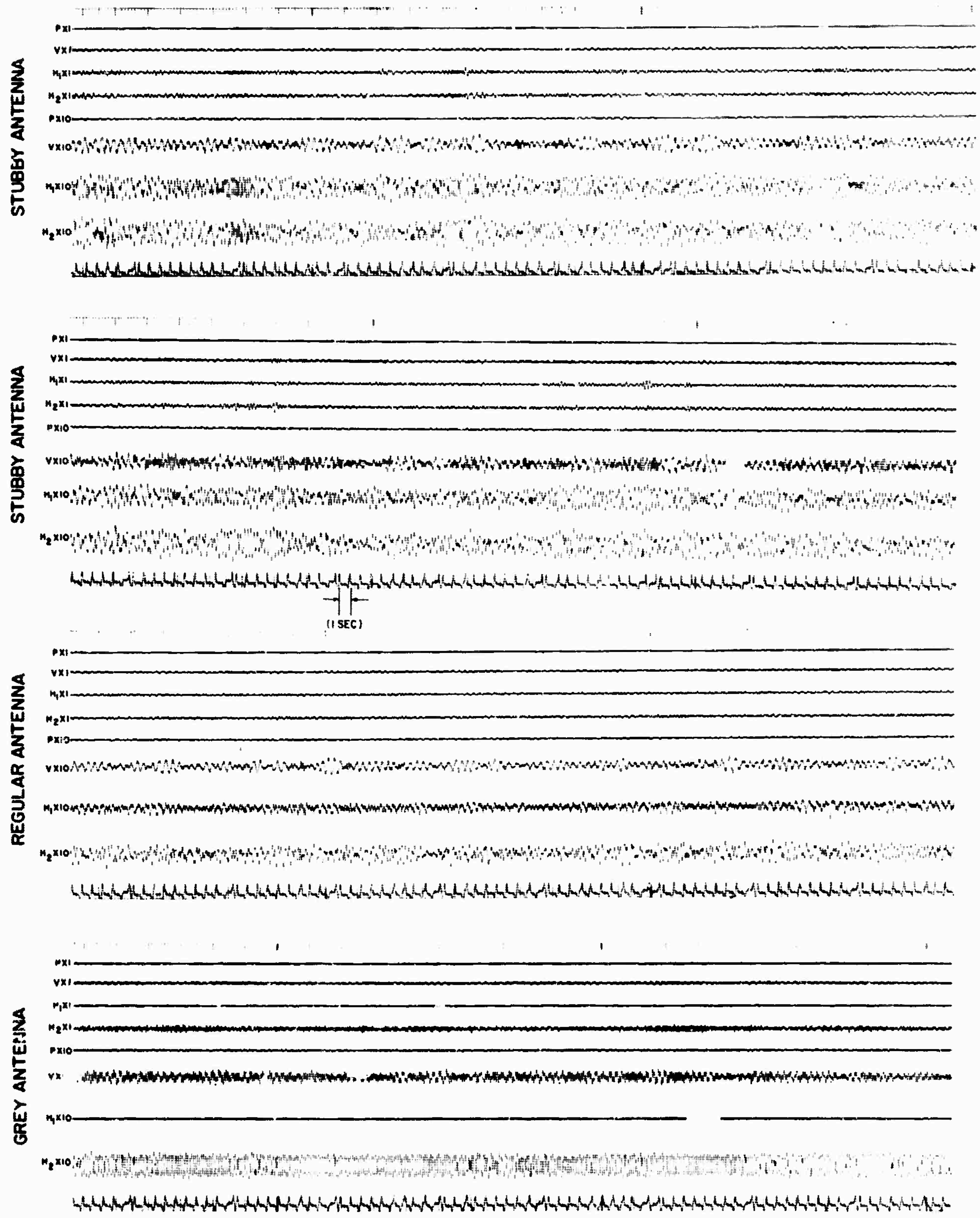


Figure VI-4. Simultaneous Noise Sample Showing Horizontal Resonance on Unit With "Grey" Antennas

## SECTION VII

## CONCLUSIONS

The testing program served to check out two modifications made previously:

- The increase in the pressure transducer sensitivity brought it to a recording level comparable to the velocity components for ocean bottom data
- The sonar threshhold circuitry is operating properly

The testing program also resulted in the following modifications:

- Addition of an 8-cps high-cut passive filter ahead of the preamplifier to electrically reduce high frequency noise due to vibration
- Replacement of the Barber-Coleman tape recorder motor with a Sperry-Farragut motor which has a lower effective noise level
- Stabilization of the tape recorder assembly and improvement of the shock mounting of the tape recorder, both to reduce vibration
- Redesign of the antenna to eliminate horizontal resonance

As a result of the testing program, the OBS system appears to be ready for an operational program.

# APPENDIX A

# SPECIFICATIONS OF THE SPERRY FARRAGUT BRUSHLESS D-C MOTOR

# APPENDIX A

## SPECIFICATIONS OF THE SPERRY FARRAGUT BRUSHLESS D-C MOTOR

The following are Texas Instruments specifications for the tape recorder motor which were met by the brushless d-c motor, parts number 490-200, manufactured by the Sperry Farragut Co.

- Operating Voltage — 12 v-dc
- Speed — 2400 rpm
- Torque — 0.05 to 0.10 in. oz
- Bearings — ABEC 7
- Shaft — 303 Stainless
  - Length - 5/3 in.
  - Straightners - ± 0.005 in.
  - No Flats or Keyways
  - Outside Diameter Not Less Than Bearing Bore (OD) Minus 0.0005
- Weight — Less than 7 oz
- Mounting — Four evenly-spaced threaded studs on bolt circle concentric within 0.005 in. of shaft center line. Shaft will be perpendicular to mounting face/end place/within ±30 min of arc.
- Dynamic Balance — Typically 100 μin. oz
- Power Connection — Two leads marked plus and minus
- Shock — 15 G in each of 3 orthogonal directions
- Environment
  - Temperature - 0° C to 60° C
  - Humidity - 95 percent salt air
  - Altitude - 4 in. mercury
- Life — 10,000 hr.
- Direction of Rotation — Counterclockwise viewed from shaft end

- Bearings will survive constant radial load of 16 oz and constant thrust loads of 8 oz for 10,000 hr

# APPENDIX B

# REPORTS SUBMITTED FOR OCEAN BOTTOM SEISMOMETER

## APPENDIX B

## REPORTS SUBMITTED FOR OCEAN BOTTOM SEISMOMETER

| | | | |
|---|---|---|---|
| AF 19(604)-8368 | 9/18/61 | Automatic Marine Seismic Monitoring and Recording Device, Semiannual Technical Report No. 1 | Davis |
| AF 19(604)-8368 | 3/1/62 | Special Report on the Program to Research, Develop, Construct and Test an Automatic Marine Seismic Monitoring and Recording Instrument | Rokke |
| AF 19(604)-8368 | 4/23/62 | Automatic Marine Seismic Monitoring and Recording Device, Semiannual Technical Report No. 2 | Baker |
| AF 19(604)-8368 | 4/27/62 | Preliminary Evaluation of Records from TI-Ocean-Bottom Monitoring and Recording Instrument | Murdock |
| AF 19(604)-8368 | 4/27/62 | Ocean-Bottom Seismometer Data Analysis Program, Semiannual Technical Report No. 3 | Rokke |
| AF 19(604)-8368 | 1962 | Automatic Marine Seismic Monitoring and Recording Device | Thompson<br>Schneider |
| AF 19(604)-8368 | 3/15/63 | Advanced Ocean-Bottom Seismometer, Semiannual Technical Report No. 4 | Farrell |
| AF 19(604)-8368 | 5/11/63 | Ocean-Bottom Seismometer Tests at Uinta Basin Observatory and Lake Pend Oreille, Special Report | Farrell |
| AF19(604)-8368 | 11/14/63 | Ocean-Bottom Seismometer Data Collection and Analysis, Semiannual Technical Report No. 5 | Farrell |

| | | | |
|---|---|---|---|
| AF 19(604)-8368 | 10/12/64 | Ocean-Bottom Seismometer Data Collection and Anaylysis, Final Report | Schneider |
| AF 19(628)-4075 | 7/20/64 | 30-Day Ocean-Bottom Seismograph, Semiannual Technical Report No. 1 | Farrell |
| AF 19(628)-4075 | 2/5/65 | 30-Day Ocean-Bottom Seismograph, Semiannual Technical Report No. 2 | Farrell |
| AF 19(628)-4075 | 10/31/65 | 30-Day Ocean Bottom Seismograph Aleutian-Kurile Operations, Final Report | Schneider |
| AF 19(628)-4075 | 3/4/66 | 30-Day Ocean-Bottom Seismograph Shallow and Deep Water Tests, Final Report Supplement | Guidroz<br>Kimler<br>Harley |

The following papers on the ocean-bottom seismometer have also been presented

Schneider, W.A., P.J. Farrell and R.E. Brannian, 1964, Collection and Analysis of Pacific Ocean-Bottom Seismic Data: Geophysics v. XXIX, n. 5, Oct. p 745-771

Coburn, H. (with Buford Baker) 1965
A Vehicle for the Ocean-Bottom Seismograph: Paper Presented to Dallas Chapter, American Society of Mechanical Engineers, January 12.

Arnett, R.A. and T.W. Newhouse, 1965, Ocean-Bottom Seismograph: PROCEEDINGS OF THE IEE v. 53, no. 12. Dec.

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4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

Final Report; 1 February 1966 to 30 November 1966

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Harley, Terence W.
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13. ABSTRACT

Dallas modifications and tests, Albuquerque land tests, shallow and deep water tests off the coast of California, and antenna tests were run to prove that the Ocean-Bottom Seismograph is a practicable seismograph.

Dallas modifications included pressure switches added to the radio transmitter and the beacon light. A new high-precision motor was added to the tape recorder. Pressure transducer sensitivity was increased by approximately 20 db. The trigger board was redesigned for sonar recall. The U-joint, battery boxes, bottom and side plugs, and secondary release were also modified, and an input filter was added.

Albuquerque land tests showed almost exact duplication between OBS data and that from adjacent reference seismometers.

Shallow and deep water tests showed that the unit was basically reliable, but showed a resonance problem. The consequent antenna tests resulted in a switch to wrap around antennas to solve the ocean current-induced resonance.

Clock tests were run to test the accuracy of the clocks at 3°C and 25°C and to measure the thermal time lag.

DD FORM 1 JAN 64 1473

| 14. KEY WORDS | LINK A | | LINK B | | LINK C | |
|---|---|---|---|---|---|---|
| | ROLE | WT | ROLE | WT | ROLE | WT |
| Ocean-Bottom Seismograph | | | | | | |
| OBS Modifications | | | | | | |
| OBS Land Tests | | | | | | |
| OBS Shallow and Deep Water Tests | | | | | | |
| OBS Resonance | | | | | | |
| OBS Clock Tests | | | | | | |

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