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TECHNICAL REPORT NO. 68-32

OPERATION OF THE TONTO FOREST SEISMOLOGICAL OBSERVATORY

Quarterly Report No. 2, Project VT/8702

1 April through 30 June 1968

GEOTECH

A TELEDYNE COMPANY

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Quarterly Report No. 2, Project VT/8702
1 April through 30 June 1968

Sponsored by

Advanced Research Projects Agency
Nuclear Test Detection Office
ARPA Order No. 624

GEOTECH
A Teledyne Company
3401 Shiloh Road
Garland, Texas

15 July 1968

IDENTIFICATION

AFTAC Project No:	VELA T/8702
Project Title:	Operation of TFSO
ARPA Order No:	624
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Contract Number:	AF 33657-68-C-0766
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Program Manager:	B. B. Leichliter, BR1-2561, ext. 222

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ABSTRACT

This is a report of the work accomplished on Project VT/8702 from 1 April through 30 June 1968. Project VT/8702 includes the operation, evaluation, and improvement of the Tonto Forest Seismological Observatory (TFSO) located near Payson, Arizona. It also includes special research and test functions carried out at TFSO and research and development tasks performed by the Garland, Texas, staff using TFSO data.

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OPERATION OF THE TONTO FOREST SEISMOLOGICAL OBSERVATORY

1. INTRODUCTION

1.1 AUTHORITY

The research described in this report was supported by the Advanced Research Projects Agency, Nuclear Test Detection Office and was monitored by the Air Force Technical Applications Center (AFTAC) under Contract AF 33657-68-C-0766. The effective date of the contract is 1 January 1968; the statement of work for Project VT/8702 is included as the appendix to this report.

1.2 HISTORY

The Tonto Forest Seismological Observatory (TFSO) was constructed by the United States Corps of Engineers in 1963. TFSO was designed to record seismic events and to be used as a laboratory for testing, comparing, and evaluating advanced seismograph equipment and seismometric recording techniques. The instrumentation was assembled, installed, and operated until 30 April 1965, by the Earth Sciences Division of Teledyne Industries, under Contract AF 33(657)-7747. On 1 May 1965, Geotech assumed the responsibility for operating TFSO. The location of TFSO is shown in figure 1.

2. OPERATION OF TFSO

2.1 GENERAL

Data are recorded at TFSO on a 24-hour-a-day basis. The observatory is manned continuously. A full complement of personnel is on duty 8 hours a day, 5 days a week; at other times, a reduced operating crew is on duty.

The funds for Contract AF 33657-68-C-0766 were negotiated on 21 May 1968.

Mr. G. S. Gerlach visited the Project Office at the VELA Seismological Center on 15 May to review the status of the evaluation of the 37-element array and other work in progress.

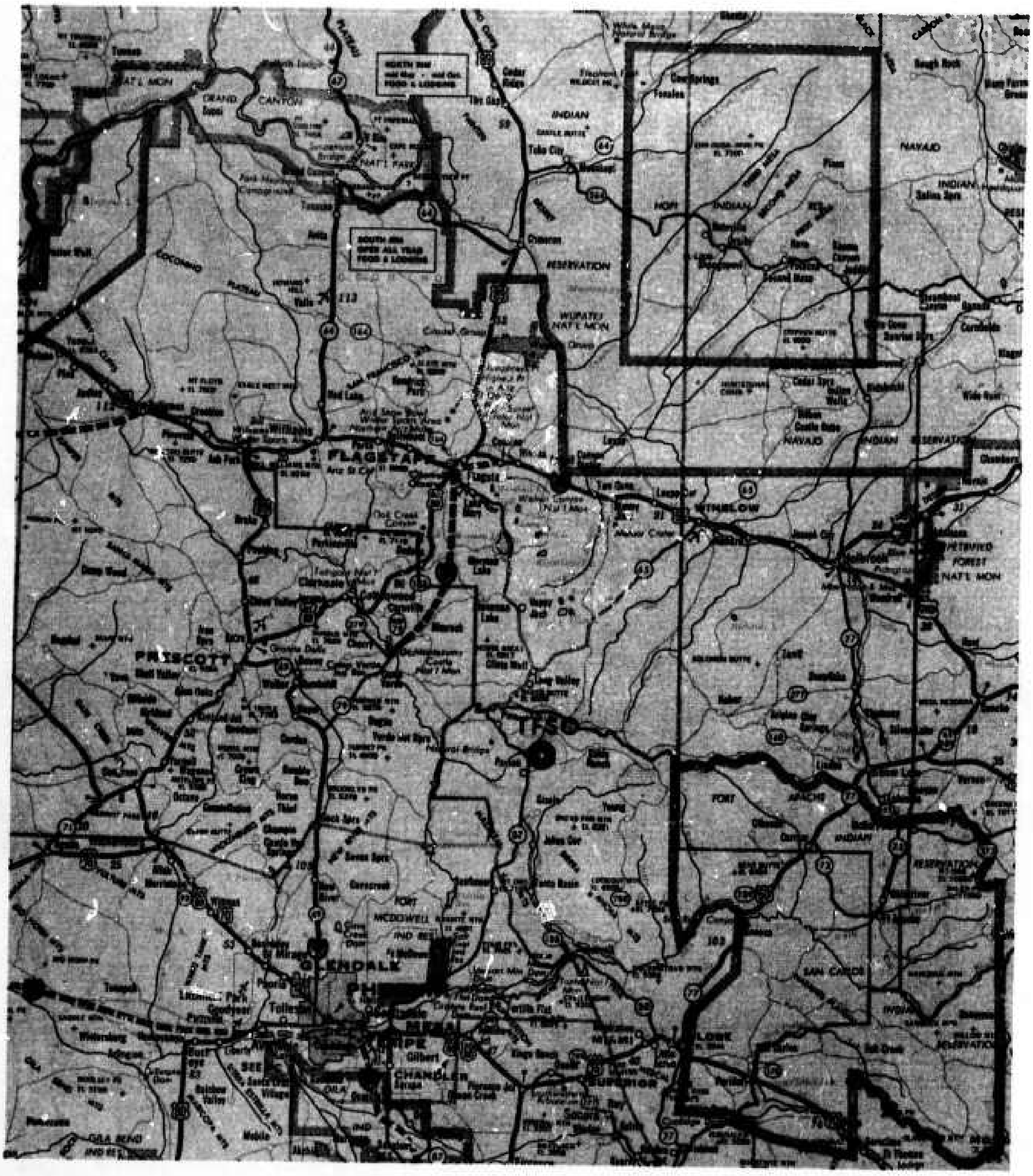

Figure 1. Location of TFSO

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2.2 STANDARD SEISMOGRAPH OPERATING PARAMETERS

The operating parameters and tolerances for the TFSO standard seismographs are shown in table 1. Frequency response tests are made routinely, and parameters are checked and reset to maintain the specified tolerances.

Normalized response characteristics of TFSO standard seismographs are shown in figure 2. In addition to these standard seismographs, two filtered summation seismographs are recorded. One ΣTF seismograph is filtered by a UED filter with a high-cut frequency of 1.75 cps and a slope of 12 dB per octave. This seismograph was recorded on 16-millimeter film data trunk 1 and on magnetic-tape data trunk 5, until 25 June 1968. The second ΣTFK seismograph utilizes a Krohn-Hite filter; the high-cut frequency is set at 2.0 cps with a slope of 24 dB per octave, and the low-cut frequency is set at 1.0 cps with a slope of 24 dB per octave. This filtered seismograph is recorded on 16-millimeter film data trunk 1.

The intermediate band system was deactivated on 25 June 1968 in order to provide recording space for the high-frequency seismograph system.

2.3 DATA CHANNEL ASSIGNMENTS

Each data format recorded at TFSO is assigned a data group number. When a data format is changed, a new data group number is assigned. Several data format change notices reporting changes in channel assignments were submitted to the Project Officer and to frequent users of TFSO data during this reporting period.

2.4 COMPLETION AND SHIPMENT OF DATA

The magnetic-tape seismograms are shipped from TFSO each week. Six magnetic-tape recorders are used to record data for the AFTAC/VELA Seismological Center (VSC).

Film seismograms from 12 Develocorders are routinely shipped to data users. The film and magnetic-tape operation logs and calibration logs are copied and shipped with the seismograms. Copies of selected film-seismogram data are sent to the Geotech Program Manager regularly and to other data users on special request. The shipments of 16-millimeter film seismograms routinely sent to the Seismic Data Laboratory (SDL) repository are complete through April 1968, except for selected seismograms being held for use in conjunction with special investigations or instrument tests that are in progress.

Table 1. Operating parameters and tolerances of standard seismographs at TFSO

Seismograph				Operating parameters and tolerances				Filter settings		
System	Comp	Type	Model	Ts	λs	Tg	λg	δ^2	Bandpass at 3 dB cutoff (sec)	Cutoff rate at SP side (dB/oct)
SP[a]	Z	Johnson-Matheson	6480	1.25 ±2%	0.54 ±5%	---	---	0.0000	0.3 - 10	6
SP[b]	Z	Johnson-Matheson	6480	1.25 ±2%	0.54 ±5%	0.33 ±5%	0.65 ±5%	0.0117	0.1 - 100	12
SP[b]	H	Johnson-Matheson	7515	1.25 ±2%	0.54 ±5%	0.33 ±5%	0.65 ±5%	0.0117	0.1 - 100	12
SP	Z	Benioff	1051	1.0 ±2%	1.0 ±5%	0.2 ±5%	1.0 ±5%	0.0104	0.1 - 100	12
SP	H	Benioff	1101	1.0 ±2%	1.0 ±5%	0.2 ±5%	1.0 ±5%	0.0104	0.1 - 100	12
SP	Z	UA Benioff	1051	1.0 ±2%	1.0 ±5%	0.75	1.0 ±5%	0.0245	---	--
SP	H	UA Benioff	1101	1.0 ±2%	1.0 ±5%	0.75	1.0 ±5%	0.0245	---	--
IB[c]	H	Wood-Anderson	TS 220	0.8	0.78	---	---	---	---	--
IB[c]	Z	Melton	10012	2.25 ±5%	0.65 ±5%	0.64 ±5%	1.2 ±5%	0.0006	0.05 - 100	18
LP	H	Lehner-Griffith	SH-216	2.25 ±5%	0.65 ±5%	0.64 ±5%	1.2 ±5%	0.0004	0.05 - 100	18
	Z	Geotech	7505A	20.0 ±5%	0.77	---	---	0.00	80 - 300	6
LP	H	Geotech	8700C	20.0 ±5%	0.77	---	---	0.00	80 - 300	6

KEY

SP Short period
IB Intermediate band
LP Long period
UA Unamplified (i.e., earth powered)

Ts Seismometer free period (sec)
Tg Galvanometer free period (sec)
λs Seismometer damping constant
λs Galvanometer damping constant
δ^2 Coupling coefficient

[a] 37-element hexagonal array
[b] Linear array and 3 comp
[c] Discontinued after 25 June

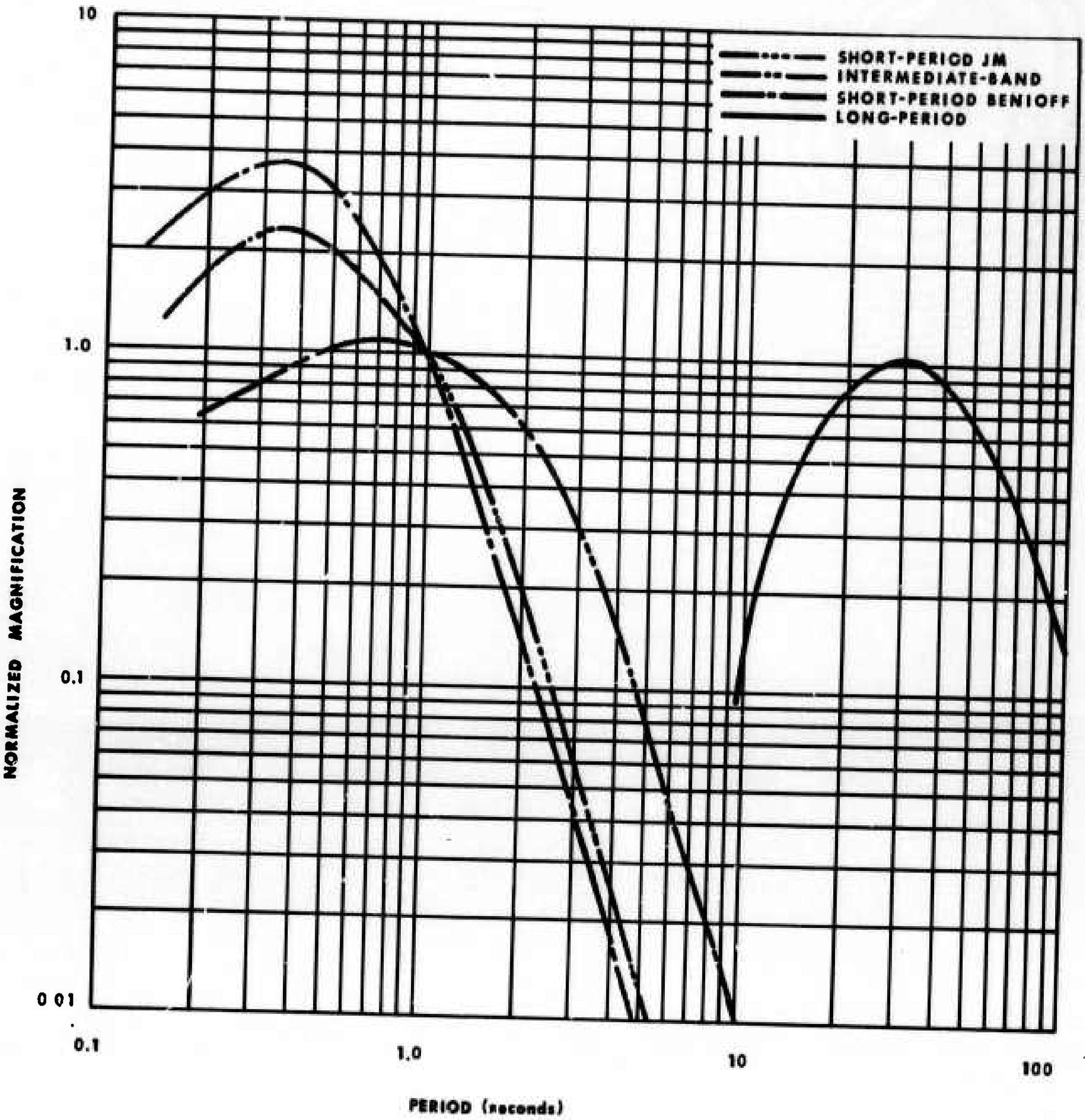

Figure 2. Normalized response characteristics of standard seismographs at TFSO

2.5 QUALITY CONTROL

2.5.1 Quality Control of 16-Millimeter Film Seismograms

Quality control checks of randomly-selected 16-millimeter film seismograms from data trunks 1, 2, and 8, and the associated operation logs are made in Garland. Items that are routinely checked by the Quality Control Analyst include:

a. Film boxes - neatness and completeness of box markings;

b. Develocorder logs - completeness, accuracy, and legibility of logs;

c. Film:

1) Quality of the overall appearance of the record (for example, trace spacing and trace intensity);

2) Quality of film processing;

d. Analysis - completeness, legibility, and accuracy of the analysis sheets.

Results of these evaluations are sent to the observatory for their review and comment.

2.5.2 Quality Control of Magnetic-Tape Seismograms

Routine quality control checks of randomly-selected magnetic-tape seismograms were made in Garland and at TFSO to assure that recordings met specified standards. The following are among the items that were checked by the Quality Control Group:

a. Tape and box labeling;

b. Accuracy, completeness, and neatness of logs;

c. Adequate documentation of logs by voice comments on tape where applicable;

d. Seismograph polarity;

e. Level of calibration signals;

f. Relative phase shift between array seismographs;

g. Level of the microseismic background noise;

h. Level of the system noise;

i. PTA dc balance:

j. Oscillator alignment;

k. Quality of the recorded WWV signal where applicable;

l. Time-pulse carrier;

m. Binary coded digital time marks.

Quality-control effort resulted in the adjustment of tape speed on four FM magnetic-tape recorders.

2.5.3 Quality Control of Astrodata Digital Magnetic Seismograms

Quality control checks of Astrodata tape were initiated during June. At present, one tape per day is checked for the following items:

a. Neatness and accuracy of the associated logs;

b. Parity errors;

c. Recording level of each channel;

d. Fidelity of reproduction;

e. Presence of header record and correct record length.

Quality control efforts have resulted in an improvement of the accuracy of the logs. The last record and the end-of-file on each tape appear to be missing; efforts are continuing to isolate and correct the malfunction.

2.6 SECURITY INSPECTION

Mr. M. Craig, Industrial Security Inspector from Phoenix, Arizona, made a routine security inspection of the observatory on 17 May. All items checked were found to be in order.

2.7 EMERGENCY POWER GENERATOR

The emergency power generator was operated 49.3 hours during the reporting period. Approximately 69 percent of the emergency power operation was required because of activity that resulted in commercial power fluctuations and outages.

3. EVALUATE DATA AND DETERMINE OPTIMUM OPERATIONAL CHARACTERISTICS

3.1 SHORT-PERIOD ARRAY SYSTEMS MODIFICATIONS

3.1.1 Vault Isolation Filters

The installation of the 1.0 μF capacitor between the positive side of the power line and ground in the vault isolation filter was completed in 81 percent of the systems. To further reduce noise and spiking, 100 kohm resistors are being placed across each 1.0 μF capacitor in the vault isolation filter. This modification has been completed in 46 percent of the systems. Figure 3 shows the circuit modifications.

3.1.2 Power Source

The power source for Z22 and Z34 was changed during June. Z22 now uses a dc power supply operating on commercial power, which was available at LP2. The thermoelectric generator at LP7 is supplying power to Z34.

3.1.3 Solid-State Amplifier

During June a modification of all short-period solid-state amplifiers was started. The modification consists of replacing a resistor in the voltage-controlled oscillator board. This change results in an increase in signal level from about 1800 mV to about 2900 mV.

3.2 ASTRODATA SYSTEM

3.2.1 Overload Circuit Modification

On 16 April the Astrodata system was modified so that the channel-overload protection circuits included an automatic reset circuit. This modification eliminates long data outages experienced in the past, because the overloaded channels are reset automatically after a 4-second delay.

3.2.2 Parity Errors

On 9 May a tape-guide roller was replaced on Astrodata tape transport 1. The new roller eliminated the constant parity errors encountered in processing digital seismograms recorded by transport 1 during April.

3.2.3 Recording Level

On 12 April the sensitivity of the Astrodata acquisition system was increased by a factor of three to insure adequate resolution of the noise in the evaluation

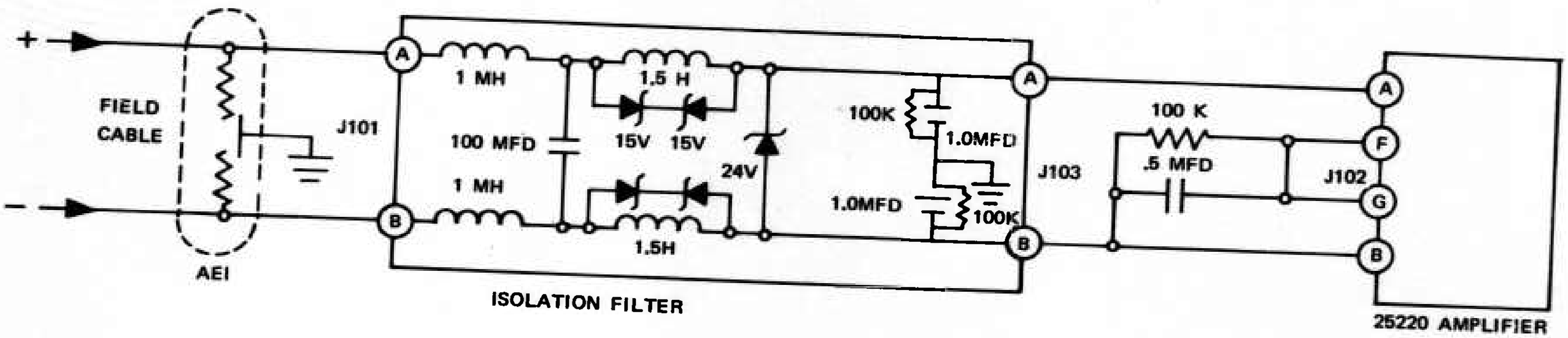

Figure 3. Block diagram of the vault isolation filter for the short-period seisographs showing modifications made to system to reduce noise and spiking due to line leakage

of the signal-to-noise improvement of the beam-formed outputs of the 37-element array.

3.3 MAINTENANCE OF TFSO EQUIPMENT

3.3.1 FM Magnetic-Tape Recorder Heads

Six sets of FM magnetic-tape record and playback heads were delivered to TFSO during May. Detailed check-out procedures have been planned; however, installation was not started by the end of the report period.

3.3.2 FM Magnetic Tape

Data loss after a few hours of recording has been observed with the new Scotch Brand magnetic tape No. 860. The difficulty has been attributed to excessive buildup of tape lubricant on the record heads. About 100 reels of the tape have been temporarily set aside while procedures for removing the excess lubricant are being planned.

3.4 LINE SPIKING PROBLEM

From latter May to 10 June, the output data from the 37-element short-period array and the crossed-linear array exhibited a large increase in transient (spike) noise level. Such noise normally appears with the occurrence of a local thunderstorm; however, during this period TFSO did not have any thunderstorms. The spiking noise was observed to have the following characteristics:

1. In general, the spiking was random in time with the highest frequency of occurrence between 6 p.m. and 3 a.m. local time.

2. Some spikes appeared on all traces of the 37-element array simultaneously; others appeared on small groups of traces simultaneously.

3. During the high noise period, an average of one spike per minute was observed on the noisier channels.

Tests indicated that the noise was not the result of faulty instruments or bad cable, but that the noise was being picked up by the spiral-4 cables. No positive correlation was observed between the spikes and any commercial power fluctuations, radio static, or special meteorological conditions. Before the mechanism that produced the spikes could be determined, the spiking frequency and amplitude dropped to an almost negligible level after 10 June. A detailed report on this problem and the tests undertaken to solve it is being prepared in a letter progress report to be submitted about 15 July.

4. ANALYZE DATA

4.1 DAILY REPORTS TO THE COAST AND GEODETIC SURVEY

TFSO reports the arrival time, period, and peak amplitude of events recorded at TFSO to the Director of the Environmental Science Services Administration's Coast and Geodetic Survey in Washington, D. C., daily. The number of events reported by TFSO during each month of the reporting period is shown in table 2, by type.

Table 2. Events reported to the C&GS by TFSO during April, May, and June 1968

Month	Local	Near Regional	Regional	Teleseisms	Total
April	7	386	12	1074	1475
May	6	140	15	1394	1555
June	4	112	41	2087	2244

The number of events reported by C&GS in their "Earthquake Data Report" for December 1967, January, and February 1968 are given in table 3. Also shown in table 3, by month, are the percentages of the C&GS hypocenters in which TFSO data were used to establish the location; the percentages of the C&GS hypocenters from which TFSO recorded a P or PKP arrival, based on associated data; and the percentages of the C&GS hypocenters from which TFSO recorded a P, PKP, or later phase, based on updated ABP associated data. Figures 4 and 5 show the world-wide distribution of the C&GS-located epicenters for November and December 1967, and January 1968. The three types of symbols used to show the epicentral locations represent the detection, by TFSO, of a P or PKP phase; the detection of an event in which the first recorded arrival was not P or PKP; and no detection by TFSO.

4.2 DAILY ANALYSIS FOR MULTISTATION EARTHQUAKE BULLETIN

Data from TFSO are combined with data from CPSO, BMSO, UBSO, and WMSO and published in a monthly multistation earthquake bulletin. The bulletins for November and December 1967 were published during this reporting period. The ABP output for January 1968 was received from the Seismic Data Laboratory on 31 May. The January bulletin is scheduled for distribution about 10 July.

Table 3. Percentage of hypocenters reported in the C&GS "Earthquake Data Report" for which TFSO data were used

Month	No. events reported by TFSO	No. C&GS hypocenters	Percent of C&GS hypocenters for which the C&GS listed a TFSO P or PKP arrival	Percent of C&GS hypocenters for which TFSO recorded a P or PKP phase, based on associated data	Percent of C&GS hypocenters for which TFSO recorded a P, PKP, or later phase based on updated associated data
December 1967	997	379	49.9	61.9	66.1
January 1968	1136	410	65.6	68.2	72.1
February 1968	951	412	49.5	61.2	65.5

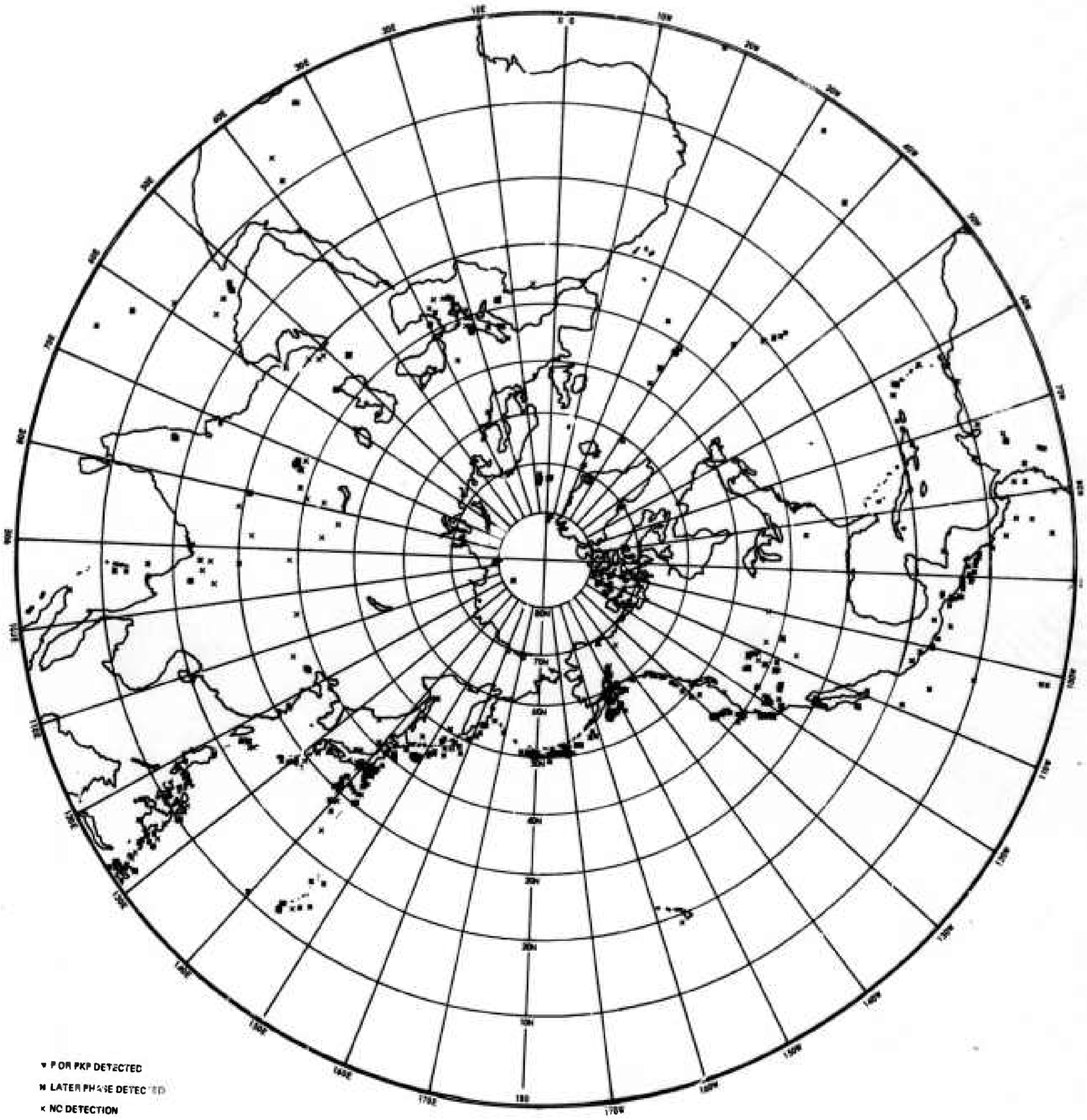

Figure 4. Distribution of Coast and Geodetic Survey located epicenters in the northern hemisphere for November and December 1967, and January 1968

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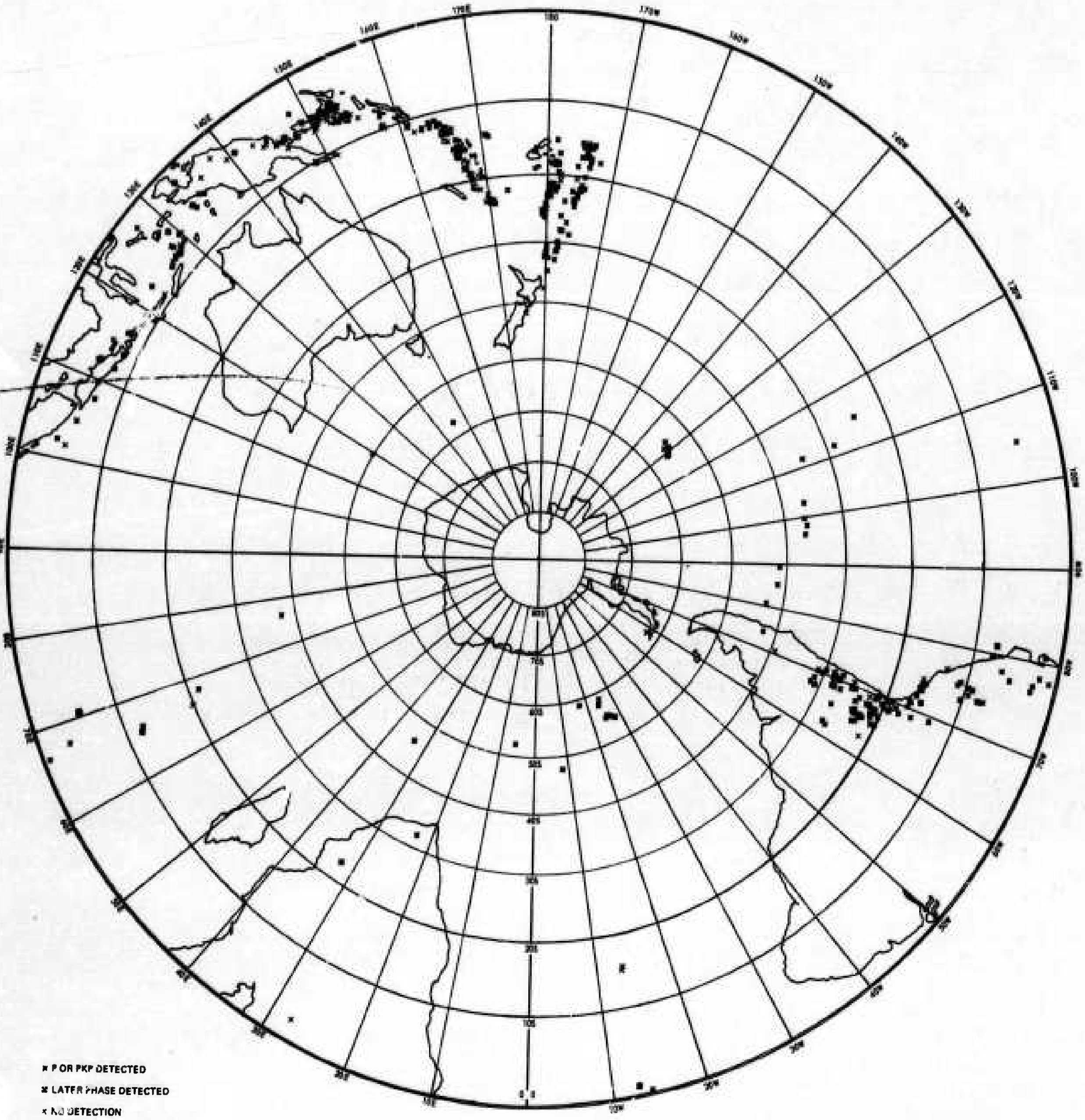


Figure 5. Distribution of Coast and Geodetic Survey located epicenters in the southern hemisphere for November and December 1967, and January 1968

G 3180

4.3 ROUTINE NOISE SURVEY

Measurements of ambient noise in the 0.4-1.4-second period range are made from the short-period 16-millimeter films seismograms, daily, at TFSO. Data are processed in Garland, and monthly cumulative probability curves of trace amplitude and ground displacement as recorded on the Z60, ΣT, and ΣTF seismograms are published. Curves for the months of February, March, April, and May 1968 were sent to the Project Officer during this reporting period.

5. PROVIDE OBSERVATORY FACILITIES AND ASSISTANCE TO OTHER ORGANIZATIONS

5.1 ASTRODATA DATA ACQUISITION SYSTEM

The Astrodata system operated on a 24-hour-a-day basis throughout the reporting period. Recordings are preselected by station personnel prior to shipment to SDL.

5.2 TELEMETRY TO MASSACHUSETTS INSTITUTE OF TECHNOLOGY

Telemetry of seven seismograph channels to Lincoln Laboratory, Massachusetts Institute of Technology (MIT) continued throughout this reporting period. MIT is notified, in advance when possible, if the seismographs are to be attenuated for special tests.

5.3 ASTROGEOLOGICAL DEPARTMENT OF THE U. S. GEOLOGICAL SURVEY

TFSO has continued to support Dr. Harold Krivoy of the Astrogeological Department of the United States Geological Survey (USGS) in Flagstaff, Arizona. Dr. Krivoy receives copies of the daily station message and all Helicorder records not needed by the observatory on a regular basis.

5.4 GEOPHYSICS DEPARTMENT OF THE UNIVERSITY OF UTAH

During June, TFSO started sending copies of the daily station message to Dr. Kenneth Cook, University of Utah.

5.5 VISITORS

5.5.1 Visits by School and Professional Groups

Arizona State University students and instructors visited TFSO on 5 April, 19 April, and 3 May 1968. Approximately 188 visitors were given tours of the observatory and brief lectures on seismology. Approximately 108 visitors from Phoenix and Payson high school science classes were given tours of the observatory on 11 and 20 April and 17 May 1968. On 8 June, thirty members of the Arizona Institute of Aeronautical Engineers visited the observatory.

5.5.2 Teledyne Visitors

Mr. Arnold Sisson, Program Engineer, and Mr. O. D. Starkey, Geotech, visited the station from 7 through 19 May for the purpose of modifying the long-period solid-state amplifiers and assist in the installation of the long-period array.

Mr. S. Montoya, Geotech, visited TFSO from 5 through 18 June for the purpose of solving long-period telephone and microwave carrier problems.

5.5.3 Visit by Project Officer

Captain Frederick D. Munzlinger, AFTAC Project Officer, was a visitor at TFSO from 13 through 18 April 1968. Installation of the long-period array, and recording formats were discussed.

5.5.4 Texas Instruments Visit

Mr. Don Douglas, Texas Instruments (TI), arrived at TFSO on 27 May to begin digital recording of TFSO data. Other TI personnel who assisted Mr. Douglas during the recording period were Mr. D. Hughes, Mr. B. Johnson, and Mr. B. Mathews. The TI personnel completed their recording assignment and departed on 22 June.

5.5.5 Visits by Foreign Nationals

Dr. Ola Dahlman, Sweden, visited the observatory on 29 April 1968. Dr. Claus Prodehl, West Germany, visited on 12 June 1968. Both visitors were given tours of the observatory.

6. RESEARCH PROGRAMS

6.1 DESIGN AND INSTALL A LONG-PERIOD ARRAY

6.1.1 Array Installation

Construction of the long-period array was completed, and by 30 April, the outputs of all the elements were being recorded. The Federal Communications Commission microwave license for LP5 was received about 17 April, and the microwave equipment was operational by 26 April.

All vault holes have been filled with sawdust and covered; all sites except LP3 have been cleared, smoothed, and reseeded. Fences have not been erected yet at LP2, LP3, LP4, and LP7.

6.1.2 Array Operation

During May the operation of the seismographs was improved due to stabilization of the systems, modification of the amplifiers, improvement of the telephone transmission links, and improvement of the ventilation of the microwave transmission equipment. The modification of the amplifiers included removal of the diodes acrcss the base-to-emitter junction of the input transistor and changing the damping circuit from active to passive.

Crossfeed between the data and calibration circuits for LP2 and LP3 was eliminated with the installation of specially designed filters.

Lightning has resulted in damage to equipment at LP2, LP3, and LP5; and their operation has been intermittent.

In general, the useful magnification of the vertical seismographs is limited to between 50K and 100K, and the magnification of the horizontals is limited to between 30K and 40K.

6.2 EVALUATION OF A HIGH-FREQUENCY SEISMOGRAPH

The high-frequency seismograph was assembled and checked during April. The installation of the seismograph in the shallow hole was delayed until a winch was received from UBSO. The seismometer was lowered and locked at a depth of 130 feet on 29 May. Recording of the system began on 25 June, with a magnification of about 23,000K at 8 cps.

Problems have been encountered with high-frequency oscillations; and at the end of the reporting period, work was continuing on eliminating them. Evaluation of the high-frequency seismograph will begin when the system is operating properly.

6.3 MULTICHANNEL FILTER PROCESSOR

In general, the multichannel filter operated routinely throughout the reporting period. There were two major outage intervals of more than one day. Due to a damaged transistor in the core memory power supply, the MCF was inoperative from 22 April through 2 May. From 10 May through 14 May, a faulty input circuit resulted in Z1 being the only input channel selected. There were 9 other brief outages ranging from a few minutes to several hours.

The short-period primary system, Z60, N46, and E60 has been assigned to the beam-steered recording format, data trunk 6. Routine analysis is made from this recording format, and an evaluation is in progress. Preliminary observations of the MCF outputs have indicated the following items:

1. Signals not detected on the short-period primary system have been detected on the MCF.

2. Approximate azimuths of epicenters can be determined on all signals recorded by the MCF.

3. Due to the filtering of low-frequency energy by the MCF, the detection capability is maintained during intervals of high amplitude surface waves.

4. The MCF has been an aid to the analyst in separating phases of two intermingled events from different epicenters.

6.4 BEAM-STEERING EVALUATION OF THE SHORT-PERIOD ARRAY

The beam-steering evaluation of the short-period array continued throughout the report period. At present, fourteen signals have been processed, and six of the signals have been analyzed.

Preliminary analysis of twelve of the signals indicated unexpected behavior of signal amplitudes across the array. Eight of the twelve events showed an increase in average amplitude for rings of seismometers with increasing radii. The rms of the noise samples associated with the eight signals tended to show the same pattern, but with less consistency and to a smaller degree. In order to verify that the observed behavior was not due to demagnification factors obtained from simultaneous calibrations, new demagnification factors computed from individual calibrations were applied to three events. Table 4 shows the ring-averaged rms values of the noise for the three events. Comparison of the values show about a 4 percent smaller average rms value for the individual cals.

Table 5 shows the ring-averaged signal amplitudes (p-p/2) for the three events. The individual cals give about 6 percent smaller ring-averaged signal amplitude for the three events.

The following conclusions are evident from the data:

1. The two methods of calibration give essentially the same results.

2. The increase in signal amplitude with increasing rings is evident in the data using the individual calibrations.

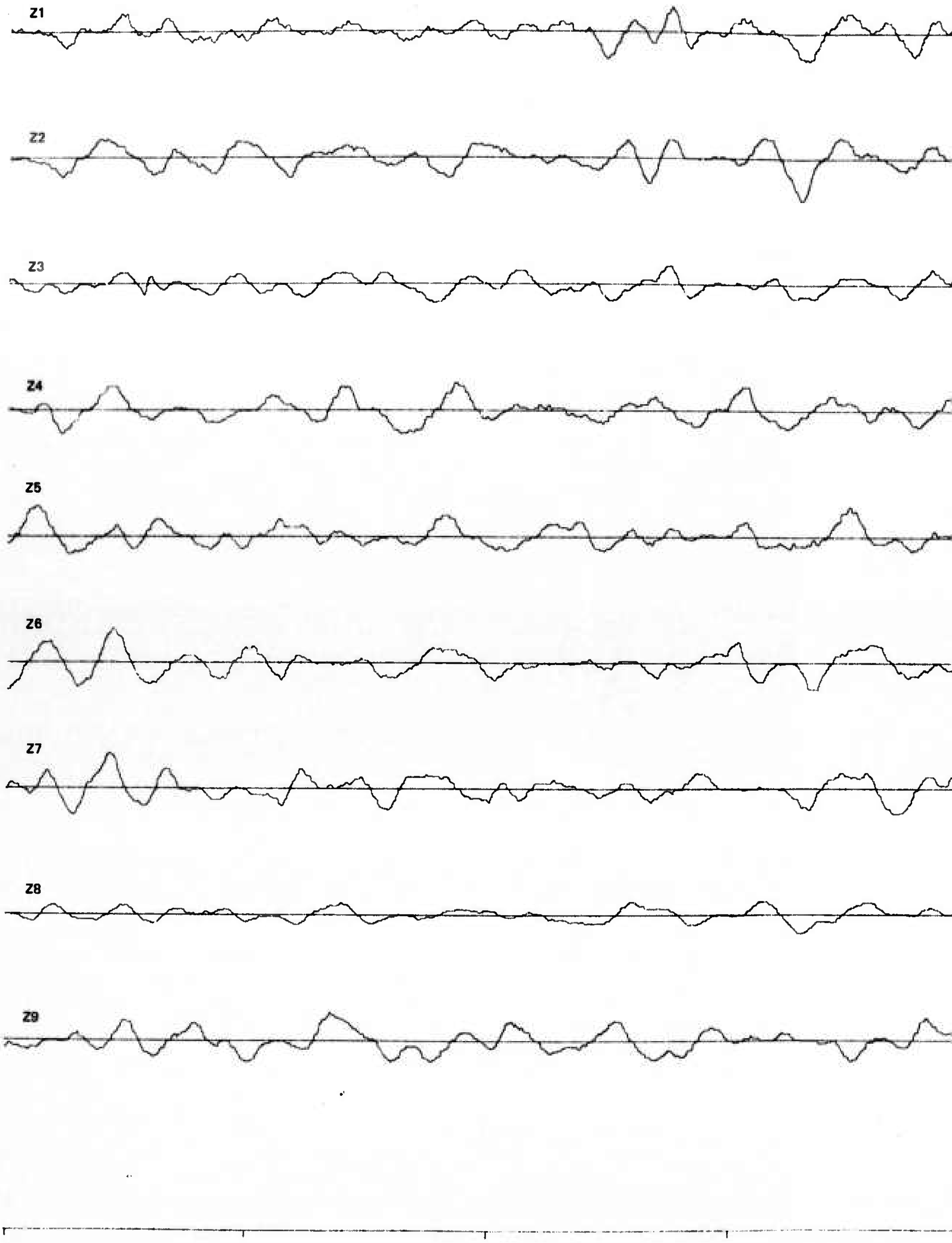
A typical event from the six analyzed to date is a signal from the Atlantic Ridge. Figures 6 through 10 show a portion of the noise sample and the

Table 4 . Ring-averaged RMS (mμ) noise values

Event	Simultaneous Cals			Individual Cals		
	Ring 1 (R=5km)	Ring 2 (R=10km)	Ring 3 (R=15km)	Ring 1 (R=5km)	Ring 2 (R=10km)	Ring 3 (R=15km)
Aleutian Islands	.38	.39	.41	.36	.38	.39
Tonga Islands	.69	.68	.73	.68	.66	.69
Alaska	.33	.36	.37	.31	.35	.35

Table 5 . Ring-averaged signal amplitudes (p-p/2, mμ)

Event	Simultaneous Cals			Individual Cals		
	Ring 1 (R=5km)	Ring 2 (R=10km)	Ring 3 (R=15km)	Ring 1 (R=5km)	Ring 2 (R=10km)	Ring 3 (R=15km)
Aleutian Islands	2.96	3.12	3.37	2.76	3.01	3.19
Tonga Islands	2.52	2.88	3.20	2.49	2.80	3.04
Alaska	2.20	2.25	2.88	2.03	2.15	2.70



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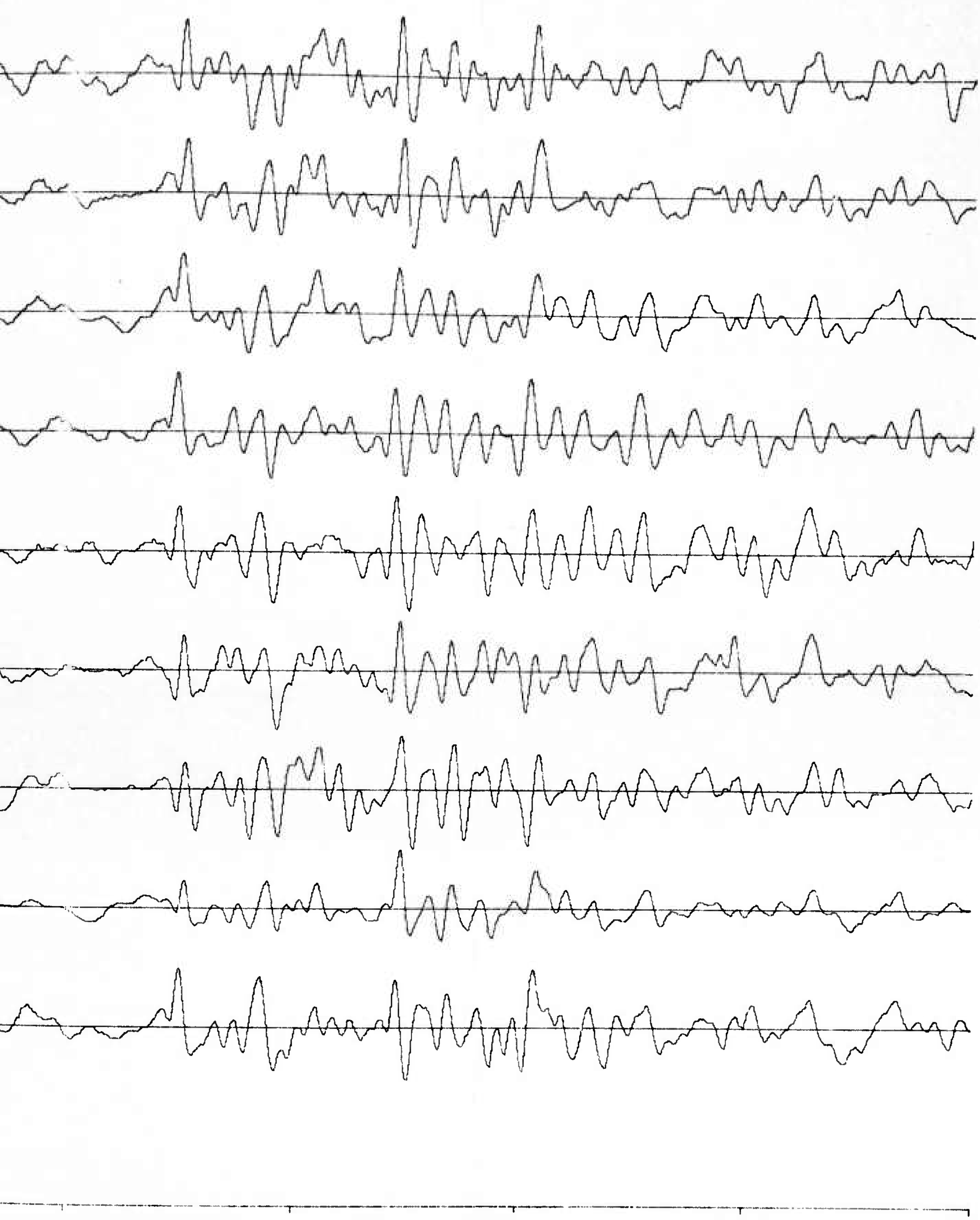
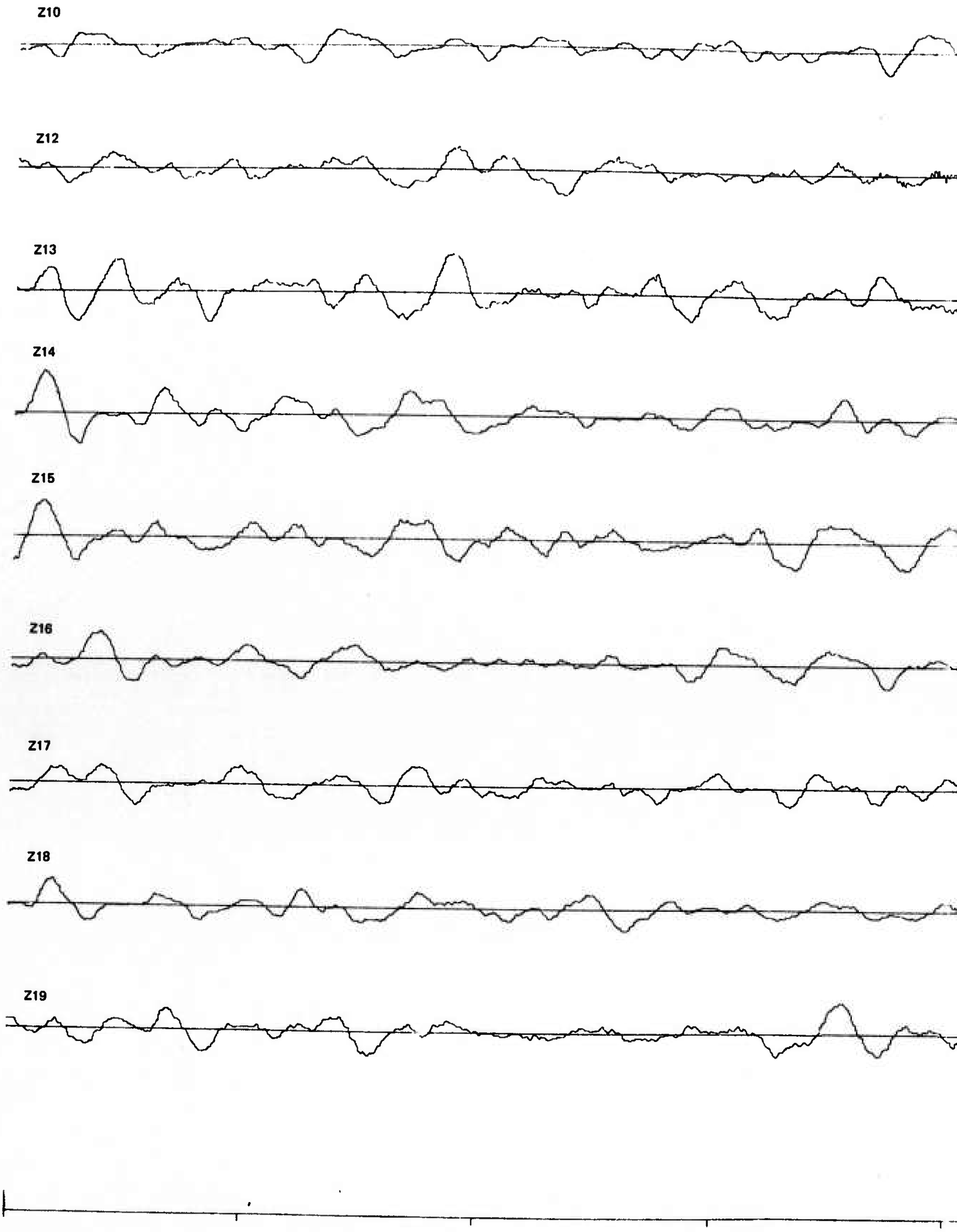


Figure 6. Astrodata recording of Atlantic Ridge signal on Z1 through Z9 of the 37-element array

B



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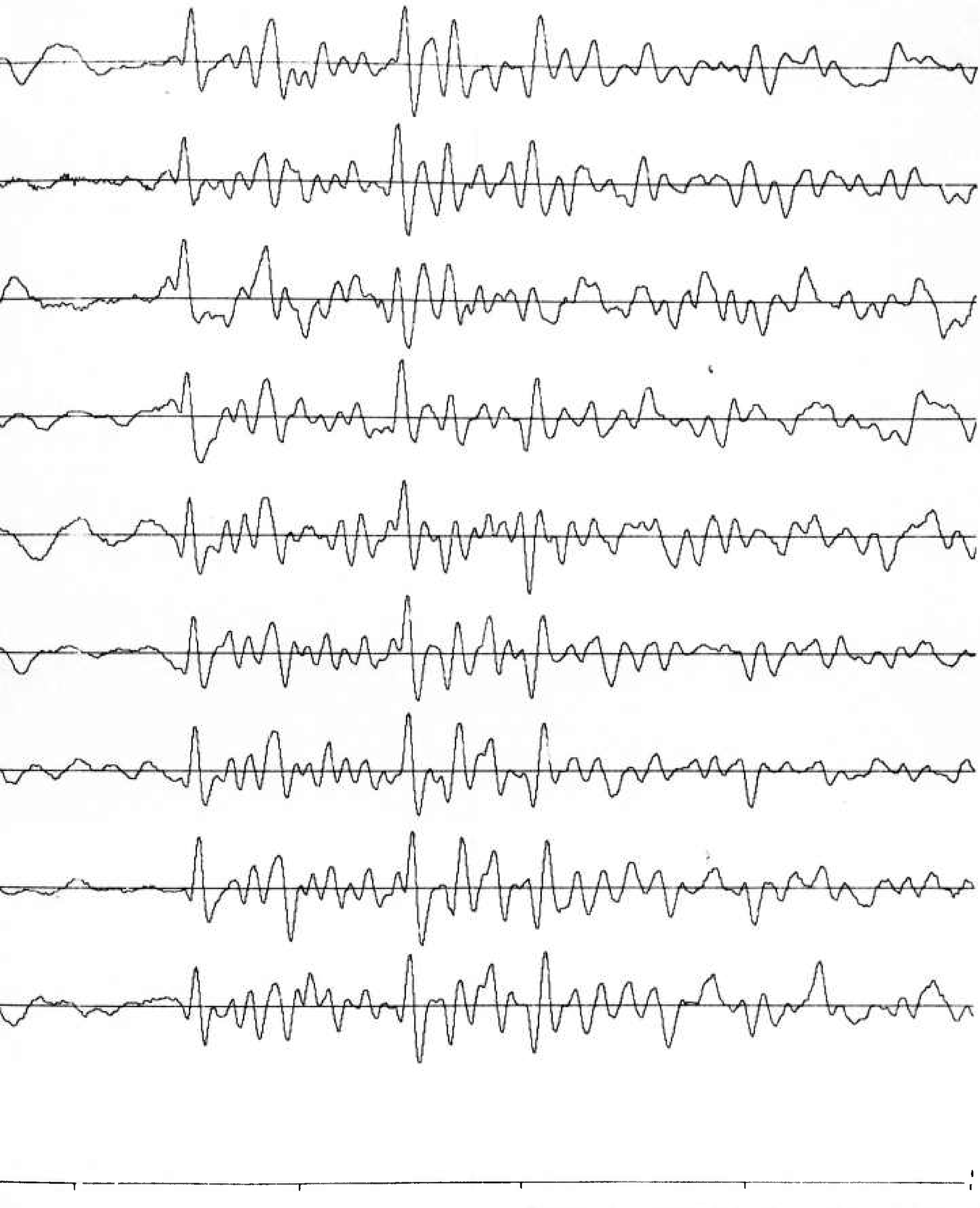

Figure 7. Astrodata recording of Atlantic Ridge signal on Z10, and Z12 through Z19 of the 37-element array

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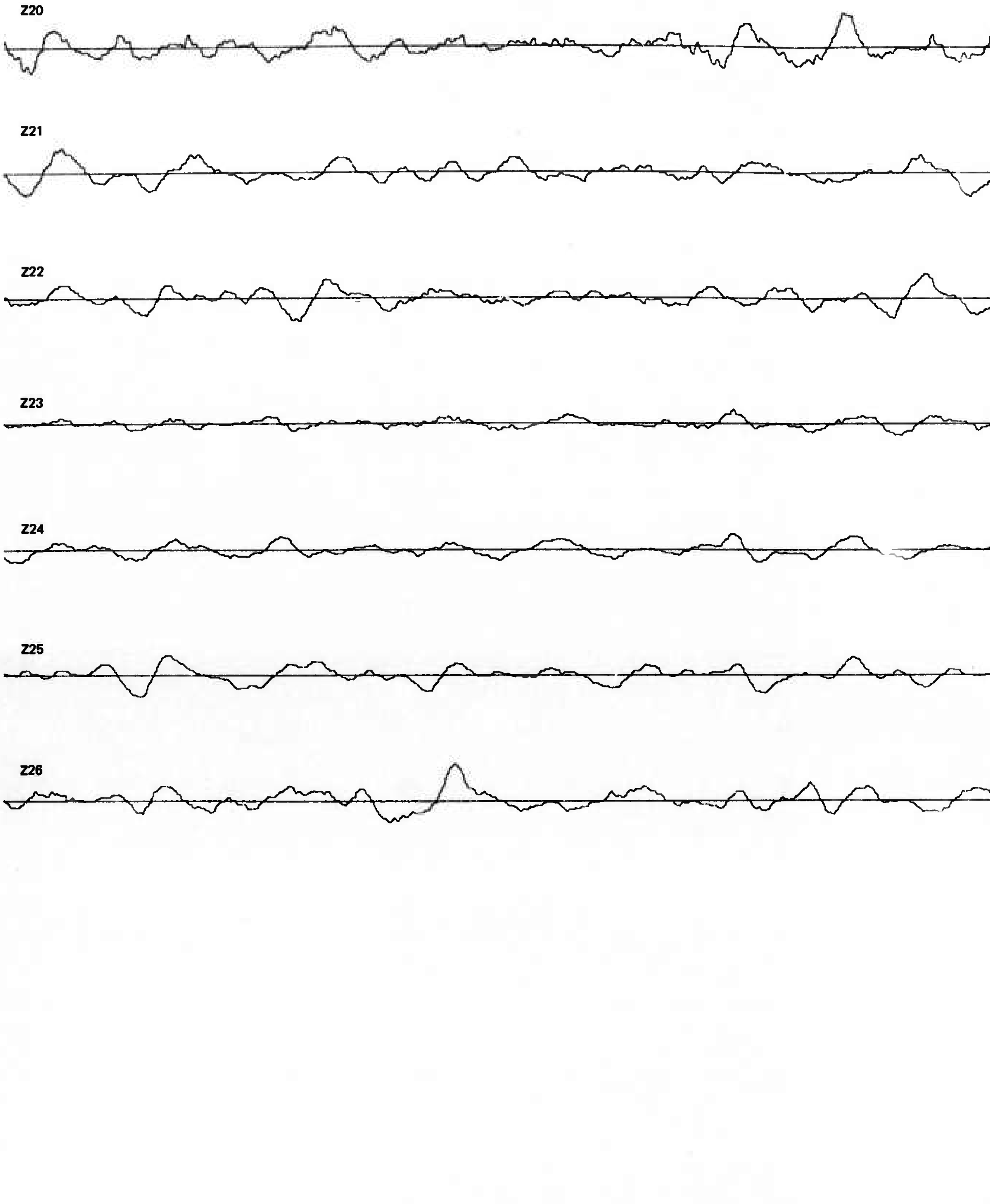

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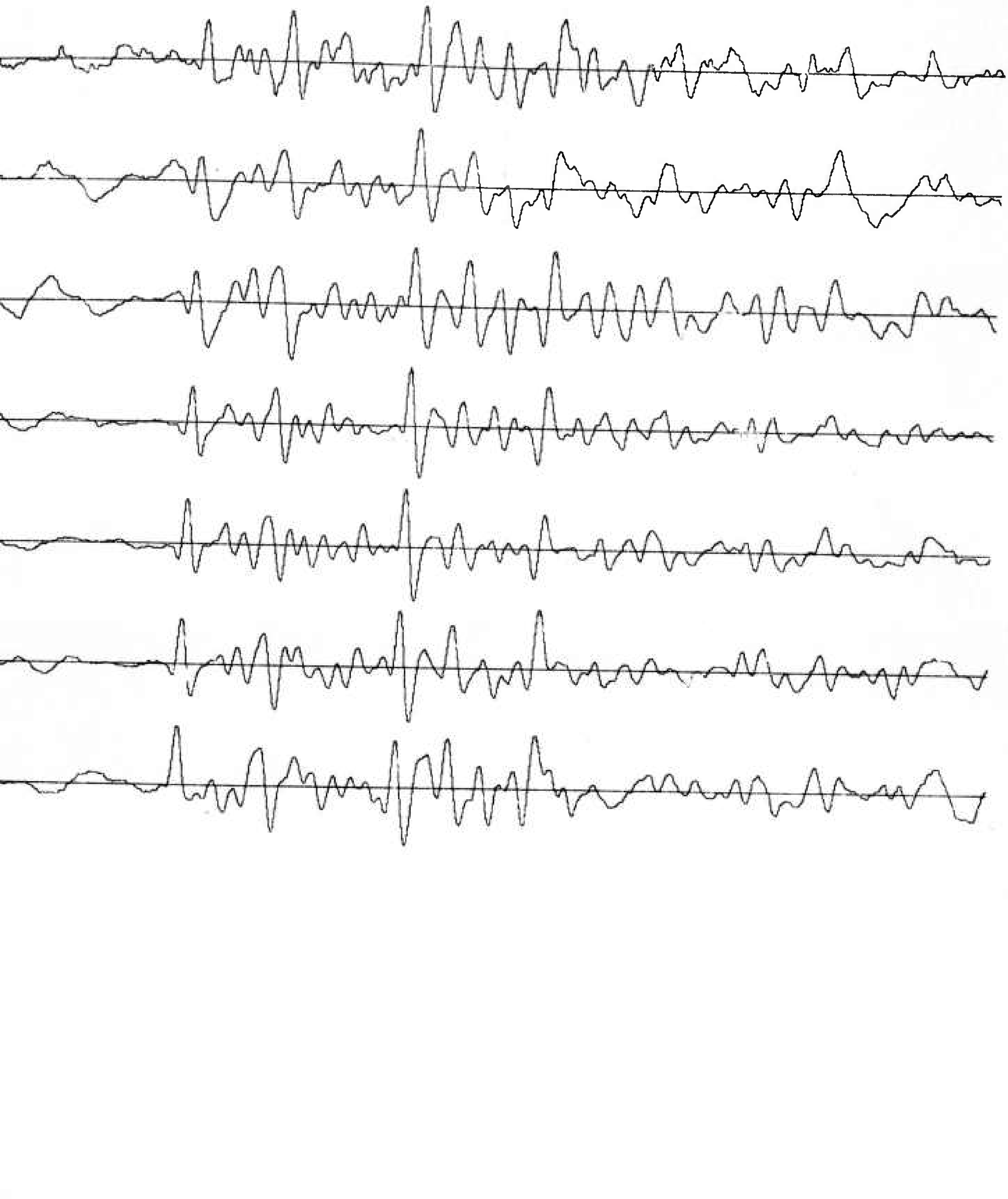
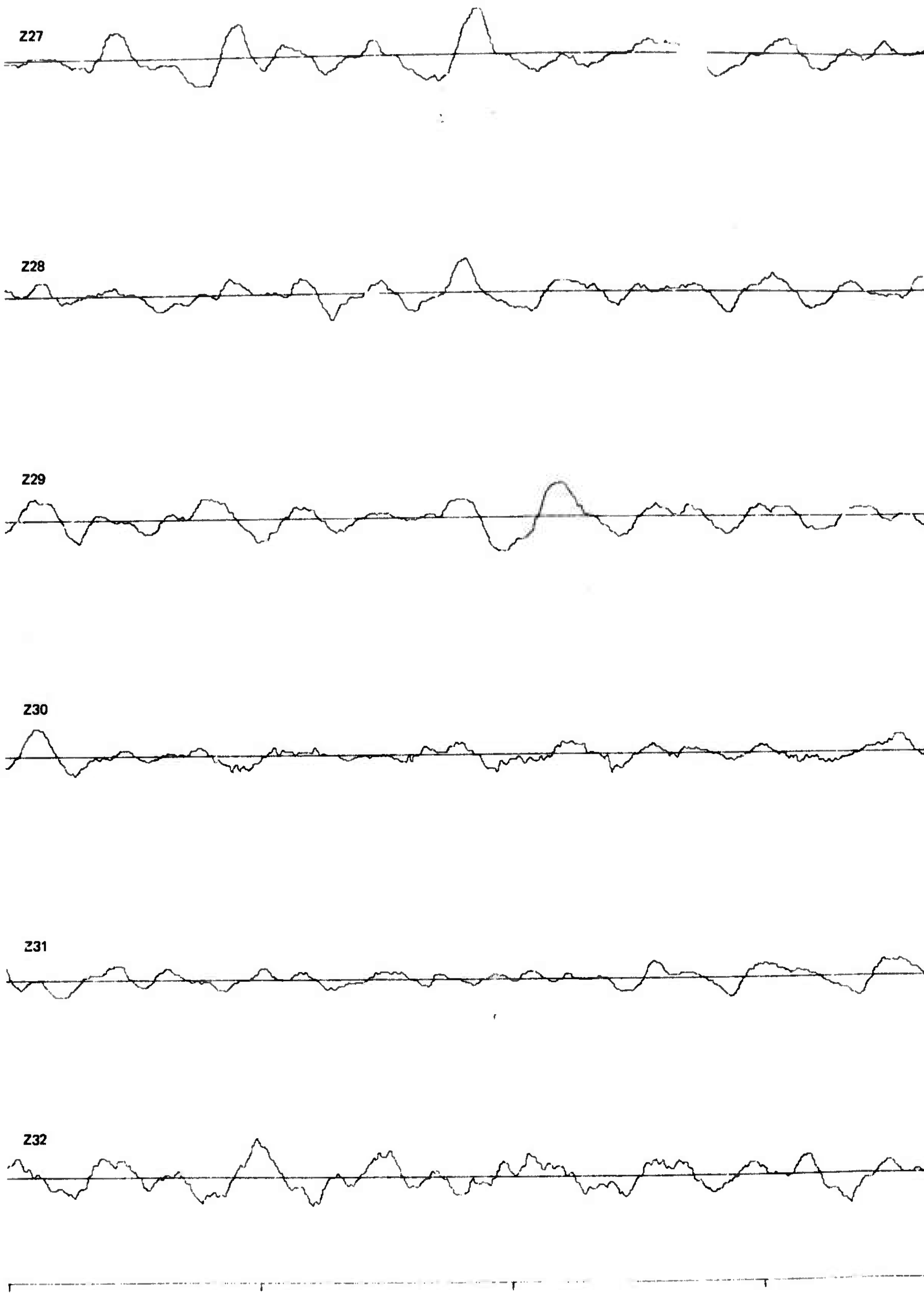


Figure 8. Astrodata recording of Atlantic Ridge signal on Z20 through Z26 of the 37-element array

B


Z27
Z28
Z29
Z30
Z31
Z32

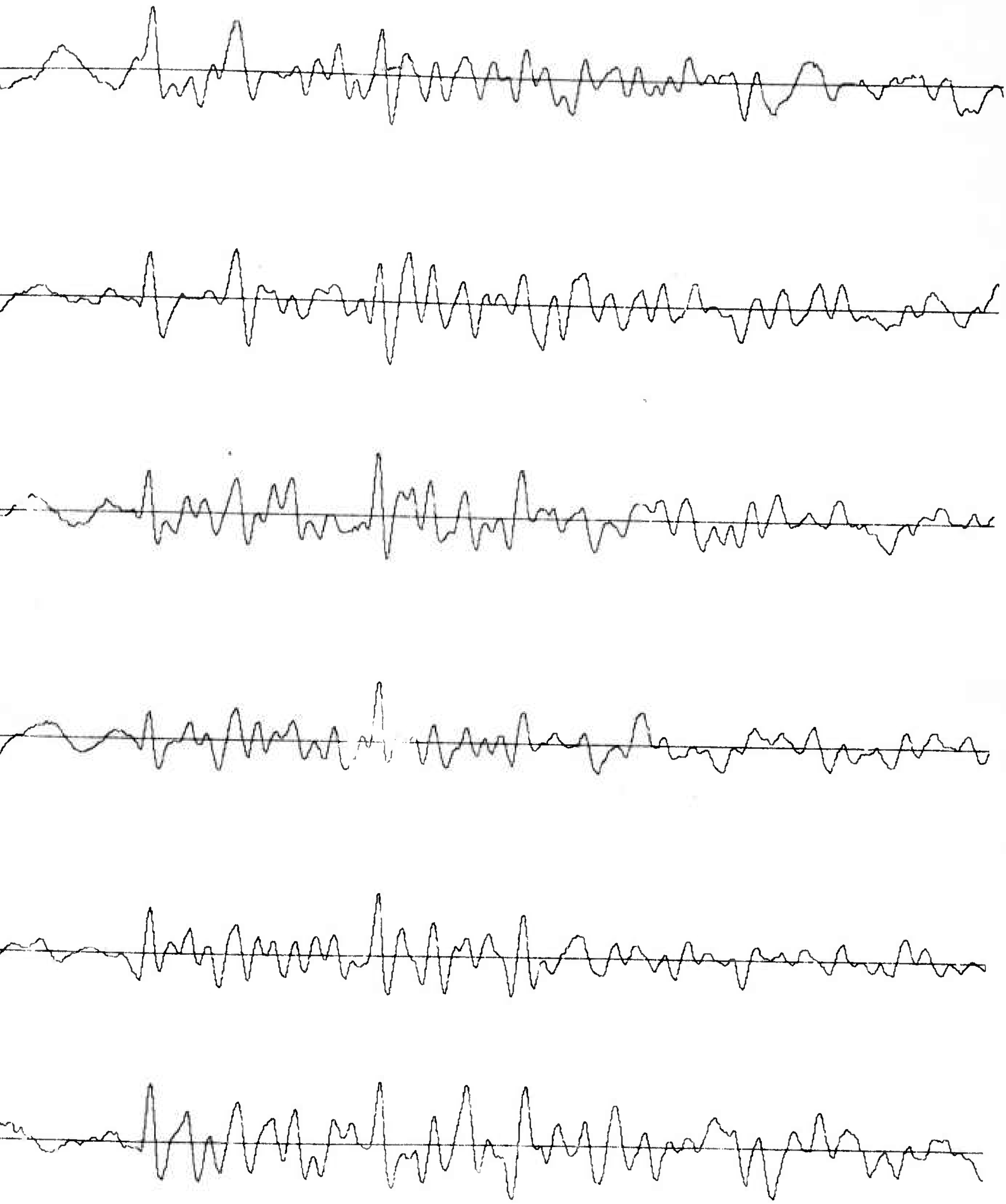
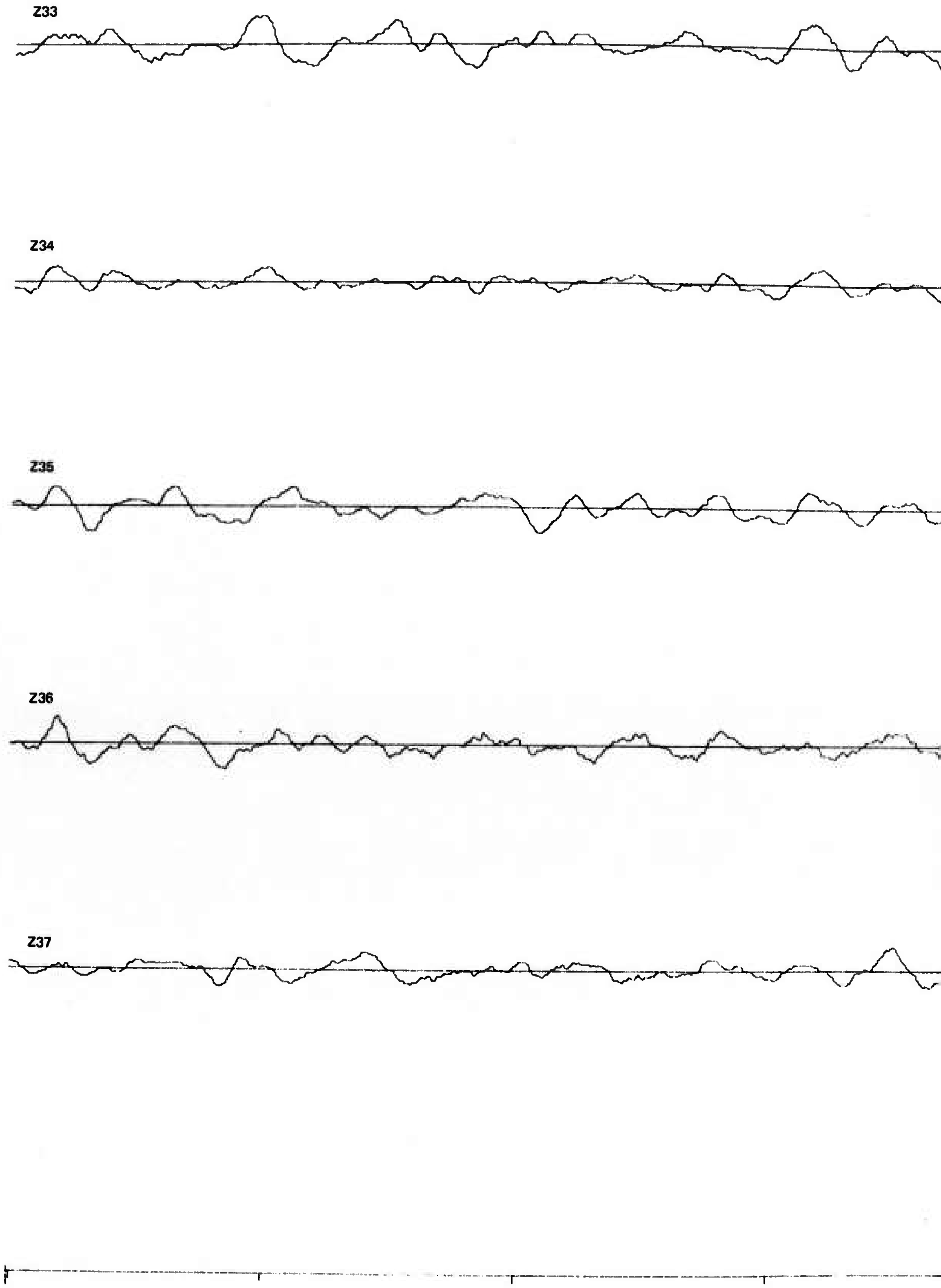


Figure 9. Astrodata recording of Atlantic Ridge signal on Z27 through Z32 of the 37-element array

B



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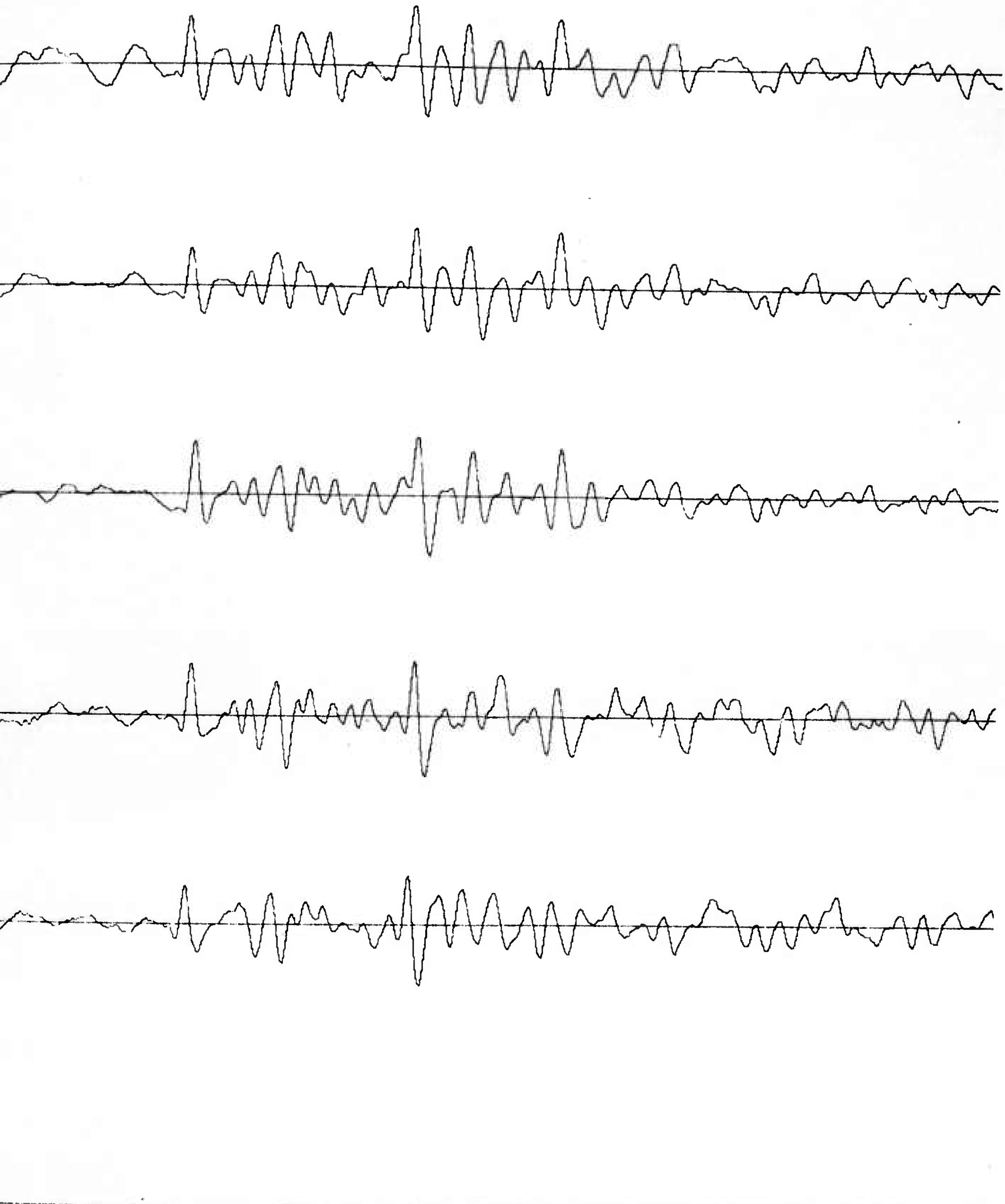

Figure 10. Astrodata recording of Atlantic Ridge signal on Z33 through Z37 of the 37-element array

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signal as it was recorded by the 37-element array (figure 11). The traces have not been normalized to the same gain, and Z11 was not used. The data were demagnified and filtered with the SDL filter, which is a bandpass filter with cutoffs at 0.4 cps and 3.0 cps and about 24 dB/octave slopes. The data were filtered both forward and backward to obtain zero phase shift at all frequencies.

Delay times were measured from Calcomp plots of the data and three phased sums were formed. The first, PS1, consisted of the center element plus the inner ring; the second, PS2, consisted of the center element plus the inner and middle rings; the third, PS3, consisted of the entire array. The spectra of the signal and the noise were computed for each of the individual elements, the three phased sums, and a summation of selected elements of the crossed-linear array. The cross-linear summation (CLS) was filtered in the same manner as the individuals prior to computing the spectra. The signal and the noise spectra for the individual elements were averaged to obtain representative spectra. Figure 12 shows the spectra plotted as a function of frequency. The ratios of noise spectra for PS1, PS2, PS3, and CLS, relative to the individual spectra, are shown in figure 13. Corresponding ratios for the signal spectra are shown in figure 14. The noise ratios show the expected noise reduction due to the addition of elements to the phased sums. The signal ratios show that at the peak power, the signal loss is less than 2.0 dB for the three phased sums and the cross-linear summation. The rise in the signal ratios at the higher frequencies is due to noise reduction and not signal loss. The signal amplitude loss for the largest half cycle in the first four seconds was less than 0.85 dB for the three phased sums.

The signal-to-noise ratios as functions of frequency for the individual, three phased sums, and the cross-linear summation are shown in figure 15. Note that the maximum in the S/N did not occur at the same frequency as the peak signal power. Signal-to-noise improvement ratios for the three phased sums and the cross-linear summation relative to an individual are shown in figure 16. Table 6 summarizes the improvement at various frequencies.

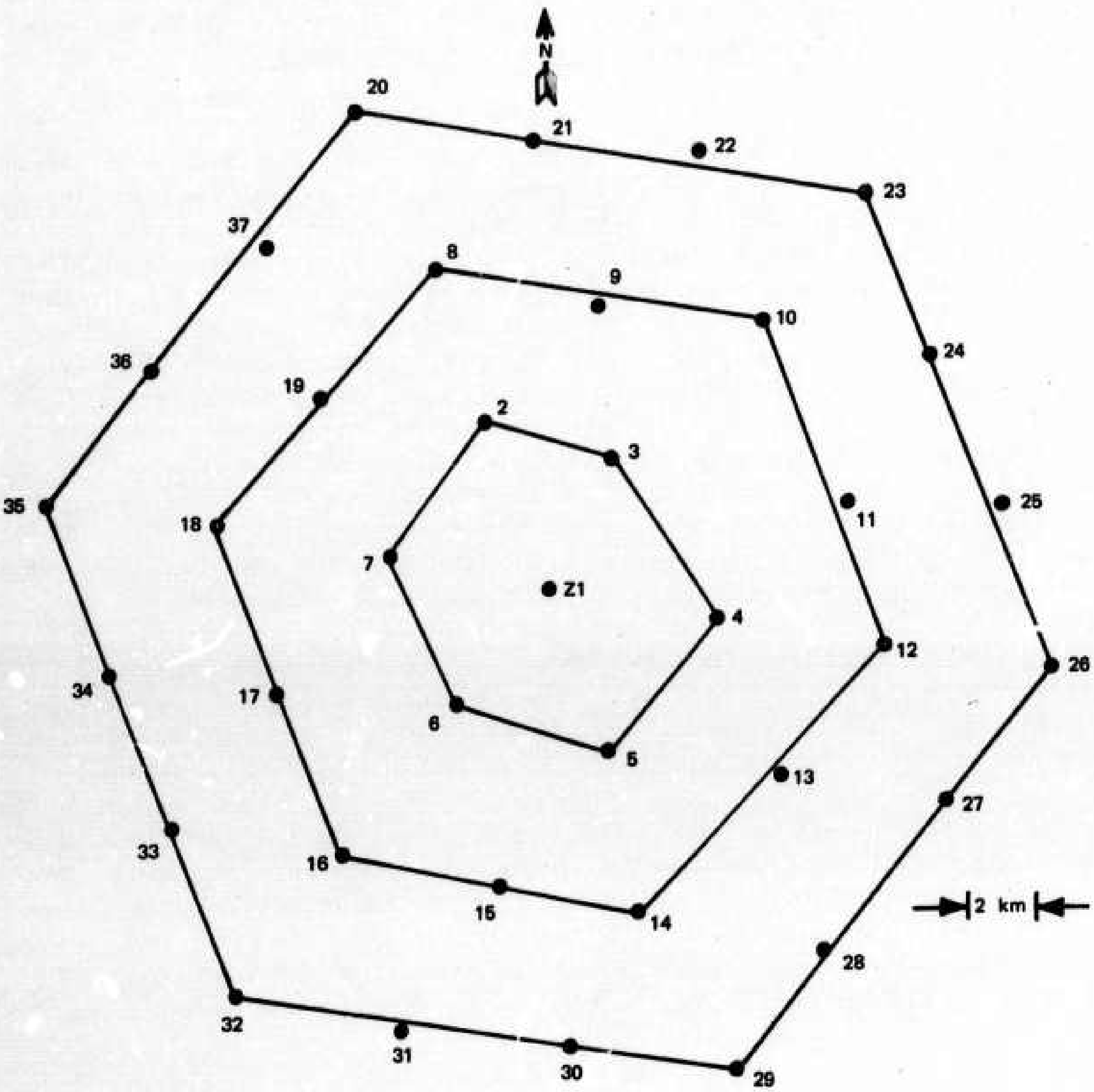
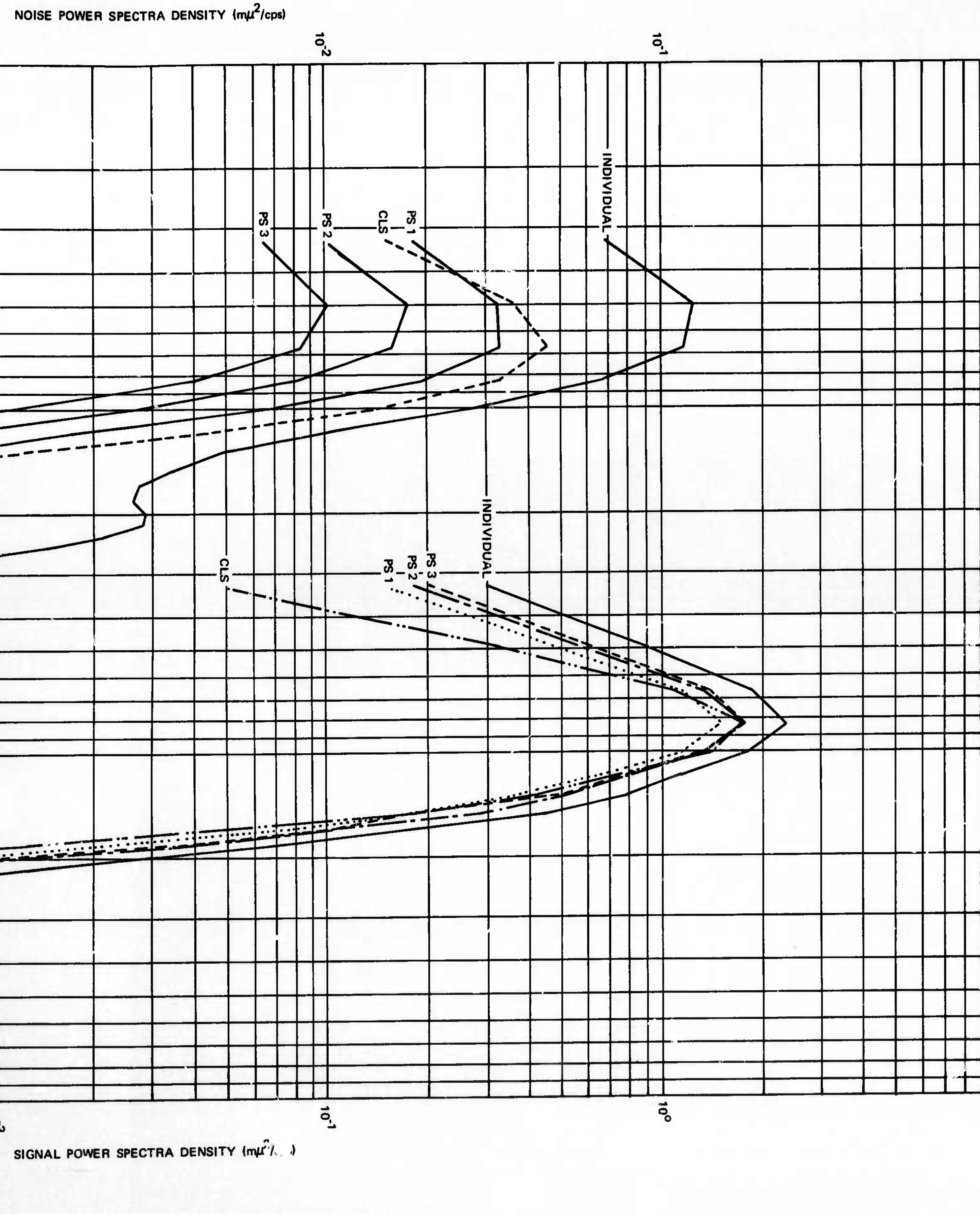


Figure 11. Tonto Forest Seismological Observatory 37-element array G 4262



NOISE POWER SPECTRA DENSITY ($m\mu^2$/cps)
10^{-2}
10^{-1}
INDIVIDUAL
PS 1
CLS
PS 2
PS 3
INDIVIDUAL
PS 3
PS 2
PS 1
CLS
10^{-1}
10^{0}
SIGNAL POWER SPECTRA DENSITY

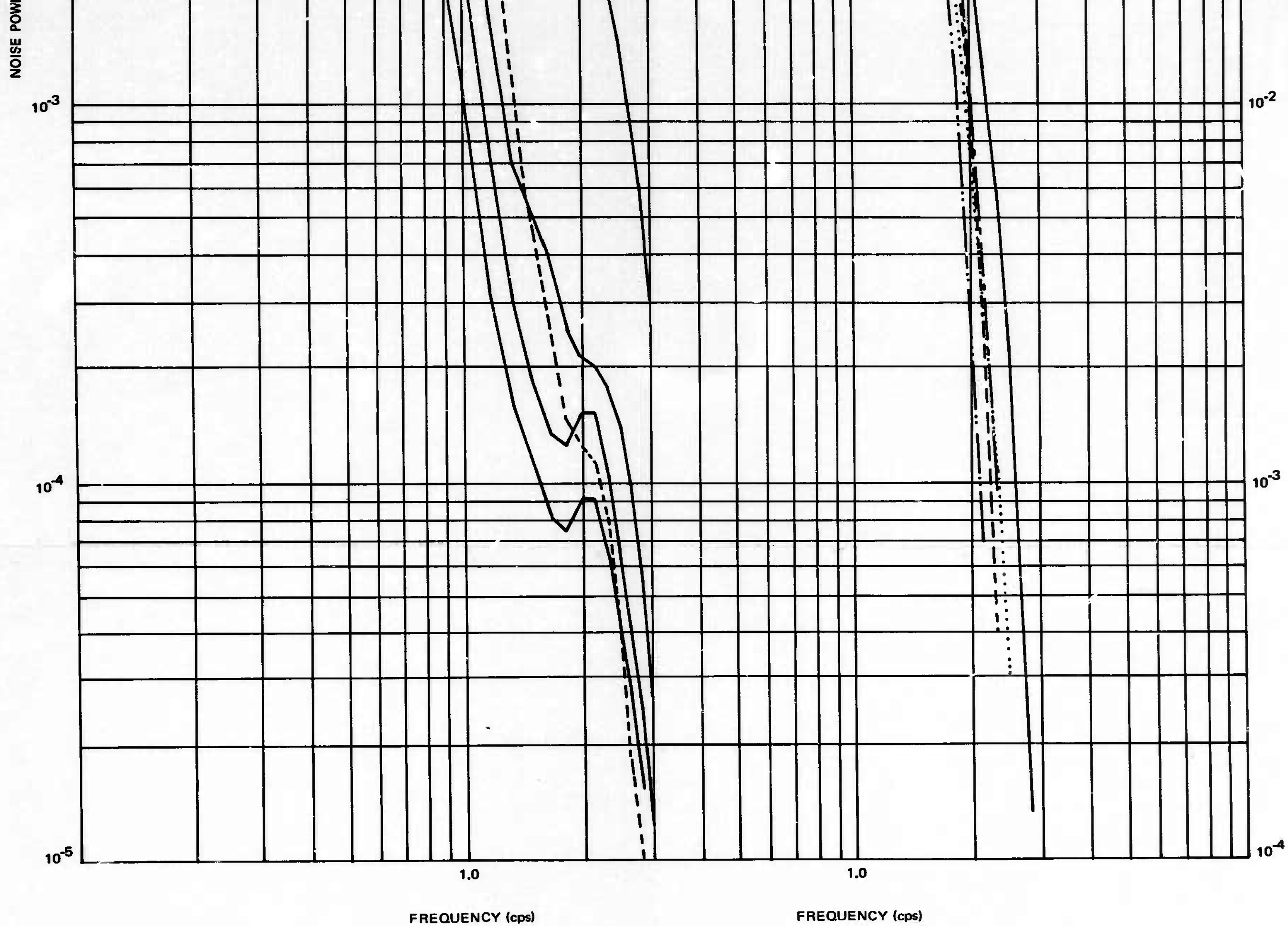


Figure 12. Power spectra of noise and signal for Atlantic Ridge event

G 4263

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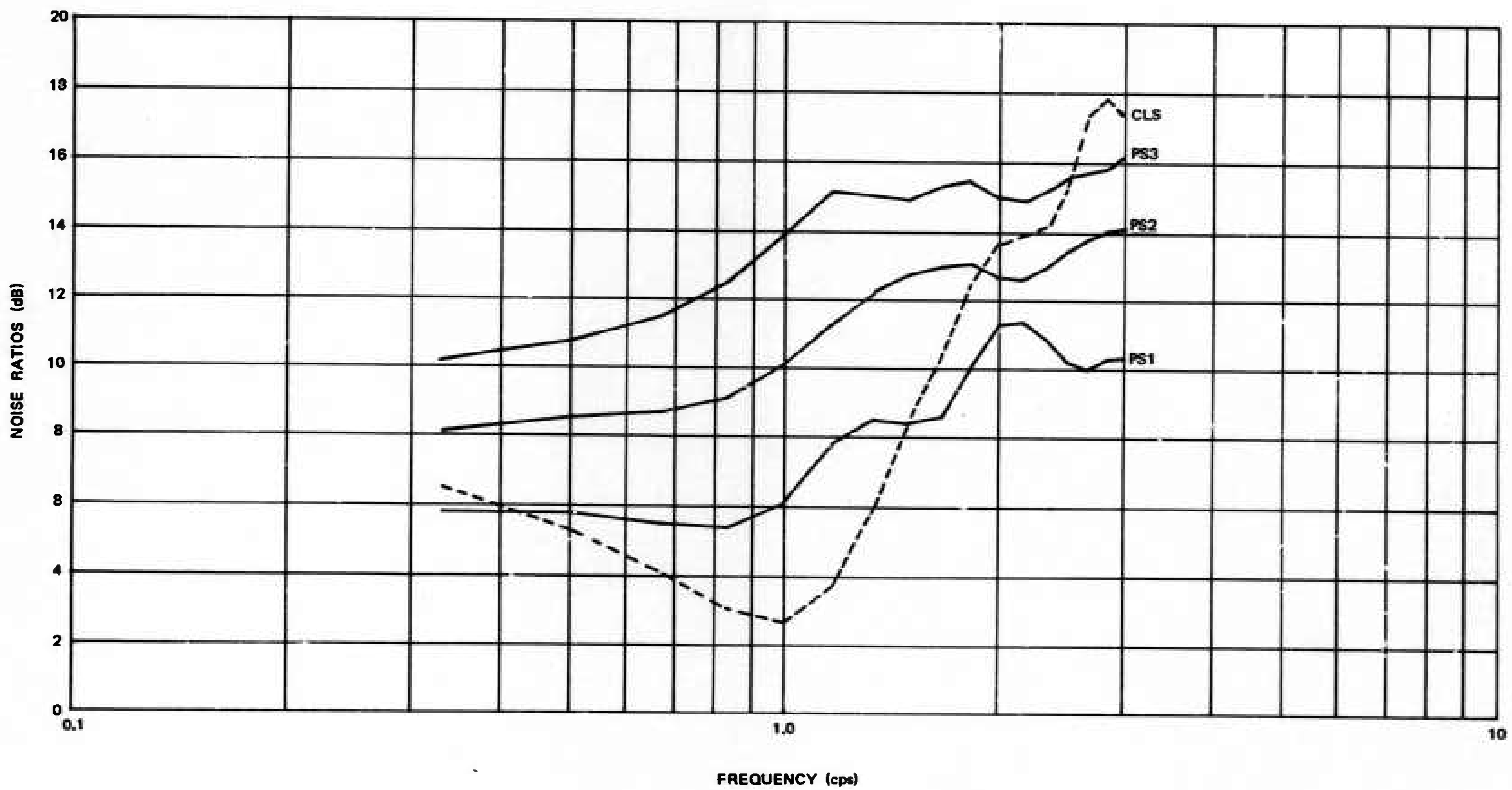

Figure 13. Ratios of noise spectra relative to the individual spectra for PS1, PS2, PS3, and CLS

G 4264

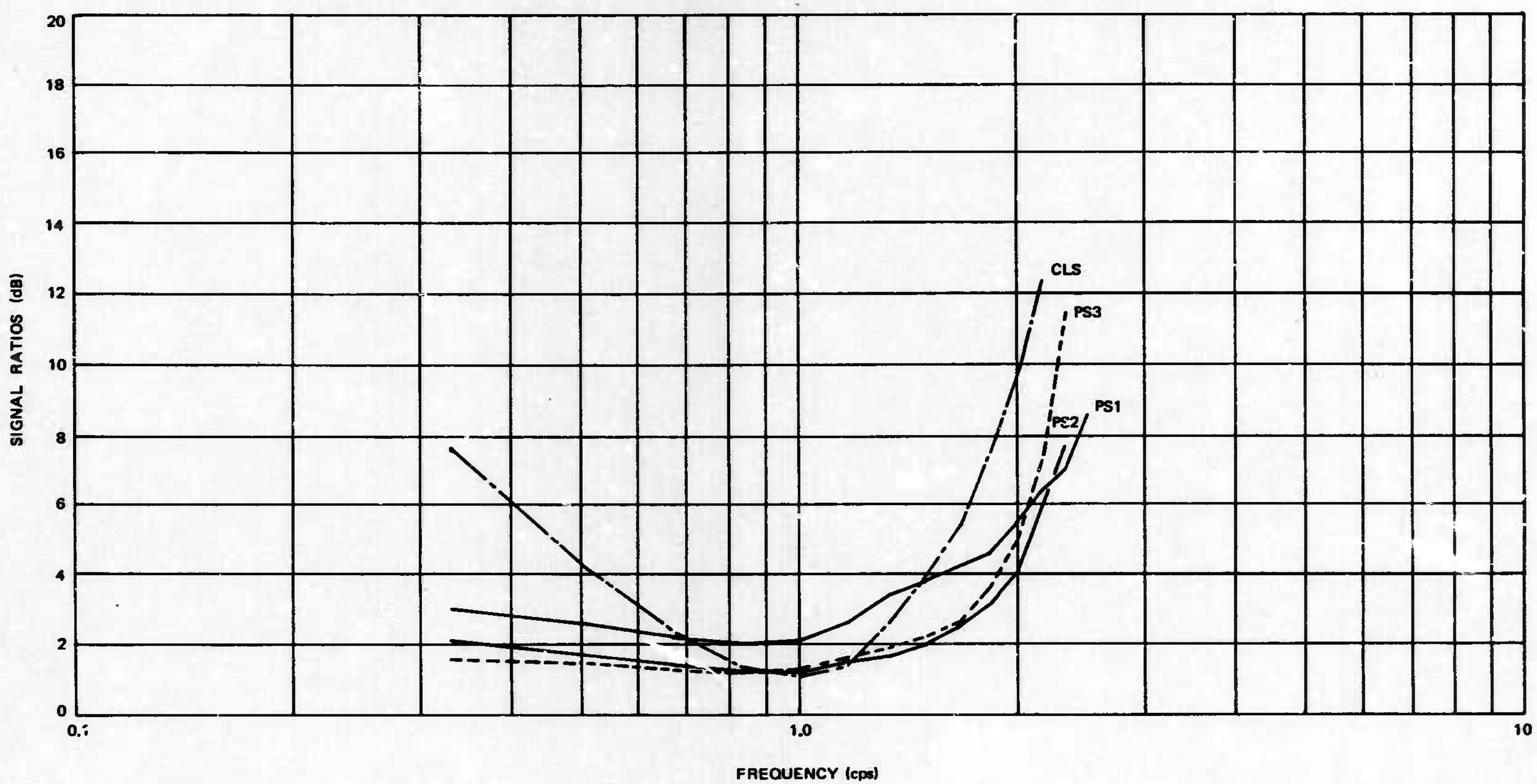

Figure 14. Ratios of signal spectra relative to the individual spectra for PS1, PS2, PS3, and CLS

G 4265

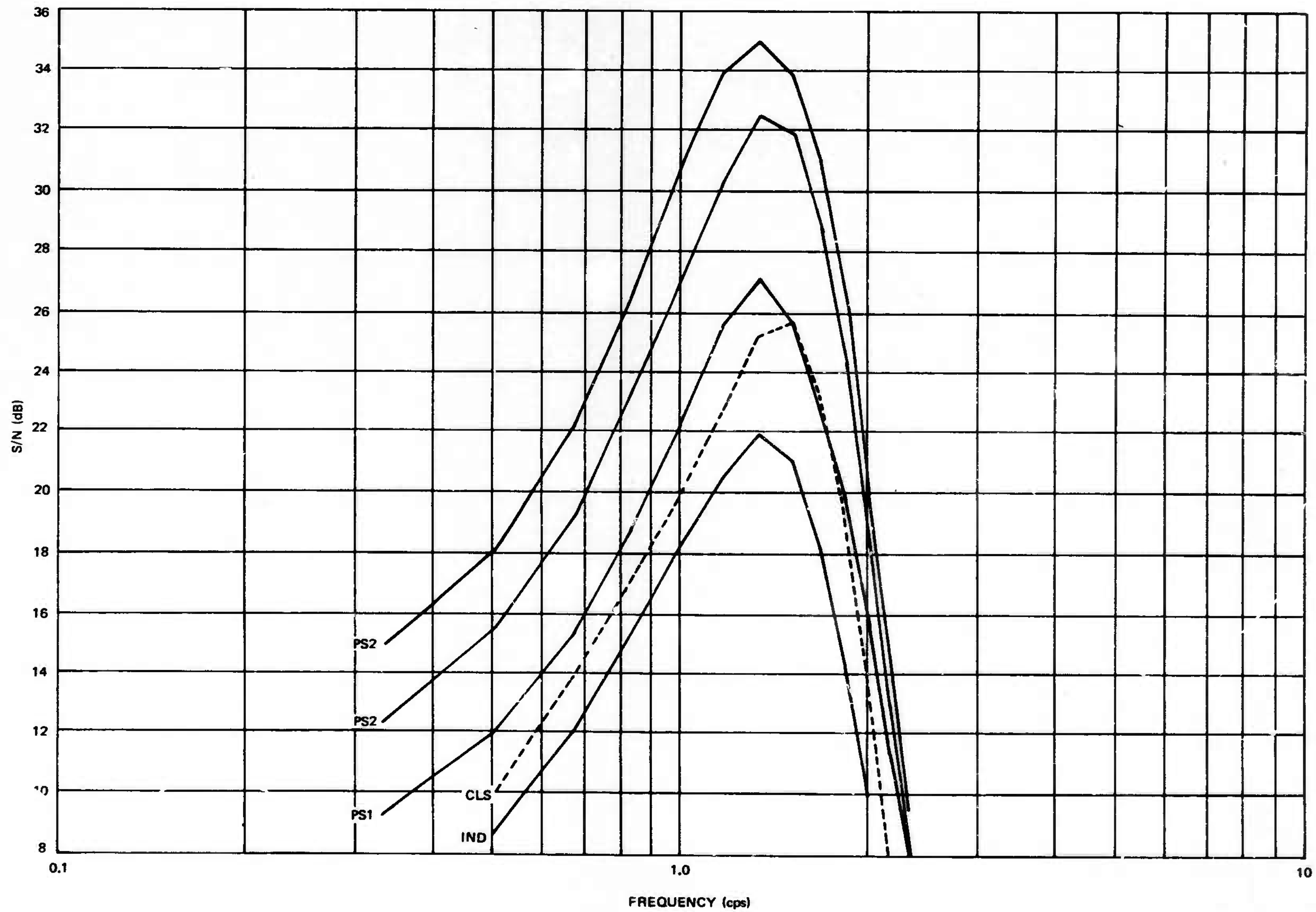

Figure 15. Signal-to-noise ratios for individual, PS1, PS2, PS3, and CLS for Atlantic Ridge event

G 4266

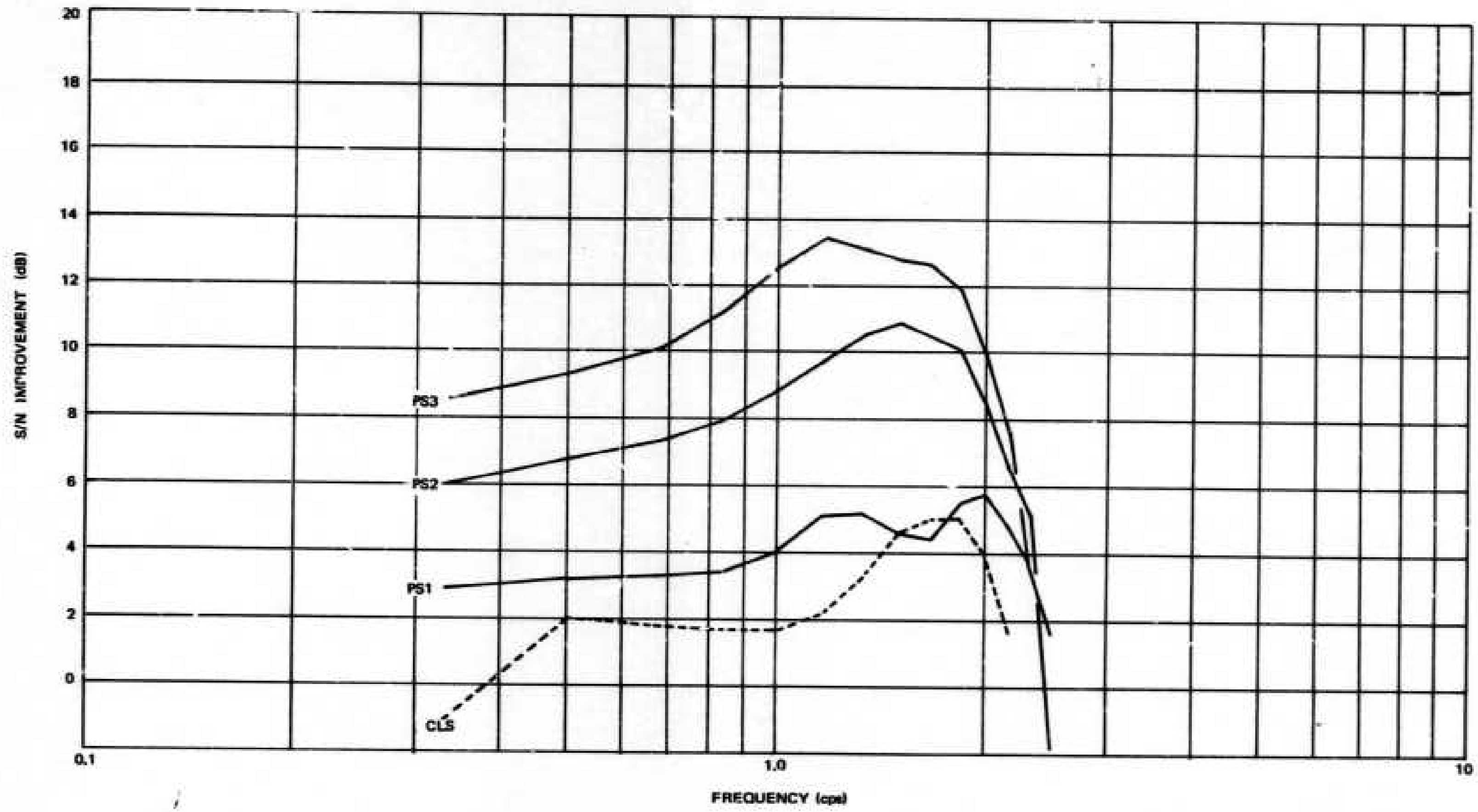

Figure 16. Signal-to-noise improvement ratios relative to individual for PS1, PS2, PS3, and CLS

G 4267

Table 6. Signal-to-noise improvement at three frequencies

Seismogram	Improvement at frequency of peak signal power	Improvement at 1.0 cps	Improvement at frequency of maximum S/N
PS1	3.4 dB	4.0 dB	5.2 dB
PS2	7.9 dB	8.8 dB	10.5 dB
PS3	11.2 dB	12.6 dB	13.1 dB
CLS	1.7 dB	1.7 dB	4.6 dB

APPENDIX TO TECHNICAL REPORT NO. 68-32

STATEMENT OF WORK TO BE DONE

F33657-68-C-0766

STATEMENT OF WORK TO BE DONE
(AFTAC Project Authorization No. VELA T/8702/S/ASD) (32)

Tasks:

a. Operation:

(1) Continue operation of the Tonto Forest Seismological Observatory (TFSO), normally recording data continuously.

(2) Evaluate the seismic data to determine optimum operational characteristics and make changes in the operating parameters as may be required to provide the most effective observatory possible. Addition and modification of instrument are within the scope of work. However, such instrument modifications and additions, data evaluation, and major parameter changes are subject to the prior approval of the AFTAC project officer.

(3) Conduct routine daily analysis of seismic data at the observatory and transmit daily seismic teletype reports to the Coast and Geodetic Survey, Environmental Science Services Administration, Washington Science Center, Rockville, Maryland, using the established report format and detailed instructions.

(4) Record the results of daily analysis on magnetic tape in a format compatible with the automated bulletin program used by the Seismic Data Laboratory (SDL) in their preparation of the seismological bulletin of the VELA-UNIFORM seismological observatories. The format should be established by coordination with SDL through the AFTAC project officer. The schedule of routine shipments of these prepared magnetic tapes to SDL will be established by the AFTAC project officer.

(5) Establish quality control procedures and conduct quality control, as necessary, to assure the recording of high quality data on both magnetic tape and film. Past experience indicates that a quality control review of one magnetic tape per magnetic tape recorder at the observatory during each week is satisfactory unless quality control tolerances have been exceeded and the necessity of additional quality control arises. Quality control of magnetic tape should include, but need not necessarily be limited to, the following items:

(a) Completeness and accuracy of operation logs.

(b) Accuracy of observatory measurements of system noise and equivalent ground motion.

(c) Quality and completeness of voice comments.

(d) Examination of all calibrations to assure that clipping does not occur.

(e) Determination of relative phase shift on all array seismographs.

(f) Measurement of DC unbalance.

(g) Presence and accuracy of tape calibration and alignment.

(h) Check of uncompensated noise on each channel.

(i) Check of uncompensated signal-to-noise of channel 7.

(j) Check of general strength and quality of timing data derived from National Bureau of Standards Station WWV.

(k) Check of time pulse modulated 60 cps on channel 14 for adequate signal level and for presence of time pulses.

(l) Check of synchronization of digital time encoder with WWV.

(6) Provide observatory facilities, accompanying technical assistance by observatory personnel, and seismological data to requesting organizations and individuals after approval by the AFTAC project officer.

(7) Maintain, repair, protect, and preserve the facilities of TFSO in good physical condition in accordance with sound industrial practice.

b. Instrument Evaluation: On approval by the AFTAC project officer, evaluate the performance characteristics of experimental or off-the-shelf equipment offering potential improvement in the performance of observatory seismograph systems. Operation and test of such instrumentation under field conditions should normally be preceded by laboratory test and evaluation.

c. Special Investigations:

(1) Conduct research investigations as approved or requested by the AFTAC project officer to obtain fundamental information which will lead to improvements in the detection capability of TFSO. These programs should take advantage of geological, meteorological, and seismological conditions of the observatory. The following special studies should be accomplished:

(a) Evaluate the beam-steering capabilities of the 30-kilometer long- and short-period vertical seismometer arrays.

(b) Determine the detection capabilities of the 30-kilometer long- and short-period vertical seismometer arrays.

(c) Study the properties of the noise field with the new arrays.

(d) Determine the reliability of instrumentation in the new arrays.

(2) Research might pursue investigations in, but is not necessarily limited to, the following areas of interest: microseismic noise, signal characteristics, data presentation, detection threshold, and array design (surface and shallow borehole).

(3) Prior to commencing any research investigation, AFTAC approval of the proposed investigation and of a comprehensive program outline of the intended research must be obtained.

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11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
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13. ABSTRACT

This is a report of the work accomplished on Project VT/8702 from 1 April through 30 June 1968. Project VT/8702 includes the operation, evaluation, and improvement of the Tonto Forest Seismological Observatory (TFSO) located near Payson, Arizona. It also includes special research and test functions carried out at TFSO and research and development tasks performed by the Garland, Texas, staff using TFSO data. ( )

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14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Long-Period Array						
37-Element Short-Period Array						
Seismograph Operating Parameters						
Beam-Steering Evaluation						
High-Frequency Seismograph						
Multichannel Filter Evaluation						