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GEOSCIENCES OPERATIONS

TEXAS INSTRUMENTS
INCORPORATED
SCIENCE SERVICES DIVISION

VT/5054

CUMBERLAND PLATEAU SEISMOLOGICAL OBSERVATORY

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SECTION I

INTRODUCTION

Texas Instruments Incorporated (TI) formally assumed responsibility for operation of the Cumberland Plateau Seismological Observatory (CPSO) May 1965.

CPSO is operated for the Air Force Technical Applications Center (AFTAC) under the sponsorship of the Advanced Research Projects Agency (ARPA) as part of program VELA UNIFORM.

During these first three months of operation, routine analysis and operation of the station has continued and specific research studies on ambient noise, signal-to-noise ratios and detection capability have been initiated. In addition, a digital multichannel filter unit is being built by TI for installation early in 1966.

This first quarterly progress report reviews the analysis, engineering and research tasks which have been performed or initiated during May, June and July of 1965.

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SECTION II

OPERATION

A. DESCRIPTION

A detailed description of the technical instrumentation and facilities at the observatory can be obtained from the Information Bulletin, Seismological Observatories VELA UNIFORM VT/1124 dated 14 August 1963.

For this report, a general description of the station operation and instrumentation follows.

CPSO normally records seismic data 24 hours a day. The instruments are spaced in an array as shown in Figure II-1. Positions 1 through 19 represent short-period vertical Johnson-Matheson seismometers (Z).

At position 8, in addition to the Z instrument, are

- 2 short-period horizontal Johnson-Matheson seismometers (SPH)
- 1 intermediate-band vertical Melton seismometer (IBZ)
- 2 intermediate-band horizontal Melton seismometers (IBN) (IBE)
- 1 broadband vertical Geotech 7505 seismometer (BBZ)
- 2 broadband horizontal Geotech 7505 seismometers (BBN) (BBE)
- 1 long-period vertical Geotech 8700 A seismometer (LPZ)
- 2 long-period horizontal Geotech 8700A seismometers (LPN) (LPE)
- 1 anemometer (WI)
- 1 earth-powered Benioff seismometer (V)

For analysis and storage, all data are recorded on two 14-channel tape recorders and three 16-channel develocorders. See Tables II-1 and II-2 for trace identification.

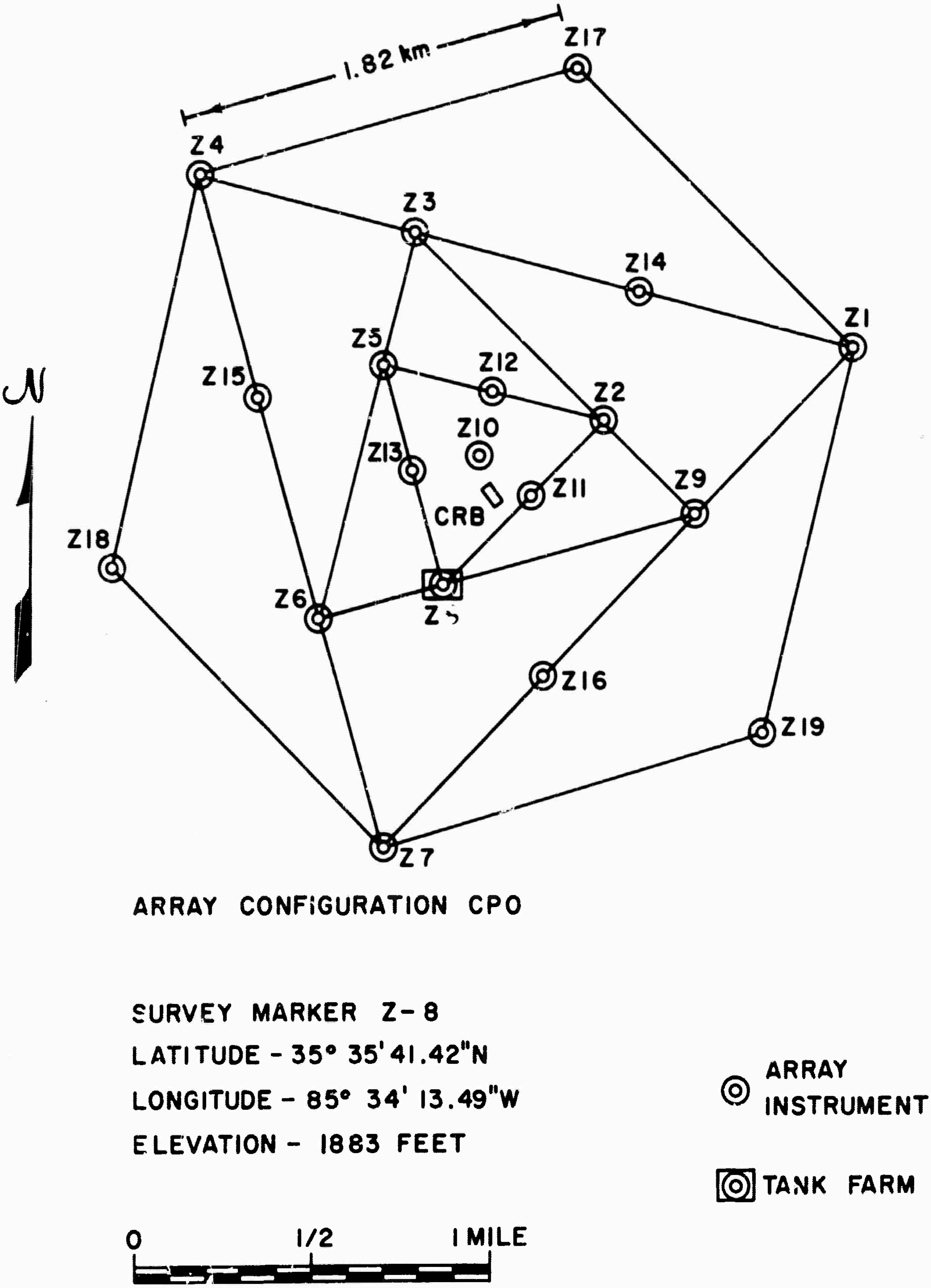

Figure II-1. Array at Cumberland Plateau Seismological Observatory

Table II-1

DEVELOCORDER TRACE ASSIGNMENTS

Channel Number	Short-Period Primary Data	Short-Period Secondary Data	Long-Period Primary Data
1	V (earth-powered Benioff)	V	WI
2	Z 7	Z 8 (low gain)	MS
3	Z 1	Z 8 (high gain)	LPZ (low gain)
4	Z 4	Σ 11, 12, 13	LPN (low gain)
5	Z 2	Σ 1, 7, 17, 18	LPE (low gain)
6	Z 3	Σ 4, 7, 17, 19	LPZ (high gain)
7	Z 5	Σ 1, 4, 7, 17, 18, 19	LPN (high gain)
8	Z 6	Σ 3, 6, 9, 14, 15, 16	LPE (high gain)
9	Z 9	Σ 1, 3, 4, 6, 7, 9, 10, 14, 15, 16	ML (uncalibrated LP microbarograph)
10	Σ 10-19	MS (uncalibrated short-period microbarograph)	BBZ
11	Σ TF (filtered 1-19)	WI (anemometer)	BBN
12	Σ T (1-19)	Σ T (high-gain sum)	BBE
13	Z 8	IBZ	Z 8
14	SPN	IBN	WWV
15	SPE	IBE	
16	WWV	WWV	

Table II-2

TAPE RECORDER TRACE ASSIGNMENTS

Channel Number	Tape Recorder No. 1	Tape Recorder No. 2
1	TCDMG (Time Code)	TCDMG
2	Z 1	LPZ
3	Z 2	LPN
4	Z 3	LPE
5	Z 4	SPN
6	Z 5	SPE
7	Compensation	Compensation
8	Z 6	IBZ
9	Z 7	IBN
10	Z 8	IBE
11	Z 9	BBZ
12	Z10	BBN
13	ΣTF	BBE
14	WWV	WWV

Nominal operating gains of the instruments are

Short Periods	400K
ΣTF	2000K
ΣT	1000K
ΣL	400K
Intermediate Bands	60K
Broadbands	6K
Long-Period Verticals	30K
Long-Period Horizontals	10K

B. ANALYSIS

1. Station Analysis — Routine

Analysis has proceeded on schedule in a normal, routine manner.

In analyzing an event, all phases are timed to the nearest 0.1 sec. A phase, by definition, consists of a notable change in either period or amplitude.

Most common phases identified are P, pP, PP, PPP, PKP, S, SKS, SS, SSS, Lq, and Lr. Less common phases are PKKP, SKKS, PcP, ScS and other core phases. When a phase cannot be identified, it is recorded as simply e or i.

Analysis is often hampered by high noise and develocorder malfunctions. During periods of high microseismic activity, identification of low-level signals requires careful scrutiny of data from all components.

All events for which a P-type phase is recorded are made known daily to the USC&GS by telegram. These messages contain the arrival times of P, the period of the maximum pulse and the amplitude (millimicrons), and the arrival times of L, Lq and Lr. For events occurring less than 16° from the observatory, period and amplitude of the earliest arrival are recorded in the same manner as that for P.

2. Station Analysis — Special

Two projects are underway at CPSO. One is an event library consisting of indexed photographs of special or interesting events taken from film. The second project, which is just starting, is a study of quarry blasts. This study will make possible the construction of accurate travel-time curves for local, near-regional and regional events recorded at CPSO. To date, most effort has been spent in selecting those quarries best located for this study and the best method of obtaining accurate origin times. St. Louis University and Xavier University observatories have been contacted for cooperation in this study.

C. ENGINEERING

1. Field Conditions

Instrument maintenance and repair is difficult because of the many swamps in the area. In general, the surface geology consists of a thinly-bedded, poorly indurated sandstone and sandy shale underlain by limestone. In valleys where erosion has removed the sandstone cap, sinkholes have formed in the limestone resulting in the aforementioned bogs and swamps.

To avoid swampy areas and permit access to the vaults, trails have been cut along the ridges with power saws. However, when cable must be replaced, existing cable trails through the swamps must be followed. Then, it becomes necessary to use a 4-wheel-drive vehicle with winch to traverse the low, boggy areas.

2. Instrumentation

In general, the instruments functioned reasonably well. Some problems experienced during the period of this report were:

(1) Develocorders' film stoppages. This is due mainly to severe corrosion caused by extended exposure to photographic chemicals.

(2) Secondary timing inoperative due to power failure.

(3) Stray d-c voltages on the console. This trouble still exists, and Nicad is investigating ways to test for cell leakage.

(4) Air-conditioning spikes, particularly on the LP's.

(5) Tape recorder spikes caused by the signal discriminators, record oscillators and noisy, worn tapes.

(6) Instrument spikes on the SP's in damp weather.

(7) PTA's drifting even with stable line voltage. This is probably due to ageing of the filters, causing the capacitors to change value and to leak.

(8) Many cables not identified and much extra cable laid without removing the old, replaced cable.

(9) Faulty relays. Several relays have been replaced in the power control unit.

(10) Slips in the time encoder. This cannot be correlated to any transient at present.

(11) Inaccurate indications on the voltage regulators.

3. Recommendations

The instruments can be repaired and modifications documented for future reference with adequate replacement spares. This will allow station personnel to substitute spares while the original unit is being overhauled.

This is especially true of the develocorder, time encoder, secondary power supply, and power control units.

A program to revise the standard procedures manual should be considered concerning instrument preventive maintenance compatible with the needs of this station. In addition, wiring diagrams should be revised to incorporate modification which would allow trouble-shooting operations without extensive wiring traceout.

4. Security

At the start of operation, a TI security officer inspected the station and informed all personnel of regulations and procedures for maintaining facility security.

D. QUALITY CONTROL

All data from CPSO are sent to the Dallas offices for quality control. Film quality and data analysis are checked by the Analysis section. Tape quality is checked at the Computer Facilities Center.

Control Post Analysis forms are sent to the Geotechnical Corporation, Garland, Texas, for key-punching by the 20th of the month following the month in which the data were recorded. Tape data, film data and their associated logs are sent to Teledyne, Inc. on the 1st and 15th, respectively, of the second month following the month in which they were recorded.

Overall quality of the film and tape has been good. However, the lens on one develocorder has apparently been etched by the chemicals, and the drive and takeup motors do not operate at a constant speed. Oxide buildup on the tape recorder heads and excessive wear from continuous use have caused FM dropouts and noise. As a result of continuous use, many of the tapes are in poor condition.

1. Develocorder Film QC

Film shipments are checked in the following manner:

(1) Control Post Analysis forms are checked for completeness and legibility to reduce errors in key-punching.

(2) Daily calibration logs are checked for completeness, and comments are noted concerning problems encountered in operation.

(3) Film quality is compared with comments in calibration logs.

(4) Data quality is checked by analysis of film for comparison with analysis forms. In this analysis,

- A check is made for missed events
- Phase identification is verified
- Measurements of events are made to check accuracy
- Calibration measurements are checked

In the first six weeks of operation, all film data were checked to insure high-quality data until the analysis personnel were more familiar with the operation. During this time, very few events were missed by station analyst, the majority being of a questionable nature. There were some errors in the completion of the forms such as wrong instrument gains, wrong phase detection number and incorrect numbering of events. At present, film quality and analysis is such that every 5th or 6th day's recording is checked in detail.

2. Magnetic Tape QC

The computer facilities section performs the following checks on one tape per week per machine. All other tapes are spot-checked for quality.

(1) Tape System Noise

- A visual inspection is made for dropouts and spikes
- Peak-to-peak wow and flutter measurements given in percent of deviation are made inside seismic bandpass only
- A check is made for outside noise spikes such as develocorder takeup, etc.
- Deterioration of data due to oxide buildup on heads is checked

(2) Tape Alignment

- Center frequency and ± deviations are checked for alignment
- Average frequency readings are taken at three places to check for frequency drift of modulator
- Sine calibration is checked for level, distortion and phasing

(3) Seismometer Calibration

- Visual inspections are made of relative amplitudes and signal level
- Relative phasing is checked

(4) Time and Timing

- Voice quality, WWV quality and comments are checked
- Time code and WWV are checked for synchronization
- Tape start and calibration times are checked

The results from approximately one-half of the tapes received are as follows:

(1) Tape System Noise

- Wow and flutter are approximately ± 0.4 percent pp within 0-10 cycles bandpass on both transports, giving a dynamic range of 50 db when played back with compensation
- Data appear to be spike-free

(2) Tape Alignment

Frequency measurements have been made only by visual inspection on a scope; however, alignment appears very close.

Since the tape recorder heads were replaced in June and July, the quality of the data has greatly improved. There are very few FM drop-outs, and noise level has been lowered.

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SECTION III

RESEARCH

A. PLANNED RESEARCH ACTIVITIES

The research activity planned for Cumberland Plateau Seismological Observatory (CPSO) will generally be directed toward a better understanding of the noise and signal fields at the station location, with the ultimate goal of obtaining maximum station detection capability through the use of optimum multichannel processing.

The following tasks will be accomplished in reaching this goal. As the research proceeds through the various analysis stages, small deviatic may be made in this outline if results indicate a need for a modified ap oach.

1. Ambient Noise Studies

In order to develop an optimum multichannel processor operable at maximum efficiency over a given time period, the noise-field properties must be known over an equivalent long term. Specifically, the spatial organization of the noise field must be characterized on the basis of time stationarity. If the coherent noise field remains time-stationary over long periods of time, then optimum on-line processing of the station data can be accomplished with one multichannel filter set. Alternately, if the noise field changes with time (for example, time of day or seasonal variations), more than one filter set may be required for optimum processing.

The CPSO noise field will be studied for a 1-year period beginning May 1965 to determine daily and seasonal variations in the spatially organized noise field. This will be accomplished by computing 48 frequency-wavenumber spectra which characterize the spatially organized ambient noise on the basis of velocity and direction. The scheme for computing these spectra is to use seven noise samples per month for the odd-numbered months, and one noise sample per month for the even-numbered months beginning May 1965. The samples will be chosen within and between months so that an entire month's period will be sampled during the year. For example, in May, seven spectra will be computed for the dates 1, 4, 8, 12, 16, 20, and 24. One spectra will be computed for June 2, and the sampling cycles will be repeated b ing July 3. In addition to studying the daily and seasonal variation in the spatially organized noise field, routine studies of single-channel power density spectra for hourly, daily and seasonal variation will be conducted. Single-channel power density spectra will be computed using data recorded by the Z-10 seismometer for each day of May, June and July, and then, one spectrum will be computed for each week for the remainder of the year.

The noise field will also be analyzed for large variations in the percentage of spatially predictable noise. Twelve spatial prediction filters, one for each month of the year, will be developed from noise used to compute the frequency-wavenumber spectra. Although it is anticipated that the percentage of coherent noise will remain relatively constant, the results of prediction filtering will be of value in properly analyzing the frequency-wavenumber spectra.

Additional work will be conducted to develop dispersion data for spatially organized energy propagating in surface modes across the array. This information will provide a description of the noise velocity vs frequency for the fundamental and higher-order mode Rayleigh wave energy, which will result in a better understanding of the low-velocity noise field at CPSO. Knowledge of the dispersion data will be of use when analyzing wavenumber spectra and particularly helpful for describing spectra at the higher frequencies where wavenumber aliasing becomes a first-order problem.

The dispersion data will be extracted from frequency-wavenumber spectra of six quarry blasts as recorded by the 19-element array. Quarry blast, which will be detected as surface mode energy by the array, will have a high signal-to-noise ratio in wavenumber space. The 19-element array should provide sufficient resolution to show the fundamental and first-order mode Rayleigh wave energy. Additional data will also be obtained from the ambient noise frequency-wavenumber spectra to support the quarry blast data.

2. Signal-to-Noise Ratio Studies

A most important consideration for a particular array is the ability to perform signal extraction. Previous studies have investigated this problem by computing signal-to-noise ratios as a function of frequency and have ignored any possibility of directional property of the signal-to-noise ratio. Since the noise field at CPSO appears directional and highly predictable below 2.50 cps, the signal-extraction capability of the array will probably vary with frequency and vector wavenumber (azimuth and velocity).

A study of the frequency-wavenumber spectra developed in ambient noise research will be conducted to develop statistics for the expected signal-to-noise ratio as a function of frequency and vector wavenumber. This information will then provide an expected level of extraction for signal as a function of range, direction and frequency for beam-steer (time shift and sum) or straight sum type processing; i.e., the information can be used in determining the detectability for the station.

3. Detection Capability

The detection probability of an array depends upon the ambient noise field of the station. In previous work at CPSO to develop probability of detection statistics under Project VT/1124, threshold-of-detection statistics were developed from single-channel data which, in effect, ignored any directionality of the noise field.

These threshold magnitudes can be reduced considerably through optimum processing of the array outputs and consequent improvement of the signal-to-noise ratio. Improvement through optimum processing is highly dependent upon the directionality of the noise field and the direction from which the signal originates and is not limited by the intensity of the entire noise field.

The present work on detection capability will be an extension of the work reported in VT/1124 Final Report (August 1963) and will be directed toward developing a 2-dimensional probability of detection. Data used in developing the probability function will be obtained by applying directional optimum multichannel filters (MCF) to many events and considering the single-channel MCF outputs in a manner similar to that used in VT/1124.

A total of six directional MCF's will be developed from average-measured noise statistics. Each filter will pass a signal azimuth of 60° so that the six filters will cover an entire 360°. These filters will first be applied at the Dallas facility to develop initial statistics and for checkout. Then, they will be applied at the CPSO site using the digital MCF to produce a sufficient number of processed events so that a reasonable statistical average can be developed for estimating the 2-dimensional probability of detection.

4. Array Amplitude and Phase Variation

In present techniques for developing optimum multichannel filter systems from measured noise statistics, it is assumed that the array gain and phase configuration will remain constant over the period for which the filter was developed and applied. If the array gain and phase vary randomly in time, then the assumption of space stationarity for the signal model (and noise model if the noise field is space-stationary) becomes invalid, and the signal is treated as noise in the filtering operation. This problem can be avoided in filter development by statistically averaging the signal model for varying gain configuration, but at the loss of filter efficiency.[1]

1 Texas Instruments Incorporated, 1964, Array research — a re-evaluation of S/N improvement for CPSO using local noise: special Report No. 5, sponsored by AFTAC Project VT/4053, December 15.

A study of the array phase and amplitude variation as a function of frequency will be made using CPSO calibration data recorded over a 1-year period. These data will result in a histogram of the short-term and long-term phase and amplitude variation by instrument for the Z1 through Z10 short-period array.

Results of these statistics will be applied in developing the measured-noise multichannel filters described in subsection 3, as well as the filters to be permanently used in the on-line digital multichannel filter.

B. RESEARCH ACCOMPLISHED FROM MAY 1965 TO AUGUST 1965

The research activity accomplished during the first quarter of the contract has been devoted entirely to the ambient noise studies. Plans for the signal-to-noise ratio studies, detectability studies and amplitude and phase variation studies have been formulated, and data acquisition has begun.

Specific work which has been accomplished in the ambient noise studies includes establishment of a routine data acquisition and processing scheme for the single-channel power density spectra and ambient noise frequency-wavenumber spectra. Data from May and June 1965 have been completely processed, and additionally, frequency-wavenumber spectra (which will be used as a comparison for current data) have been computed for 1963 data collected under project VT/4053.

Figures III-1 and III-2 are single-channel absolute power density spectra computed for data collected by the Z10 seismometer for the months of May and June 1965, respectively. Comparison of these with spectra computed using 1963 data indicates that the general noise level and spectrum shape for CPSO show little or no change.[2] The sharp drop in power above 3.00 cps occurs in the spectra in Figures III-1 and III-2 because the data have been frequency-filtered to prevent aliasing when converted from FM to digital data.

There appear to be small daily and even hourly changes in the noise level at highly defined frequencies. Specifically, four prominent spikes appear in the power density spectra at 0.30, 1.40, 1.90, and 2.90 cps which vary considerably, depending upon the noise sample used in computing the spectra. The variation in power at 0.30 cps is normal and due to changes in the 3-sec-period microseismic energy. Future work will include a detailed investigation of the peaks at 1.40, 1.90 and 2.90 cps on a directional basis in vector wavenumber space. As more data become available, an attempt will also be made to relate the power changes of these peaks to a consistent time frame.

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2 Texas Instruments Incorporated, 1964, Array research semiannual technical report No. 1: sponsored by AFTAC Project VT/4053, May 15.

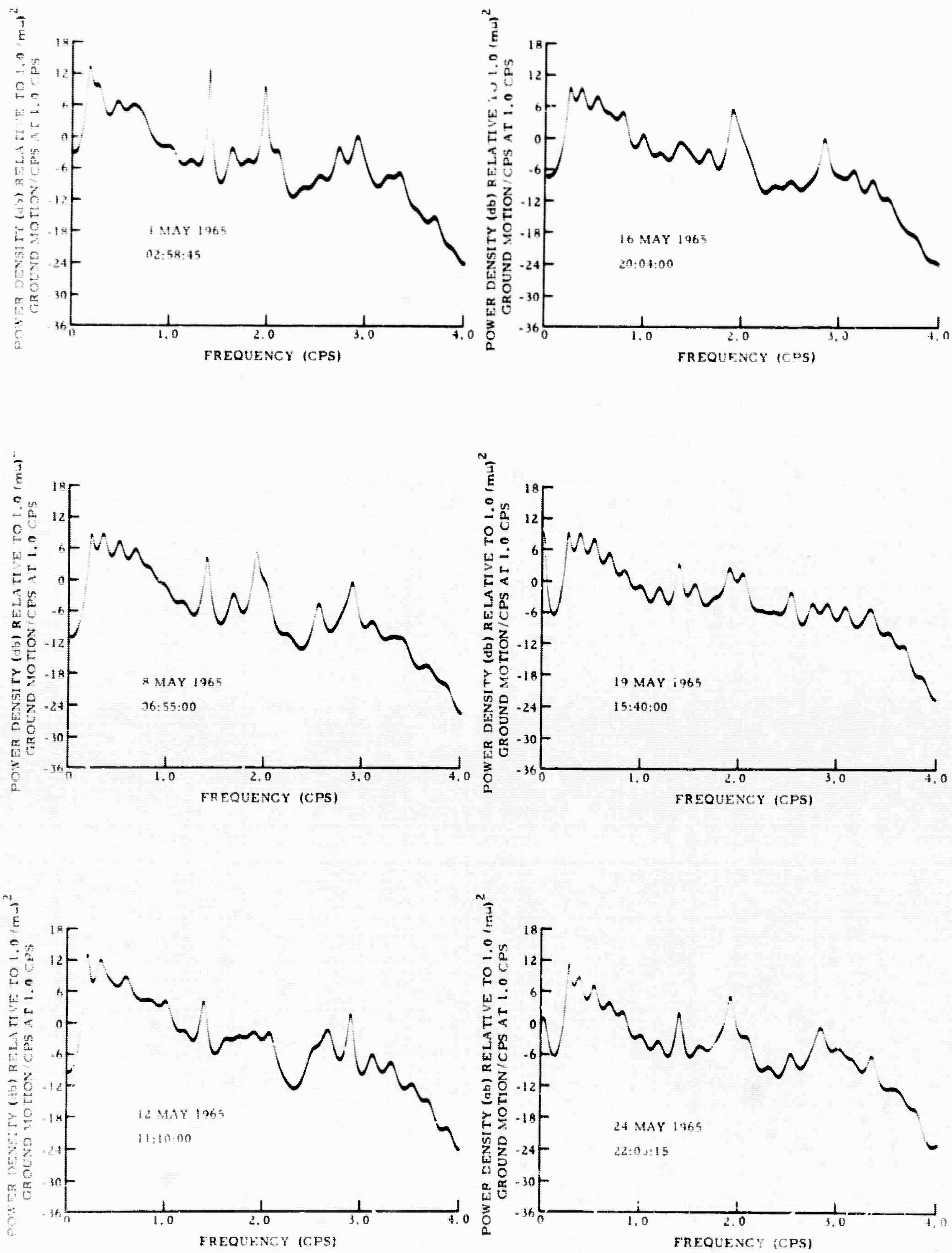

Figure III-1. CPSO Ambient Noise Power Density Spectra for May 1965

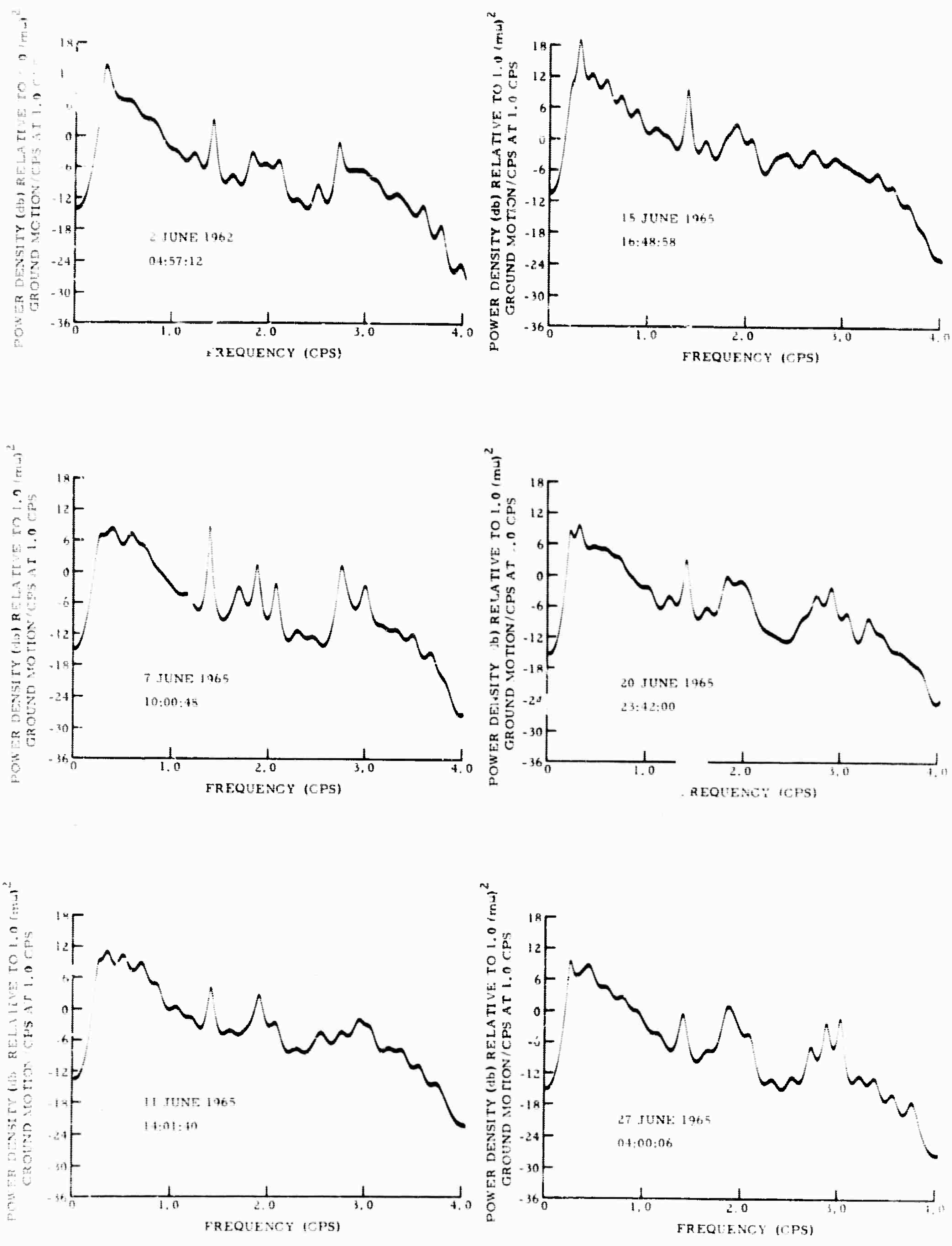

Figure III-2. CPSO Ambient Noise Power Density Spectra for June 1965

Frequency-wavenumber spectra computed over average correlation statistics of the following 1963 CPSO data are shown in Figures III-3 and III-4 for frequencies of 1.00 and 1.75 cps.

Noise Sample	Data	GCT Start Time
1	1/22/63	17:32:30
2	1/23/63	01:17:00
3	2/26/63	00:10:00
4	2/26/63	09:01:50
5	3/1/63	01:46:10

Figures III-5 through III-8 are frequency-wavenumber spectra computed over one noise sample for May and June 1965, respectively, at these same frequencies. In each of these figures, spatially organized energy which propagates from a particular direction will appear in wavenumber space as a lobe at a location identified by a vector pointing in the direction of the wave with origin at the $\vec{k}_x - \vec{k}_y$ axis intersection. For example, noise lobe 1 in Figure III-5 is propagating across the array from southeast to northwest.

The spatially organized noise field at 1.00 cps and 1.75 cps indicates a great deal of similarity between the 1963 and 1965 data. Slight differences in the spectra appear to be attributable to variations in power of the individual coherent noise lobes (numbers 1 through 7).

More conclusive evidence that the spatially organized noise field is remaining relatively constant in direction and velocity, but varying in power as a function of vector wavenumber, will require additional data which will be developed by using data from July 1965 to April 1966.

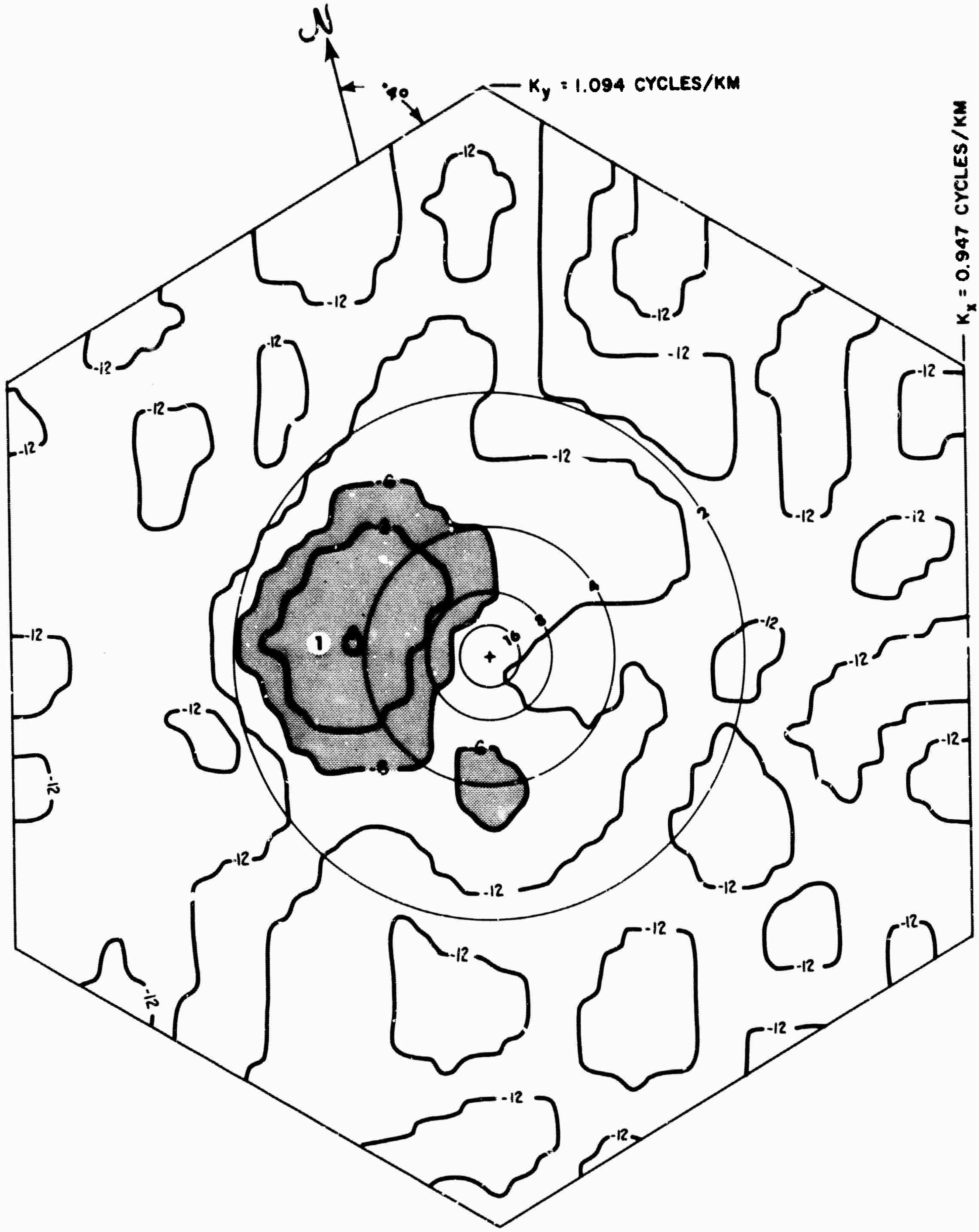

Figure III-3. CPSO Average Ambient Noise Frequency-Wavenumber Spectrum, 1963. f = 1.00 CPS

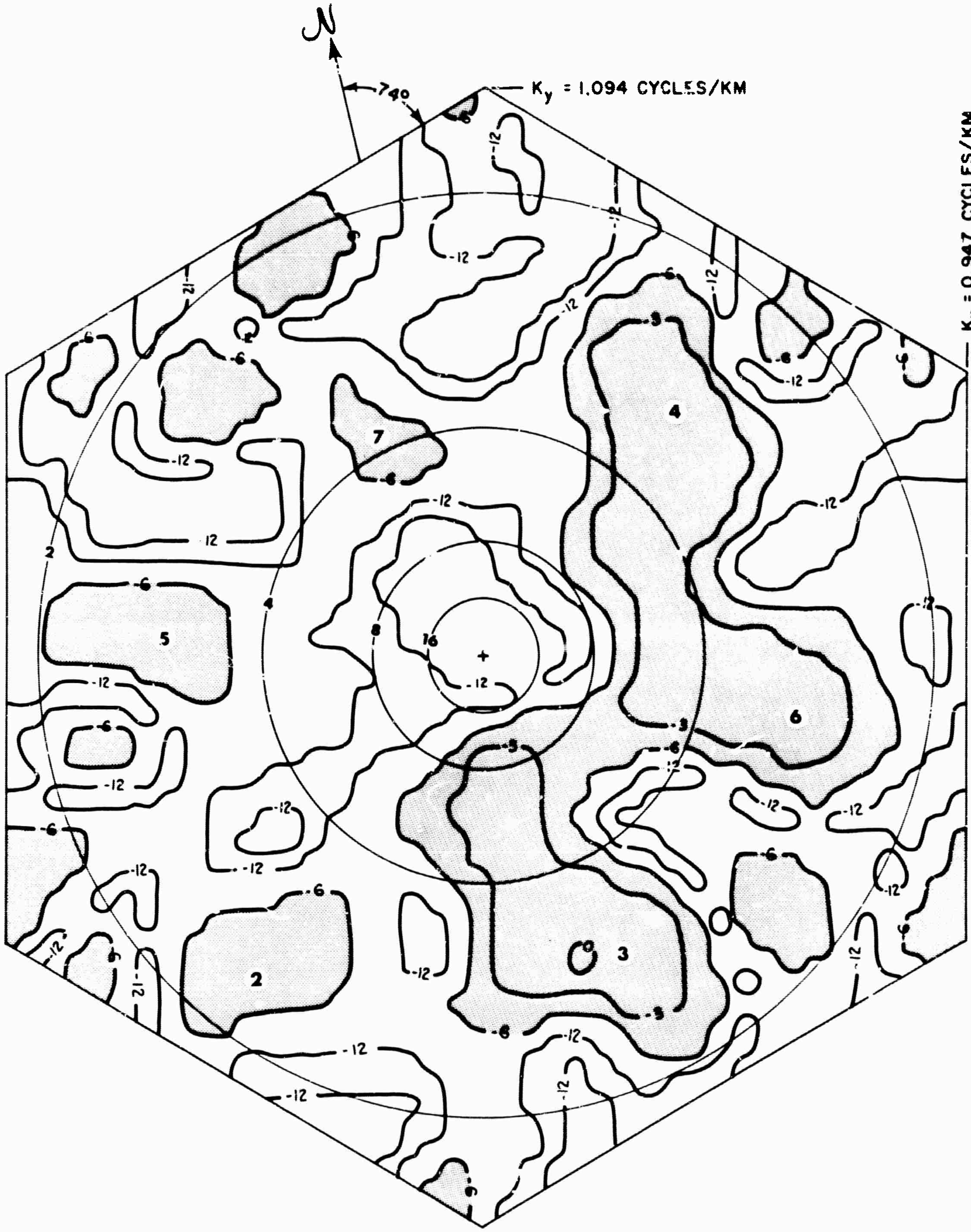

Figure III-4. CPSO Average Ambient Noise Frequency-Wavenumber Spectrum, 1963. f = 1.75 CPS

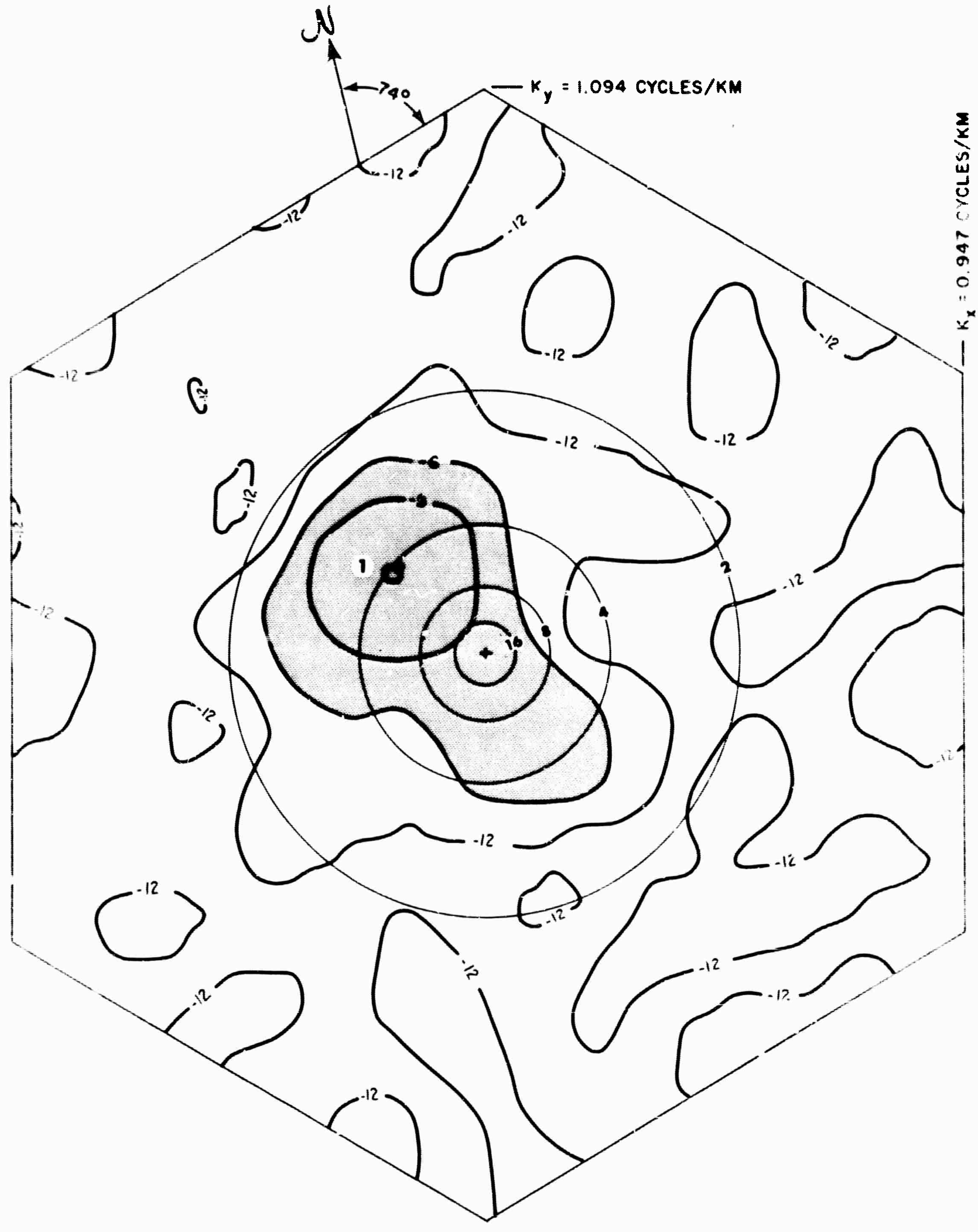

Figure III-5. CPSO .mbient Noise Frequency-Wavenumber Spectrum, May 1965. f = 1.00 CPS

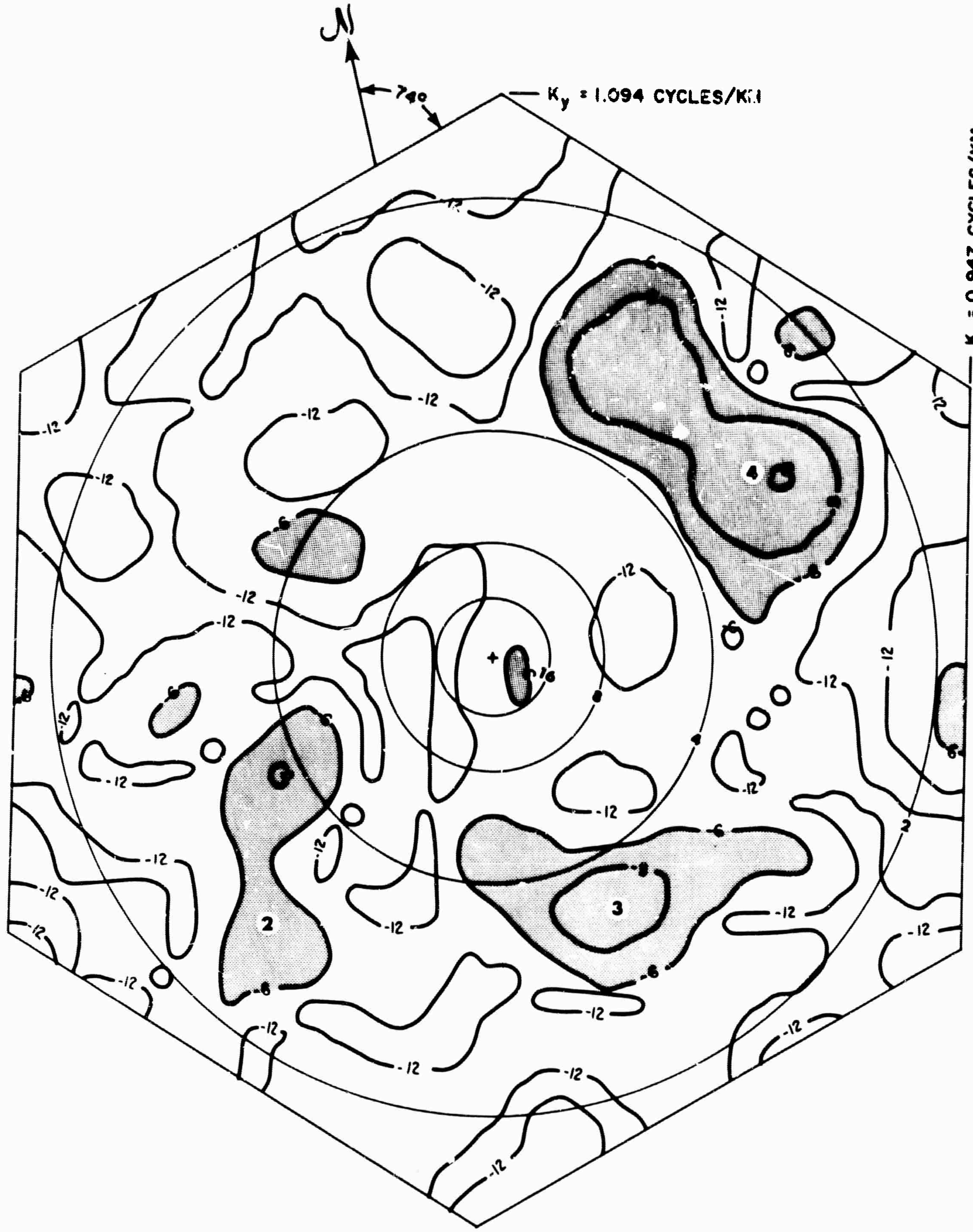

Figure III-6. CPSO Ambient Noise Frequency-Wavenumber Spectrum, May 1965. f = 1.75 CPS

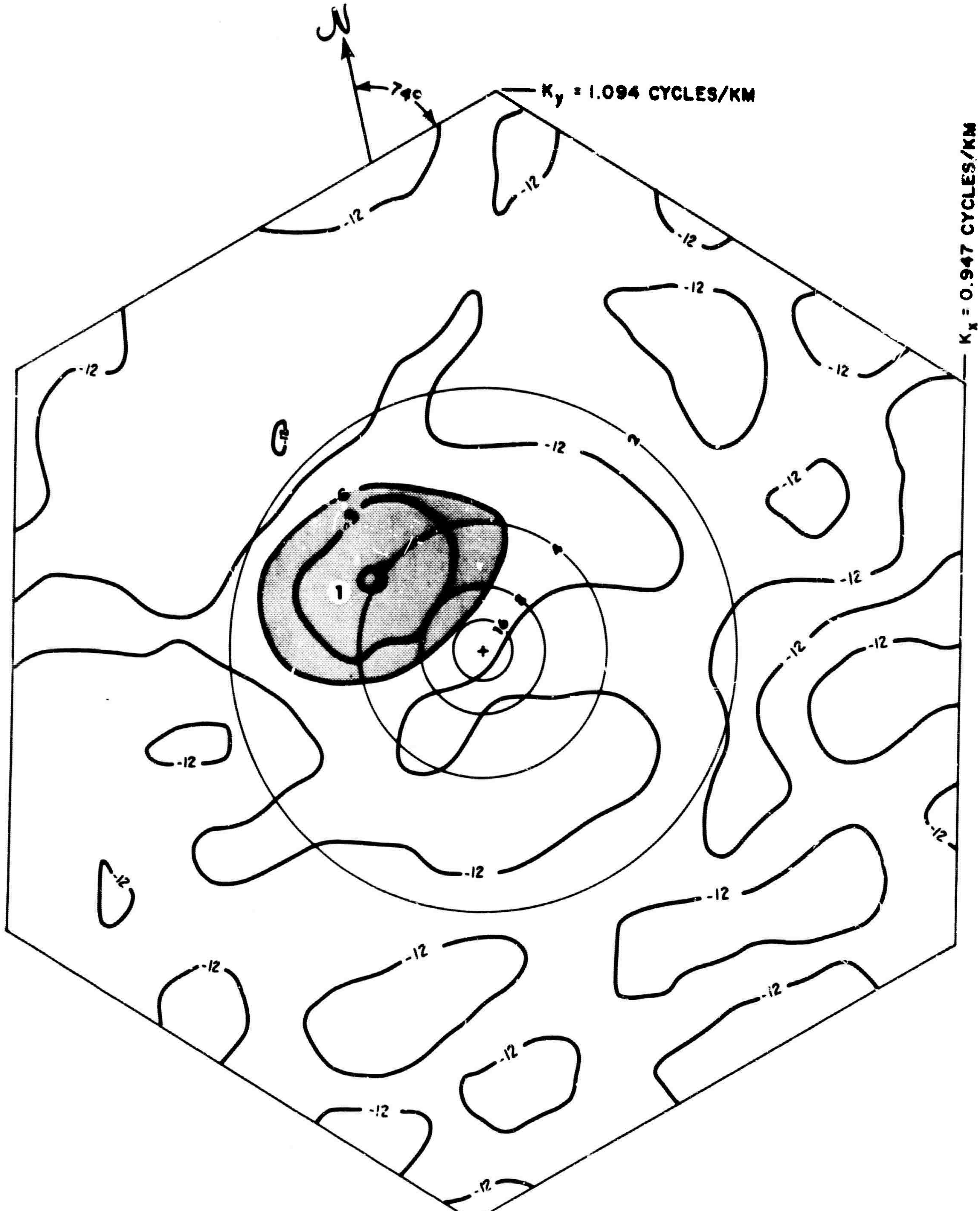

Figure III-7. CPSO Ambient Noise Frequency-Wavenumber Spectrum, June 1965. f = 1.00 CPS

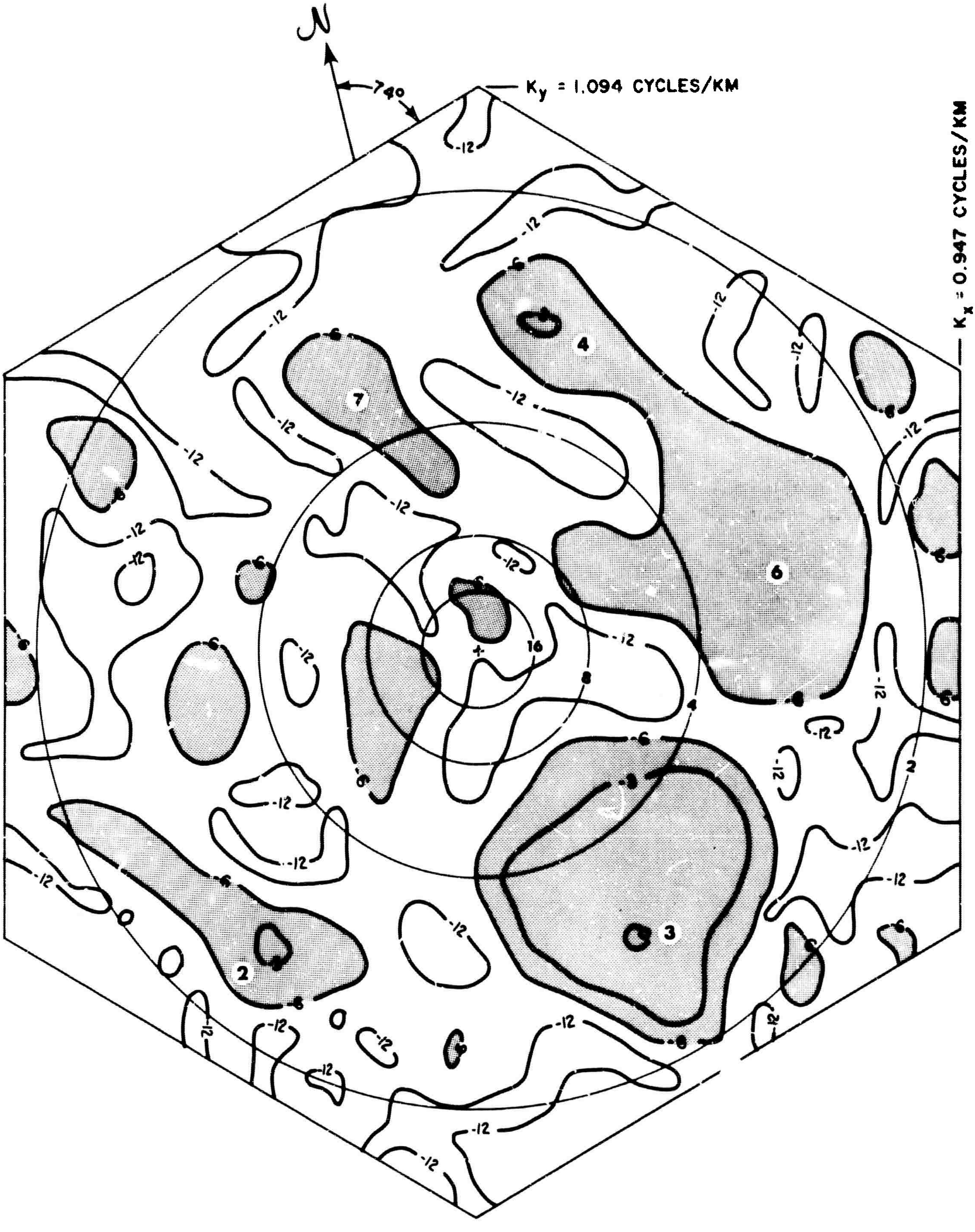

Figure III-8. CPSO Ambient Noise Frequency-Wavenumber Spectrum, June 1965. f = 1.75 CPS