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UNDERWATER SYSTEMS, INC.

TECHNICAL PROGRESS REPORT NO. 17

SPECTRAL ANALYSIS OF SEISMIC SIGNALS GENERATED
BY CHASE VII AND CHASE V DETONATIONS (U)

Prepared by:
David F. Young

Sponsored by:
ADVANCED RESEARCH PROJECTS AGENCY (ARPA)
OFFICE OF NAVAL RESEARCH (ONR)

Contract No. NONr 4026(00)
Project Code No. 3810
ARPA Order No. 218

28 November 1967

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ABSTRACT

The CHASE VII event consisted of the underwater explosion of 400 tons TNT equivalent at a nominal detonation depth of 3000 feet. The CHASE V event had a yield of 1000 tons and was detonated at a nominal depth of 4000 feet. Narrow band spectra of the seismic signals generated by these events as received at a number of LRSM stations and Vela observatories are presented. Source-receiver distances of selected stations range from approximately 700 to 5000 kilometers.

From the results obtained, it is concluded that:

(1) The odd harmonic series due to the detonation depth is readily identified in a majority of the spectra obtained for both the CHASE V and CHASE VII events.

(2) The bubble pulse frequency is not identified for either the CHASE V or CHASE VII event.

(3) Harmonic series falling in the complete integer set, as yet unexplained, are revealed in the records obtained for both the CHASE V and CHASE VII events.

(4) An odd harmonic series interpreted as being generated by sub-bottom layering at the source is observed in the CHASE VII spectra. This series is not observed in the CHASE V records.

(5) A comparison of spectra obtained from several seismic stations is essential to valid spectral interpretation.

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INTRODUCTION

This report is the third in a series published by this office presenting the results obtained from narrow band spectral analysis of seismic signals, Refs. (1) and (2), generated by the CHASE explosions. The principle purpose of this effort has been to determine the feasibility of obtaining underwater explosive yields and detonation depths through analysis of seismic records and other supporting data. Generally, the data obtained from these analyses has been most favorable. However, research in this area is still in its developmental stage and it must be emphasized that many problems concerning spectral interpretations remain to be solved.

THEORY

A fairly complete theoretical treatment of seismic signals generated by underwater explosions is presented in Ref. (3) with some additional theory provided in Ref. (2). It is shown that the predominant spectral characteristics of such signals are governed by the depth of the detonation, the water depth at the source, and the bubble pulse period. The detonation depth and the water depth give rise to harmonic series falling in the odd integer set while the bubble pulse period generates the familiar complete integer series found in hydroacoustic explosive signal spectra. The spectral maxima are

given by the following terms:

Charge depth series

$$f_{\max} = \frac{c}{4d} (2n-1), n = 1, 2, 3, \dots$$

where: d = charge depth

c = velocity of sound in the water

Water depth series

$$f_{\max} = \frac{c}{4H} (2n-1), n = 1, 2, 3, \dots$$

where: H = water depth

Bubble pulse series

$$f_{\max} = \frac{n}{T_o}, n = 1, 2, 3, \dots$$

where: T_o = bubble pulse period

In order to determine the yield of an underwater explosion it is necessary to know the depth of the detonation and the fundamental frequency of the bubble pulse series. Yield may then be computed from the following formula:

$$W = .012 T_o^3 d_o^{2.5}$$

where: W = yield in pounds

T_o = bubble pulse period in seconds

d_o = charge depth + 33 feet

In Ref. (3) a logical approach to be used in identifying the spectral series associated with the various source parameters has been set down as an example of how the relationships noted above may be utilized in the establishment of a seismic surveillance system to aid in the detection and classification of underwater explosions. The approach assumes that the analyst, in addition to having no previous knowledge of a test shot, has no supporting non-seismic data following the test shot to aid him in the analysis. While the results were very encouraging for the example presented, it has since become evident, after analysis of the seismic data obtained from the CHASE tests, that the complex nature of the majority of spectra generally preclude such a narrow approach, at least at the present state-of-the-art. However, it is not at all necessary that such an approach be made. In the event of a large yield underwater explosion, the bubble pulse frequency, if a bubble pulse exists, may be obtained from the analysis of hydroacoustic data obtained from one of the various existing monitoring stations. Through triangulation the approximate position of the event could be determined. Sounding charts of the region could then be utilized to obtain water depth information. With the information thus acquired, determination of detonation depth from seismic spectra would be a relatively easy task since the other spectral series would then be known.

Here it must be noted that, thus far, spectral content has been investigated only from the standpoint of source

parameters. Obviously, this is somewhat unrealistic since the total seismic spectrum is a combination of source, transmission, and receiver effects. As more knowledge is acquired concerning the manner in which these other variables affect spectral amplitudes and shaping, more effective utilization of the basic theory will be possible.

ANALYSIS SYSTEM AND PROCEDURES

For the past three years Underwater Systems, Inc., under contract to the Office of Naval Research, has been involved in the narrow-band spectral analysis of explosively generated transient signals. With few exceptions, the analysis work has been concerned with underwater chemical explosions.

Basically, the spectral analysis system, Government furnished, consists of the following units:

1. Sangamo 4700 Recorder/Reproducer
2. Singer Panoramic Sonic Analyzer, Model LP-1a and
Accessory Auxiliary Function Unit C-2
3. Singer Panoramic Power Spectral Density Analyzer,
Model PDA-1
4. Singer Panoramic Recorder and Sawtooth Wave Generator,
Model RC-3b

A photograph of the system, including all associated test equipment employed, is shown in Figure (1).

Briefly, the analysis is performed in the following fashion. Referring to Figure (2), the signal is transferred from the master tape to a continuous tape loop. The signal is then fed to the scanning heterodyne analyzer which has been pre-set to the desired frequency band and IF bandwidth for which the analysis is to be performed. The loop voltage is monitored and fed to the spectral density analyzer where it is integrated during the period fixed by an external integration time control recorded on a separate channel on the tape loop. The SDA is equipped for both relative mean power and voltage density measurements. The output of the SDA drives a rectilinear pen-and-ink chart recorder running in synchronism with the swept local oscillator of the analyzer.

Each line in a spectrum represents one complete revolution of the tape loop. During the time that the integration control signal is being applied to the SDA, the integrator is "dumped" and the recorder pen remains at the baseline of the chart. The termination of the control signal marks the beginning of the integration period and the pen begins its rise from the baseline. At the resumption of the control signal, the integrator again "dumps" and the pen moves back to the baseline and remains there until the beginning of the next integration period. As the tape loop revolves, the spectral analyzer is continuously scanning the frequency band of interest at a pre-set rate. Thus each line represents an analysis in a band the center of which differs slightly from the one

preceding it. The frequency separation of adjacent lines is a function of scan rate and loop length.

Frequency measurements for analyses performed in frequency ranges below approximately 0-100 Hz tend to be somewhat unreliable due to a tendency of the analyzer to drift excessively during the scan time. This problem is overcome by playing back the tape loop signal at several times the original recording speed. The analyzer then "sees" a frequency component x as αx , where α is the speed up factor.

The system is equipped with IF bandwidth settings of 2, 5, 10, 25, 50, 100, and 200 Hz. For analyses involving loop speedup factors (α), the actual bandwidths become the IF bandwidth settings divided by α .

The spectral analyses presented in this report were performed for signals taken from a composite tape containing the signal arrivals at a number of LRSM field stations and Vela observatories. All of the spectra represent analyses of approximately the first one hundred seconds of signal arrival over the frequency band 0-4 Hz with an IF bandwidth of 0.04 Hz, using a speed factor (α) of 50.

SPECTRAL NOISE

A very significant consideration in any type of transient analysis is the signal-to-noise ratio over the frequency band of

interest. The analysis technique utilized for determination of the positions of source generated spectral maxima is especially sensitive to the signal-to-noise characteristics of the signals analyzed. Indeed, spurious frequency components, even if identified as such, may, through distortion of the source generated spectrum, lead to serious errors in interpretation. In order to minimize this possibility, the selection of seismic receiving stations for inclusion in this study was based largely on the general broad band signal-to-noise characteristics exhibited at each station. However, even at relatively long ranges, it was found that the background noise levels at most stations presented little difficulty over the frequency band analyzed, thus affording wide latitude in station selection.

An estimate of the noise levels in the spectra was obtained from an analysis of portions of the noise backgrounds preceding the received signals at each station. Background analyses were performed using scale settings and integration periods identical to those of the corresponding signal spectra, thus enabling the analyst to directly compare signal and noise spectra on a visual basis. While this method has proven to be a valuable aid in the problem of identification of non-source generated spectral components, one must recognize that it is useful only as a gross indicator, as present knowledge is insufficient to permit in-depth interpretations.

ANALYSIS RESULTS - CHASE VII

The parameters pertinent to the discussion of the results obtained from the CHASE VII event are presented below, Ref. (4):

Water depth	-	7500 feet
Detonation depth	-	3000 feet
Yield	-	400 tons

Assuming an average value of 4900 ft/sec for the velocity of sound in the water at the source, we can predict the following spectral series:

Water depth maxima	-	$0.163 (2n-1) \text{ Hz}, n=1,2,3\dots$
Detonation depth maxima	-	$0.408 (2n-1) \text{ Hz}, n=1,2,3\dots$
Bubble pulse maxima	-	$1.99 (n) \text{ Hz}^*, n=1,2,3\dots$

The spectral analyses presented in Figures (3) - (13) were performed for records obtained from LRSM stations and Vela observatories. The distance of these stations from the CHASE VII event ranged from 1117 km (Bellevue, Florida) to 4968 km (Mould Bay, Northwest Territories). Records from seven stations

*Determined by Columbia University Geophysical Field Station from hydroacoustic records

were analyzed. In addition to analyzing the signals generated by the source explosion, analyses were performed on the background noise just preceding signal arrival. Noise components significant in the present study were obtained at four stations. These records are included here following the signal spectra to which they correspond; see Figures (6), (8), (11), and (13). The noise spectra for three of these four stations indicate the presence of significant noise components within a narrow region at the low end of the analysis band (approximately 0.1 - 0.8 Hz).^{*} The bands of noise dominance revealed in these records have not been considered in making spectral interpretations. Excluded regions are indicated by brackets on the signal spectra. The presence of the single peak observed at a frequency of 2.68 Hz in Figure (8) will be dealt with in the treatment of the CHASE V results which follows this discussion.

A cursory inspection of the signal records reveals that while there is wide variation in spectral detail, there is a general constancy in gross aspect. With the exceptions of Figures (4), (10), and (12), the spectra exhibit two fairly well defined broad peaks upon which are superimposed a number of narrower maxima. The detonation depth appears to be the controlling parameter in the determination of these gross spectral features, and they are interpreted to correspond to the third and fifth harmonics of the detonation depth series. Having made this

^{*}It is interesting to note that the bulk of the energy of most microseismic disturbances is also contained in this band, Ref. (5).

identification, a reappraisal of Figures (10) and (12), after excluding the low frequency noise, indicates the presence of the third harmonic in Figure (10) and the third and fifth harmonics in Figure (12). Figure (4) - Houlton, Maine - remains as the only record exhibiting spectral characteristics inconsistent with those described above.

Of the spectra presented above, Figure (7) - Winner, South Dakota - best exhibits the above described features. Also, this record clearly exhibits a maximum at about 0.67 Hz, interpreted to be related to the fundamental of the detonation depth series. However, the large discrepancy between this observed value and either the predicted value of 0.41, or the value based on the third and fifth harmonics, 0.42, (see below) is noted. It is probable that the apparent shift of this weak maximum is a transmission related phenomenon, though this has not as yet been substantiated. The possibility that this may be a station related phenomenon has been precluded from the absence of this maximum in the background noise or in the spectra of other signals analyzed from this station.

A complete listing of the measured positions of maxima for the detonation depth series as obtained for each spectrum is presented in Table (1). Although precise determination of the positions of these broad peaks is difficult due to the interference of the superimposed higher order harmonic series, an average value of about 0.42 ± 0.02 Hz is obtained. This value

TABLE (1)
 DETONATION DEPTH SERIES - CHASE VII

STATION	HARMONIC NUMBER	Frequency in Hz		
		<u>1</u>	<u>3</u>	<u>5</u>
Bellevue, Fla. (BEFL)	-	-	1.31	2.10
Houlton, Me. (HNME)	-	-	-	-
Witchita Mtns. Obs., Okla., (WMO)	-	-	1.27	2.04
Winner, S.D. (WNSD)	0.67	-	1.20	2.13
Redig, S.D. (RGSD)	-	-	1.31	-
Uinta Basin Obs., Utah (UBO)	-	-	1.22	-
Mould Bay, N.T. (NPNT)	-	-	-	2.10
Average:	0.67*	-	1.26	2.09
Fundamental:	-	-	0.42	0.42

*Not included in data averaging.

yields a detonation depth of 2900 ± 150 feet, in close agreement with the depth of 3000 feet given in Ref. (4).

Although in a few of the records there appears to be a general spectral peaking in the vicinity of 2 Hz, transmission and seismometer response effects generally distort the spectra to such an extent as to preclude reliable determination of the bubble pulse fundamental. The response curve for the seismometers utilized at the LRSM stations peaks at approximately 2 Hz and rolls off rather sharply thereafter with increasing frequency. This also accounts, in part, for the absence of observable detonation depth harmonics higher than the fifth. A rather broad portion of the upper spectrum is further suppressed due to the influence of the null between the first and second bubble pulse maxima. It must be noted, however, that the apparent absence of energy over portions of the upper analysis band is due to system dynamic range limitations and should not be construed as being real.

Table (2) contains a summary of the positions of all spectral peaks superimposed on the source depth spectra at the various stations. Comparison of results obtained for individual stations strongly indicates the presence of three distinct harmonically related series of maxima. One of these series, falling in the odd integer set with a fundamental frequency of 0.17 ± 0.005 Hz, is readily identified as that generated by the water column at the source. The indicated water depth of 7200 ± 200 feet is consistent with that given in Ref. (4). In addition

WATER DEPTH (WD) , SUB-BOTTOM (SB) , AND COMPLETE INTEGER (CI) SERIES - CHASE VII

STATION					NPNT	Harmonic No. and Series	Calc. fundamental (Hz)		
BEFL	HNME	WMO	WNSD	RGSD			UBO	WD	SB
Frequency in Hz									
----	----	0.82	----	----	0.79	----	3 CI		0.27
----	----	----	----	0.95	----	0.93	7 SB	0.13	
----	----	1.08	1.11	----	1.02	1.06	4 CI		0.27
1.18	1.15	1.17	1.16	1.19	1.11	1.15	7 WD, 9 SB*	0.13	
1.28	1.27	1.25	1.26	1.25	1.22	1.24	5 CI		0.25
1.45	1.41	1.44	1.41	1.38	----	1.40	11 SB	0.13	
1.51	1.52	1.49	1.49	1.50	1.49	----	9 WD	0.17	
----	----	1.58	----	----	1.57	1.56	6 CI		0.26
1.69	----	----	1.69	1.69	----	----	13 SB	0.13	
1.74	1.78	----	----	1.81	1.76	----	7 CI		0.25
1.87	1.88	1.91	1.85	1.90	1.92	1.87	11 WD	0.17	
1.97	2.00	----	1.96	----	----	1.92	15 SB	0.13	
----	----	----	2.03	2.03	2.05	2.05	8 CI		0.26
2.13	2.11	2.18	2.16	2.13	2.13	2.16	13 WD	0.16	
2.22	2.29	2.26	2.27	2.23	----	2.24	17 SB	0.13	
----	----	2.38	2.35	----	----	2.33	9 CI		0.26
----	----	2.55	2.53	----	----	----	15 WD	0.17	

Miscellaneous Components

.53	.30	2.09	Fundamental: WD - 0.17 Hz
.61	.55		SB - 0.13 Hz
.67	.80		CI - 0.26 Hz
.72	.99		
2.11			
3.10			

* Apparent superposition of maxima.

to the water depth series there is observed still another odd integer series with a fundamental frequency of 0.13 ± 0.005 Hz. It is probable that this series is due to the presence of a sub-bottom reflector at the source; however, no firm conclusion can be reached in this regard until more is known of the local crustal structure. The third series observed, a complete integer series with a fundamental frequency of 0.26 ± 0.005 Hz, remains unexplained at this writing.

It should be evident from the results presented in Tables (1) and (2) that a spectral interpretation based on results obtained at a single station would be, at best, questionable. Only through a comparison of several spectra is one able to determine, with any degree of confidence, which of the spectral peaks present in any particular record are truly source related. Furthermore, a comparison technique has been found essential to the determination of the various harmonic relationships arising from source related phenomena. Each spectrum differs in the degree of suppression or enhancement of the various frequency components comprising the series present. Where a particular component may be very prominent and well defined in one spectrum, it may not be observable in another. This apparent absence of certain harmonics on any one spectrum renders interpretation on an individual basis extremely complicated and generally ineffectual.

ANALYSIS RESULTS - CHASE V

The parameters pertinent to the discussion of the results obtained from the CHASE V event are presented below, Ref. (6):

Water depth	-	12,500 ± 100 feet
Detonation depth	-	3,750 ± 250 feet
Yield	-	1.0 ± 0.2 kilotons

Making the same assumption as in the previous discussion concerning the sound velocity at the source, we obtain the following predicted spectral series:

Water depth maxima	-	$0.098(2n-1)\text{Hz}$	, n=1,2,3,...
Detonation depth maxima	-	$0.327(2n-1)\text{Hz}$	, n=1,2,3,...
Bubble pulse maxima	-	$1.74(n)\text{Hz}^*$	, n=1,2,3,...

Figures (14) - (25) present analyses performed for records obtained from eight LRSM stations and Vela observatories. In addition to the explosion spectra, background noise analyses were obtained for each station and noise dominant portions of each signal spectrum were excluded for purposes of interpretation. Four of these noise records are contained herein following

*Determined by Underwater Systems, Inc. from hydroacoustic records obtained at short range

the signal spectra to which they correspond; see Figures (16), (20), (23), and (25).

The maximum observed at approximately 2.7 Hz in Figure (8) is in evidence in five of the noise spectra obtained for the CHASE V analysis. It is probable that it is an artifact generated by the recording system which was utilized in dubbing the various station records on the composite tapes used for this analysis. However, no firm conclusion in this regard can be reached at this time.

In general, the characteristics exhibited by the CHASE V spectra are very similar to those obtained for the CHASE VII event. Five of the records clearly indicate the presence of two broad peaks superimposed on which are numerous narrower maxima; see Figures (15), (17), (18), (21), and (22). The broad maxima are again interpreted to be the third and fifth harmonics of the detonation depth series. Although the series is not immediately evident in Figures (14), (19), and (24), upon comparison of these spectra with those of greater definition the presence of the fifth harmonic in Figure (19) and the third harmonic in Figure (24) is noted. A listing of the measured positions of the detonation depth maxima as observed for each station is presented in Table (3). An average fundamental frequency of 0.31 ± 0.02 Hz is obtained. This corresponds to a depth of $3,950 \pm 250$ feet which is consistent with that given in Ref. (6).

The positions of the maxima superimposed on the source depth spectrum, as obtained for each station, are listed in Table

TABLE (3)
 DETONATION DEPTH SERIES - CHASE V

STATION	HARMONIC NUMBER	Frequency in Hz		
		<u>1</u>	<u>3</u>	<u>5</u>
Mina, Nev. (MNNV)	-	-	-	-
Uinta Basin Obs., Utah (UBO)	-	-	0.95	1.62
Winner, S.D. (WNSD)	-	-	1.01	1.65
Witchita Mtns. Obs., Okla. (WMO)	-	-	0.93	1.51
Kansas City, Mo. (KCMO)	-	-	-	1.54
Red Lake, Ont. (RKON)	-	-	0.89	1.53
Alexander City, Ala. (AX2AL)	-	-	0.99	1.52
Mould Bay, N.T. (NPNT)	-	-	0.89	-
Average:		-	0.94	1.56
Fundamental:		-	0.31	0.31

(4). Through a comparison of the results obtained for the various stations, two distinct harmonic series are discerned. One of these, falling in the odd integer set with a fundamental frequency of 0.10 ± 0.005 Hz is interpreted to be the water depth series. The indicated water depth of $12,500 \pm 500$ feet compares favorably with that given in Ref. (6). The other series, as yet unexplained, falls in the complete integer set with a fundamental of 0.20 ± 0.005 Hz.

TABLE (4)

WATER DEPTH (WD) AND COMPLETE INTEGER (CI) SERIES - CHASE V

STATION									
MNNV	UBO	WMSD	WMO	KCMO	RKON	AX2AL	NPNT	Harmonic No. and Series	Calc. fundamental (Hz)
Frequency in Hz									
0.46	----	----	----	----	----	----	----	5 WD	0.10
----	----	----	0.73	----	0.70	----	0.75	7 WD	0.10
0.81	0.83	0.78	0.78	----	----	----	----	4 CI	0.20
0.90	0.93	0.91	0.90	0.93	0.89	0.88	0.91	9 WD	0.10
0.98	1.04	0.97	0.96	----	1.02	0.93	0.95	5 CI	0.20
1.12	----	1.08	----	1.15	----	1.12	1.10	11 WD	0.10
----	1.24	1.22	----	1.24	----	----	1.23	6 CI	0.21
1.33	1.32	1.36	1.34	----	1.30	----	1.32	13 WD	0.10
1.41	1.37	1.44	----	1.41	1.38	----	----	7 CI	0.20
----	----	1.49	1.45	1.51	1.49	1.46	1.48	15 WD	0.10
1.55	1.54	1.59	1.56	----	1.59	1.60	1.59	8 CI	0.20
1.68	1.72	1.71	----	1.69	1.67	1.67	1.67	17 WD	0.10
1.80	----	----	1.84	----	1.79	1.76	----	9 CI	0.20
1.85	----	1.90	----	----	----	----	1.90	19 WD	0.10
2.02	----	----	----	----	----	----	----	10 CI	0.20
2.12	2.08	----	----	----	----	2.10	2.07	21 WD	0.10
2.23	2.26	2.23	2.24	----	----	2.24	----	11 CI	0.20
2.33	----	2.30	----	----	----	----	2.31	23 WD	0.10

Miscellaneous Components

1.17	1.09	1.13	1.05	1.05	
	1.62	1.65			
Fundamental: WD - 0.10 Hz					
CI - 0.20 Hz					

CONCLUSIONS

From the results obtained from the spectral analysis of the CHASE V and CHASE VII seismic signals, it is concluded that:

1. The gross spectral characteristics of the records obtained for the CHASE V and CHASE VII events are very similar.
2. An odd harmonic series interpreted as being generated by sub-bottom layering at the source is observed in the CHASE VII spectra. This series is not observed in the CHASE V records, indicating considerable difference in crustal structure at the two source locations.
3. Harmonic series falling in the complete integer set are revealed in the records obtained for both the CHASE V and CHASE VII events.
4. The detonation depth series is readily identified in a majority of the spectra obtained for both the CHASE V and CHASE VII events.
5. The bubble pulse frequency is not identified for either the CHASE V or CHASE VII event, though the bulk of the energy observed occurs in the predicted band for the fundamental of the bubble pulse series.
6. A comparison of spectra obtained from several seismic stations is essential to valid spectral interpretation.
7. The bulk of the energy observed in background noise records obtained for the CHASE V and CHASE VII analyses is contained in a rather narrow band below 0.8 Hz.

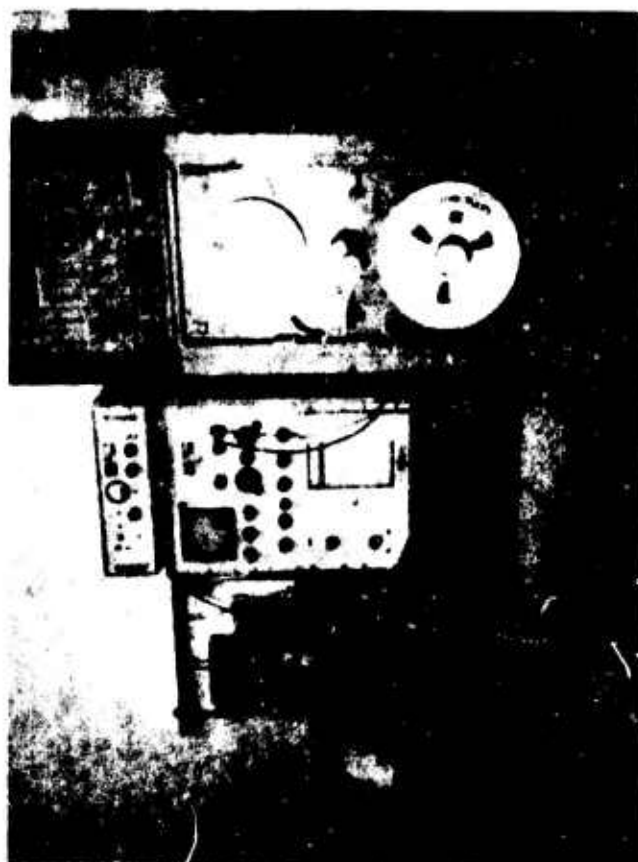


Figure (1)
Photograph showing spectral analysis system

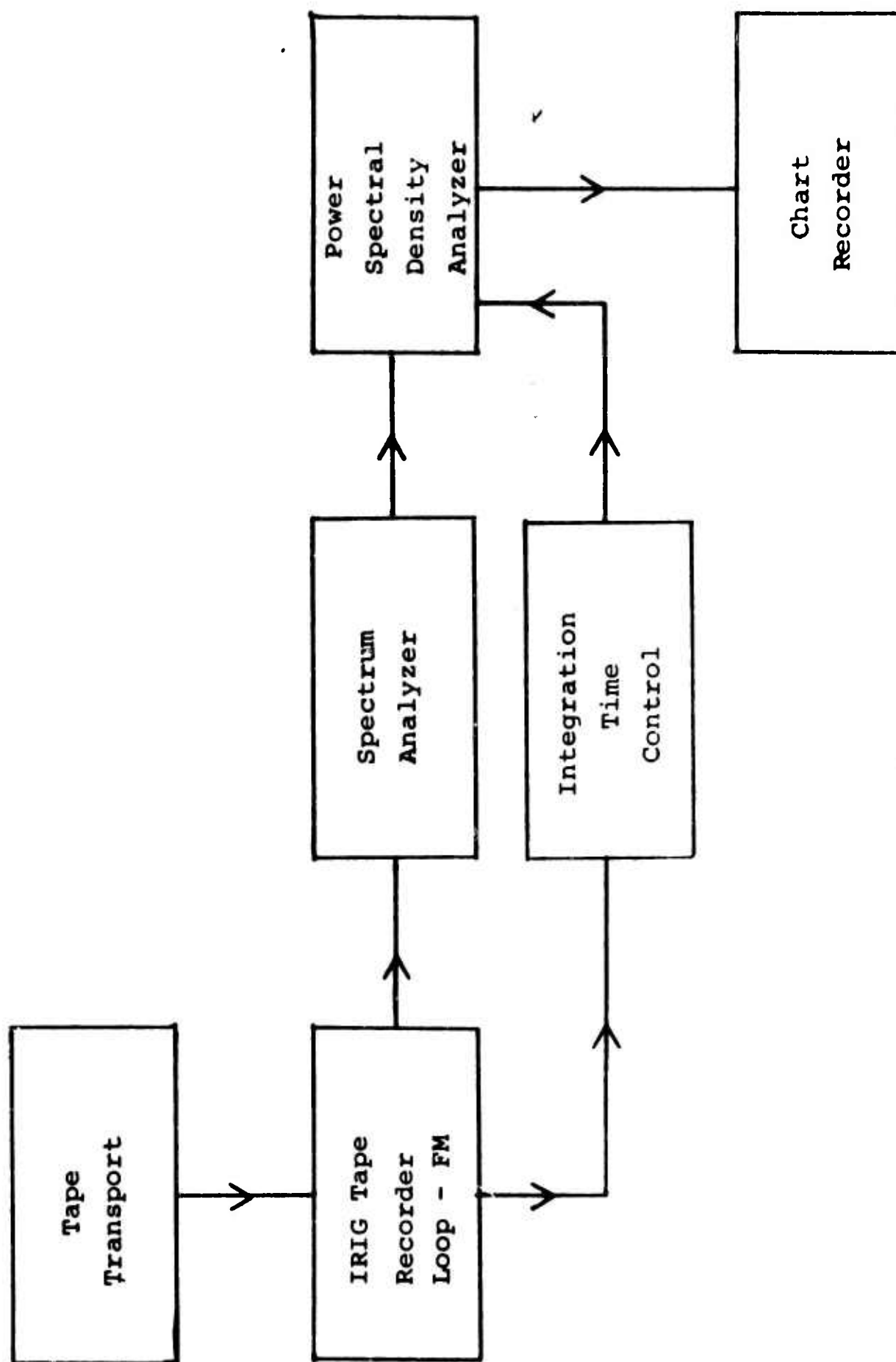


Figure (2)
Block diagram showing principle units employed
in narrow band spectral analysis system.

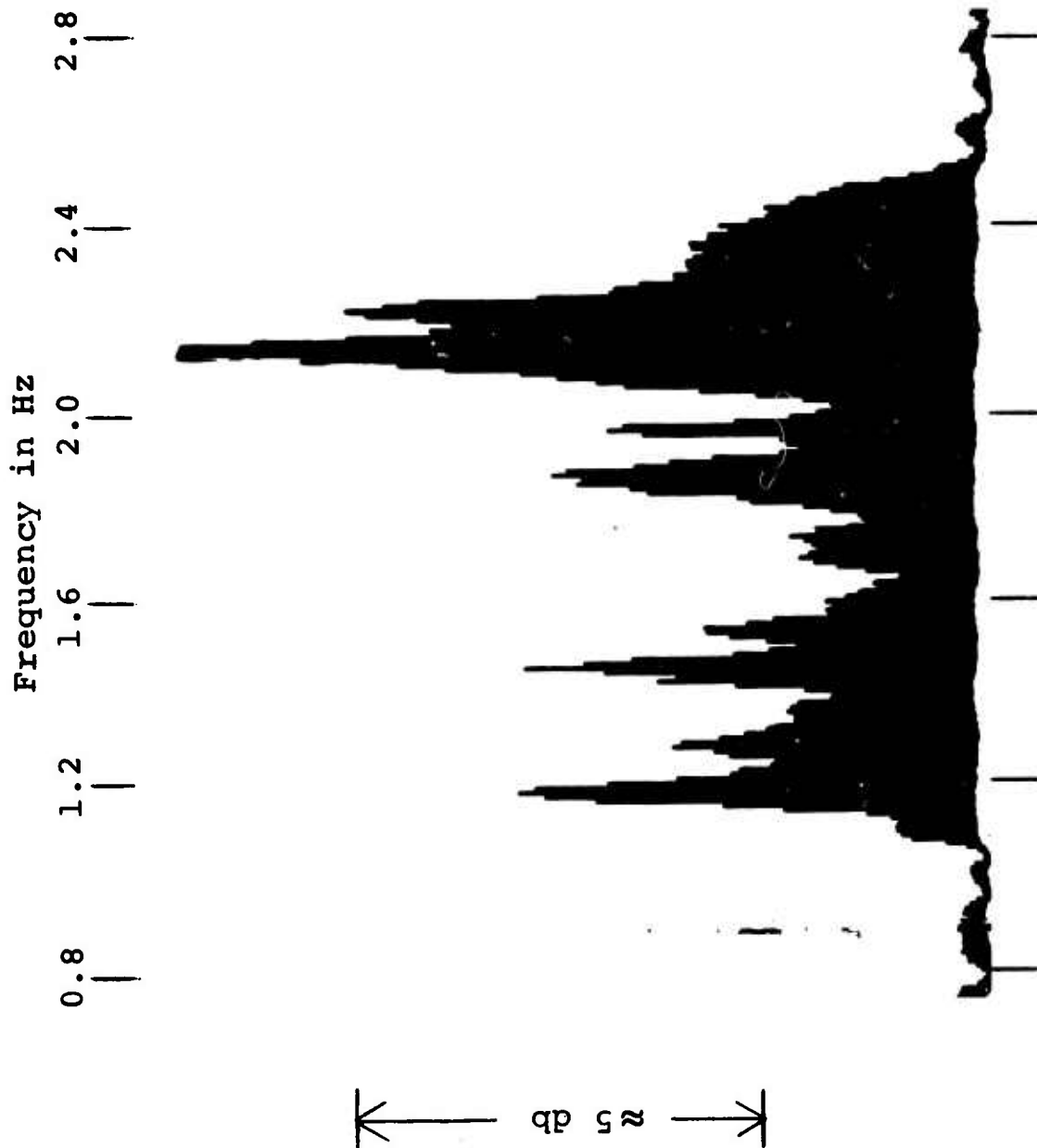


Figure (3)
Spectral analysis of seismic
signal generated by CHASE VII
detonation as received at
Bellevue, Florida.
Range - 1117 km.

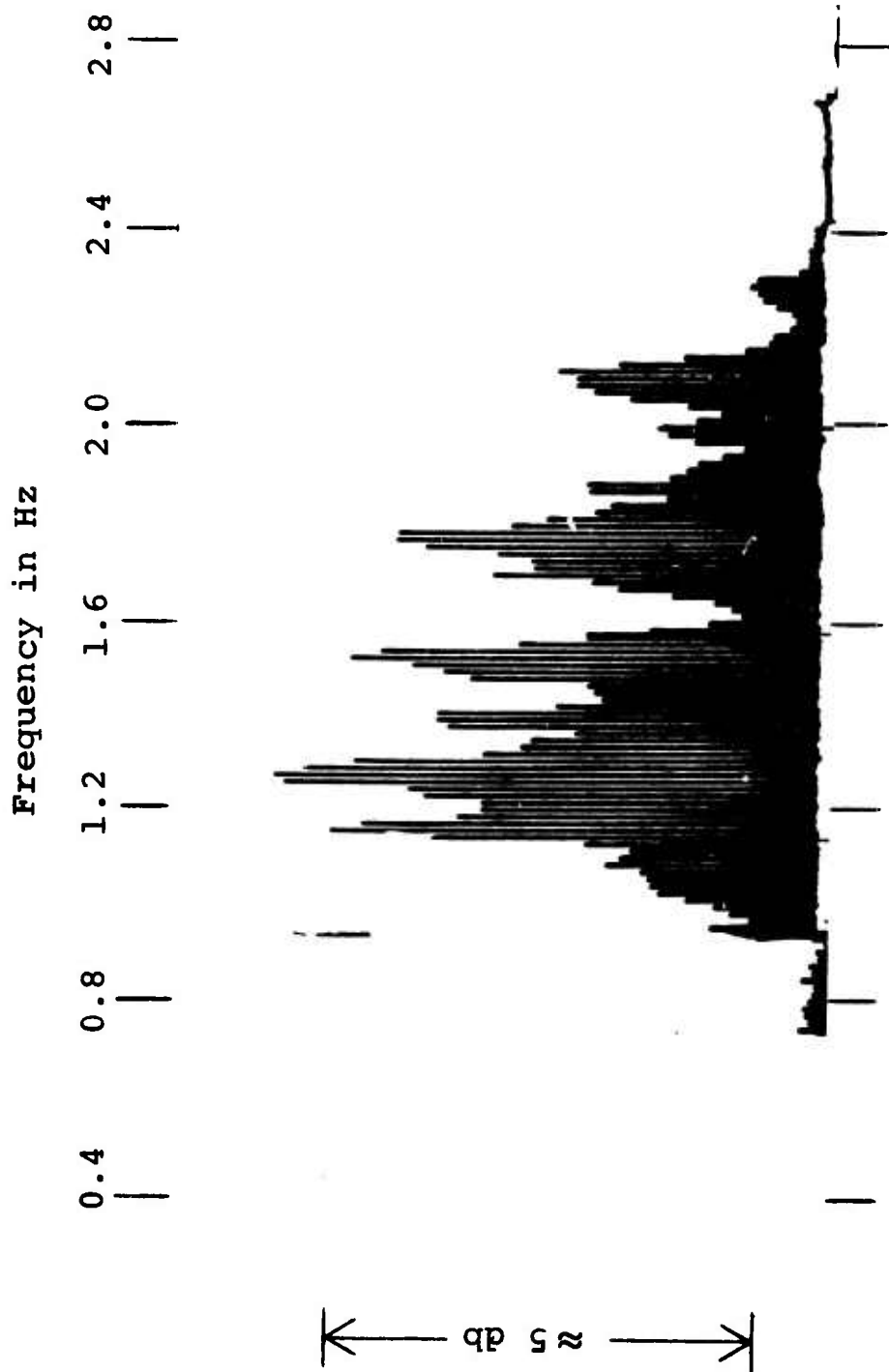


Figure (4)
Spectral analysis of seismic
signal generated by CHASE VII
detonation as received at
Houlton, Maine. Range - 1193 km.

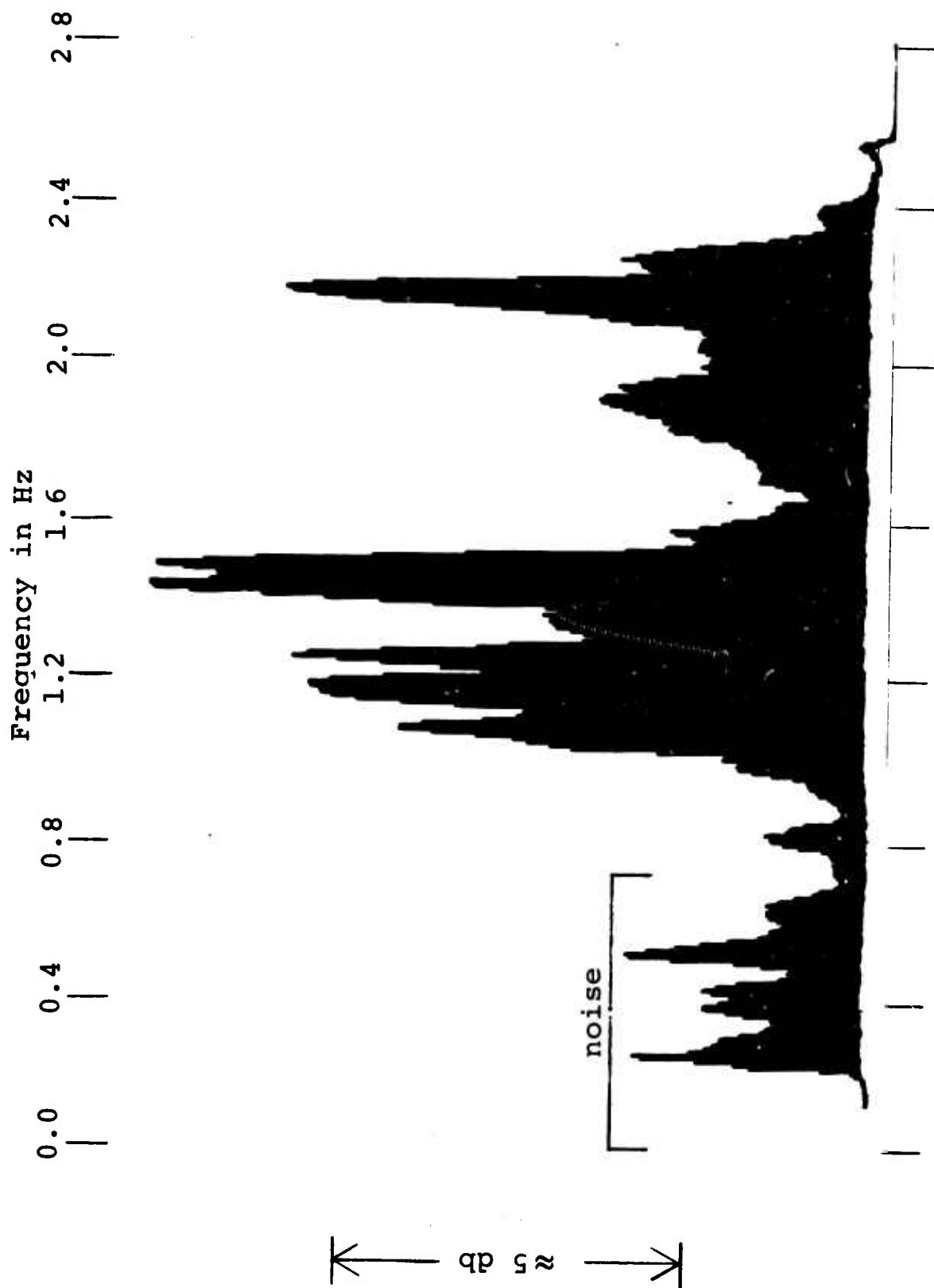


Figure (5)
Spectral analysis of seismic
signal generated by CHASE VII
detonation as received at
Witchita Mountains Observatory,
Oklahoma. Range - 2210 km.

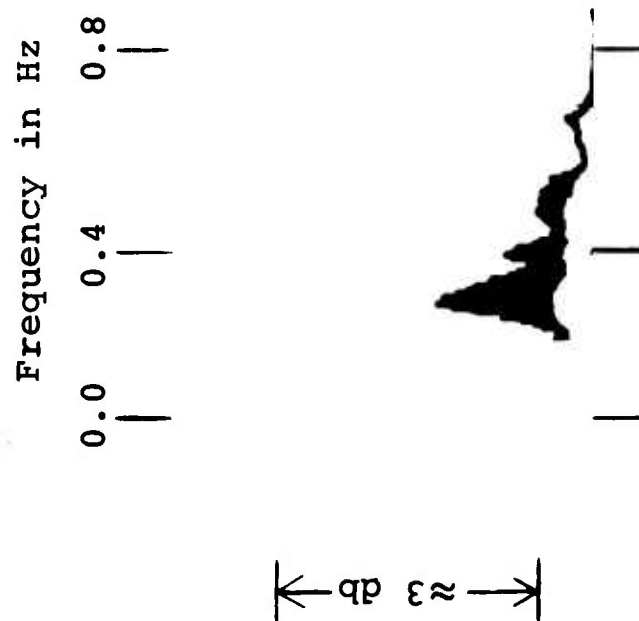


Figure (6)
Spectral analysis of back-ground noise preceding signal analyzed in Figure (5).

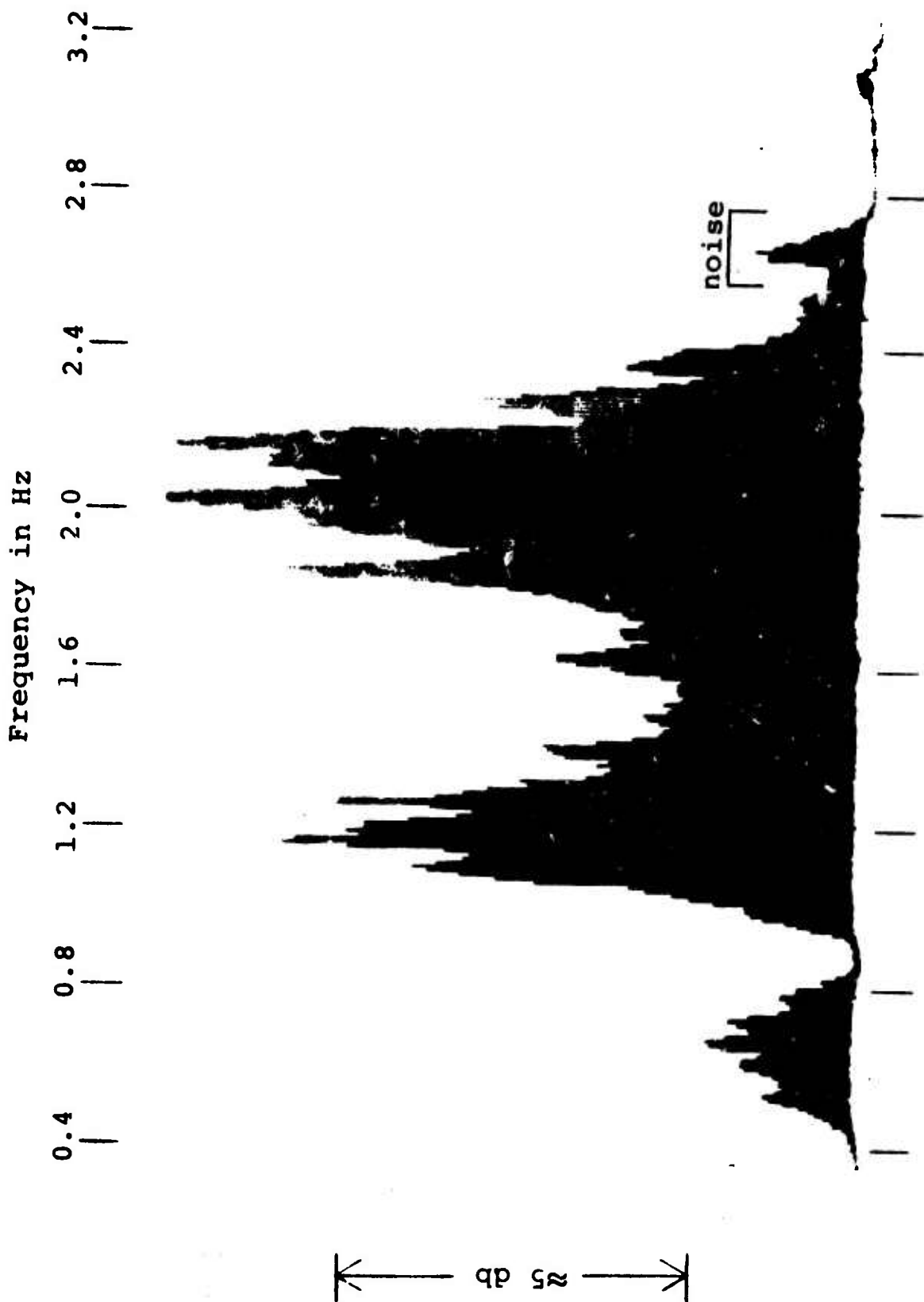


Figure (7)
Spectral analysis of seismic
signal generated by CHASE VII
detonation as received at
Winner, South Dakota.
Range - 2334 km.

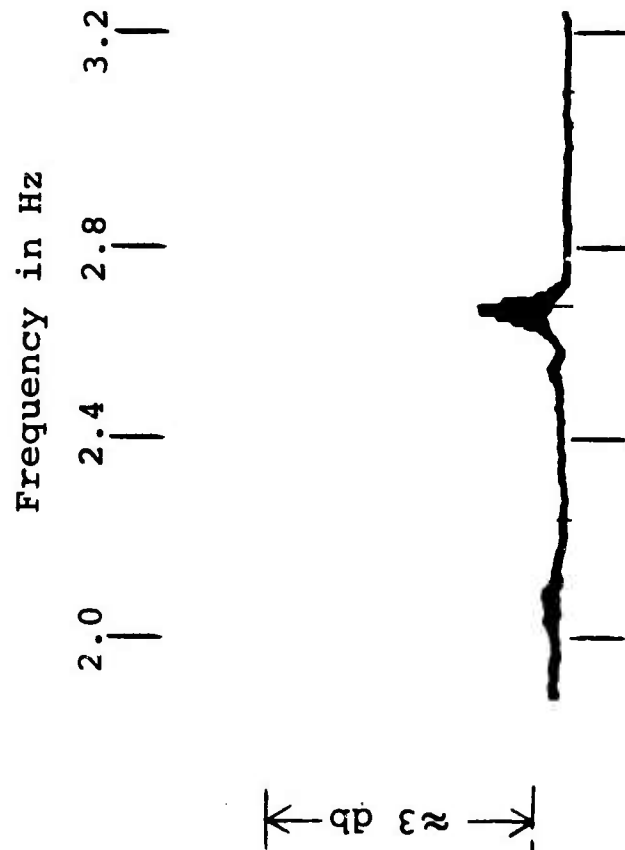


Figure (8)
Spectral analysis of back-ground noise preceding signal analyzed in Figure (7).

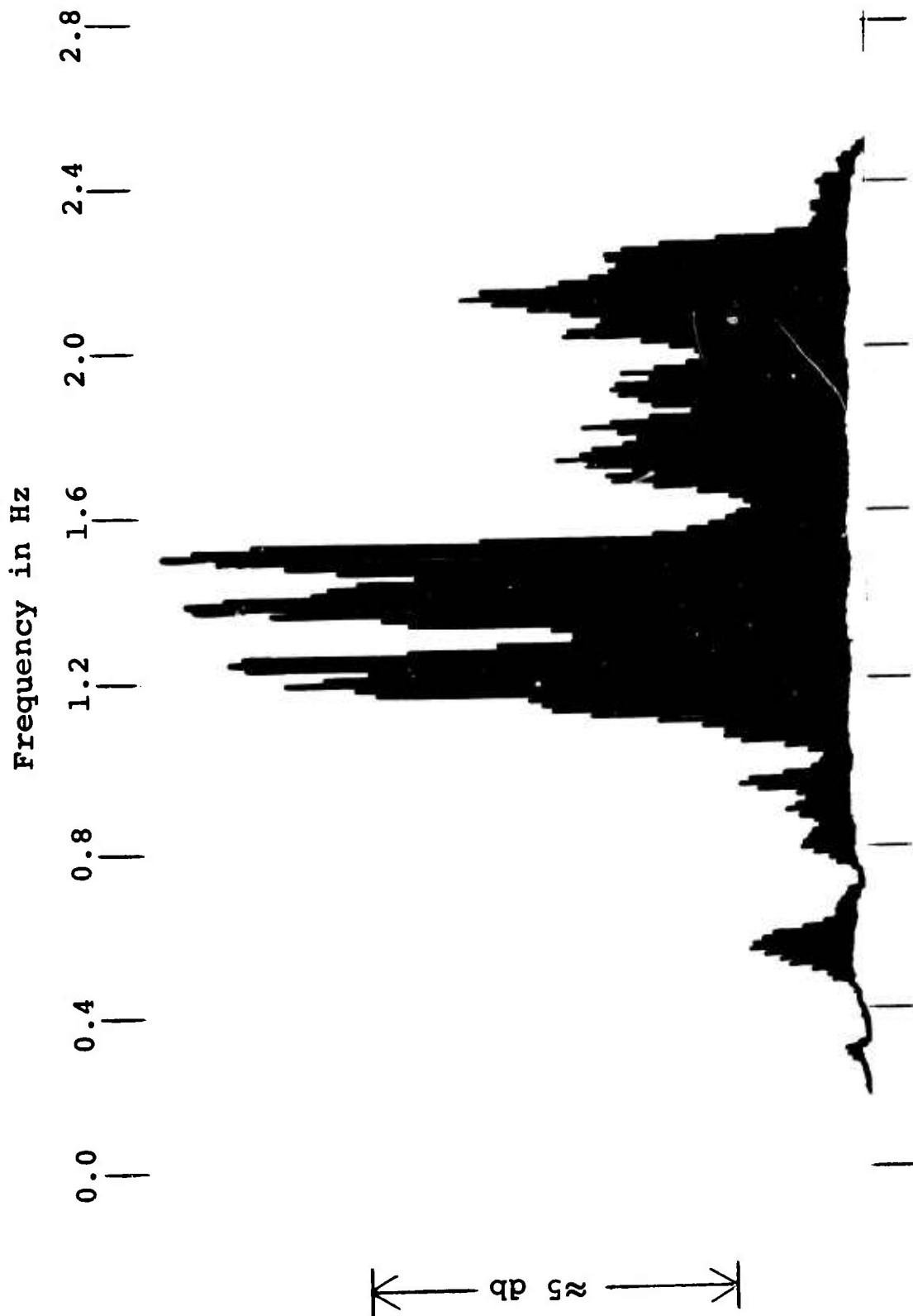


Figure (9)
Spectral analysis of seismic
signal generated by CHASE VII
detonation as received at
Redig, South Dakota.
Range - 2637 km.

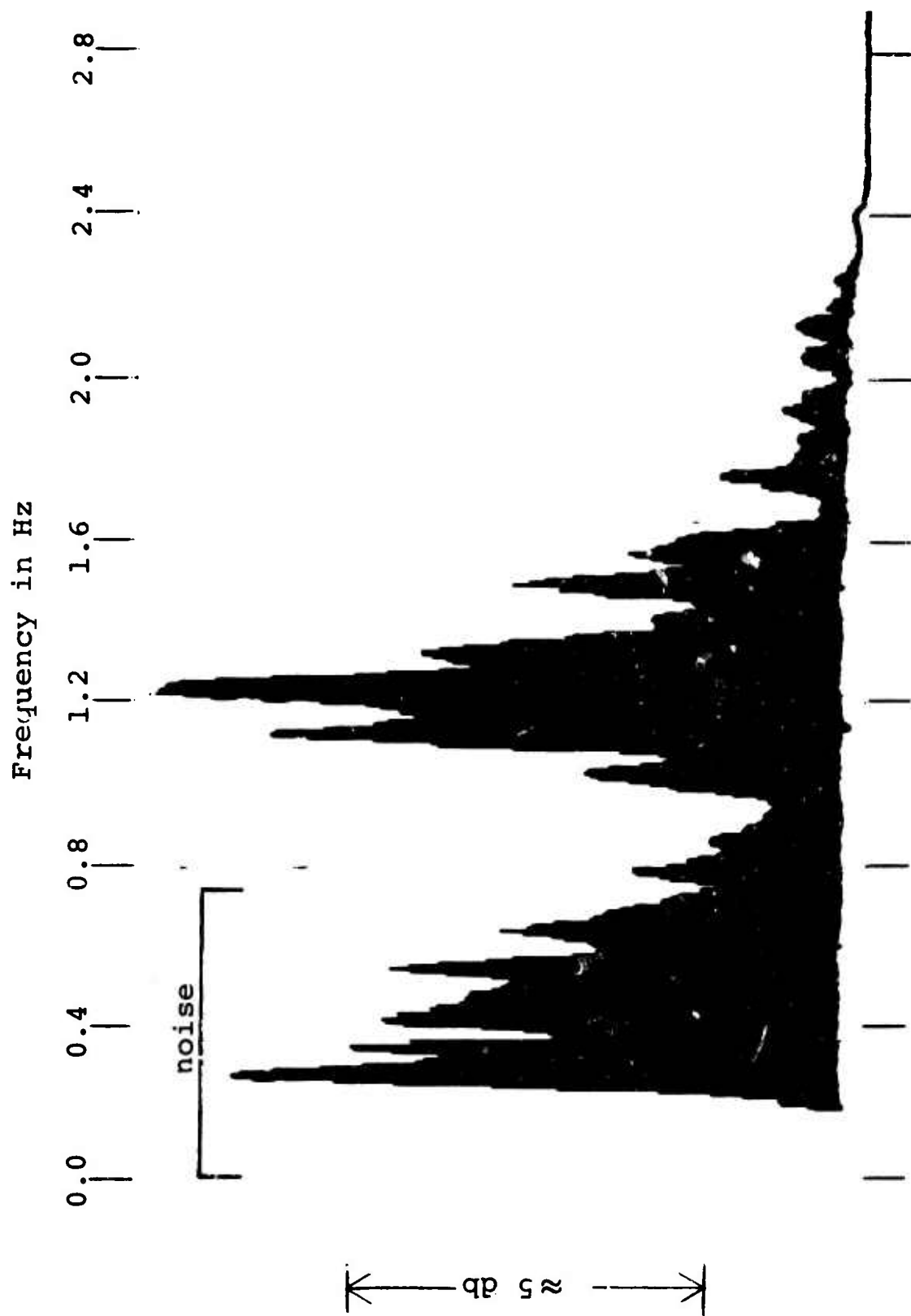


Figure (10)

Spectral analysis of seismic signal generated by CHASE VII detonation as received at Uinta Basin Observatory, Utah. Range - 3096 km.

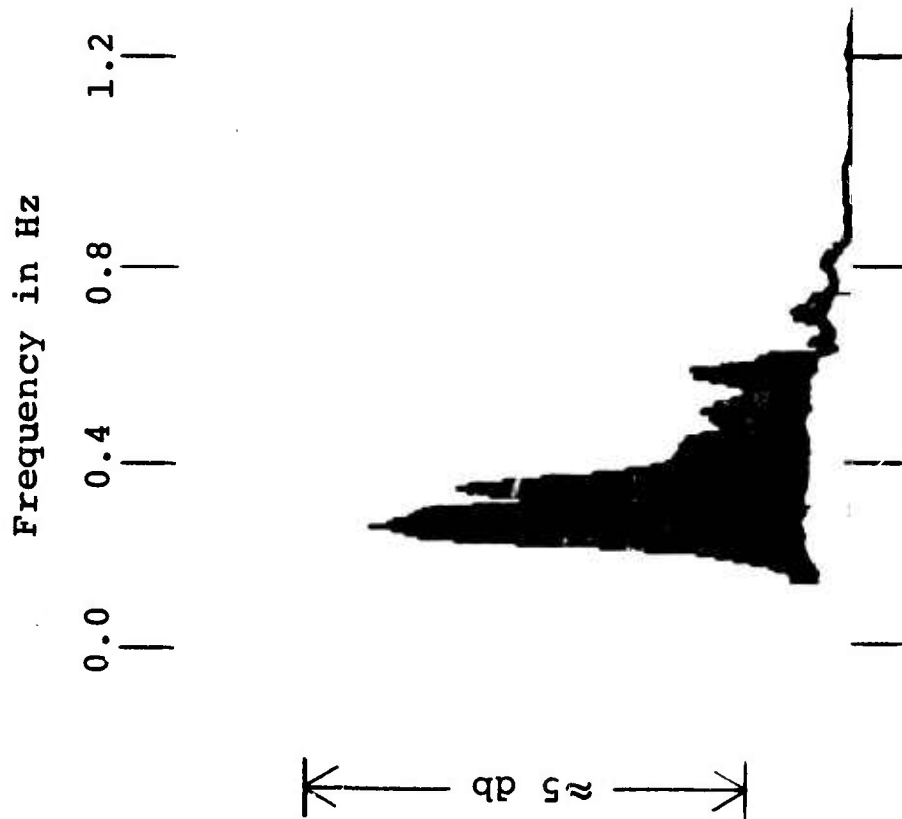


Figure (11)
Spectral analysis of background
noise preceding signal analyzed
in Figure (10).

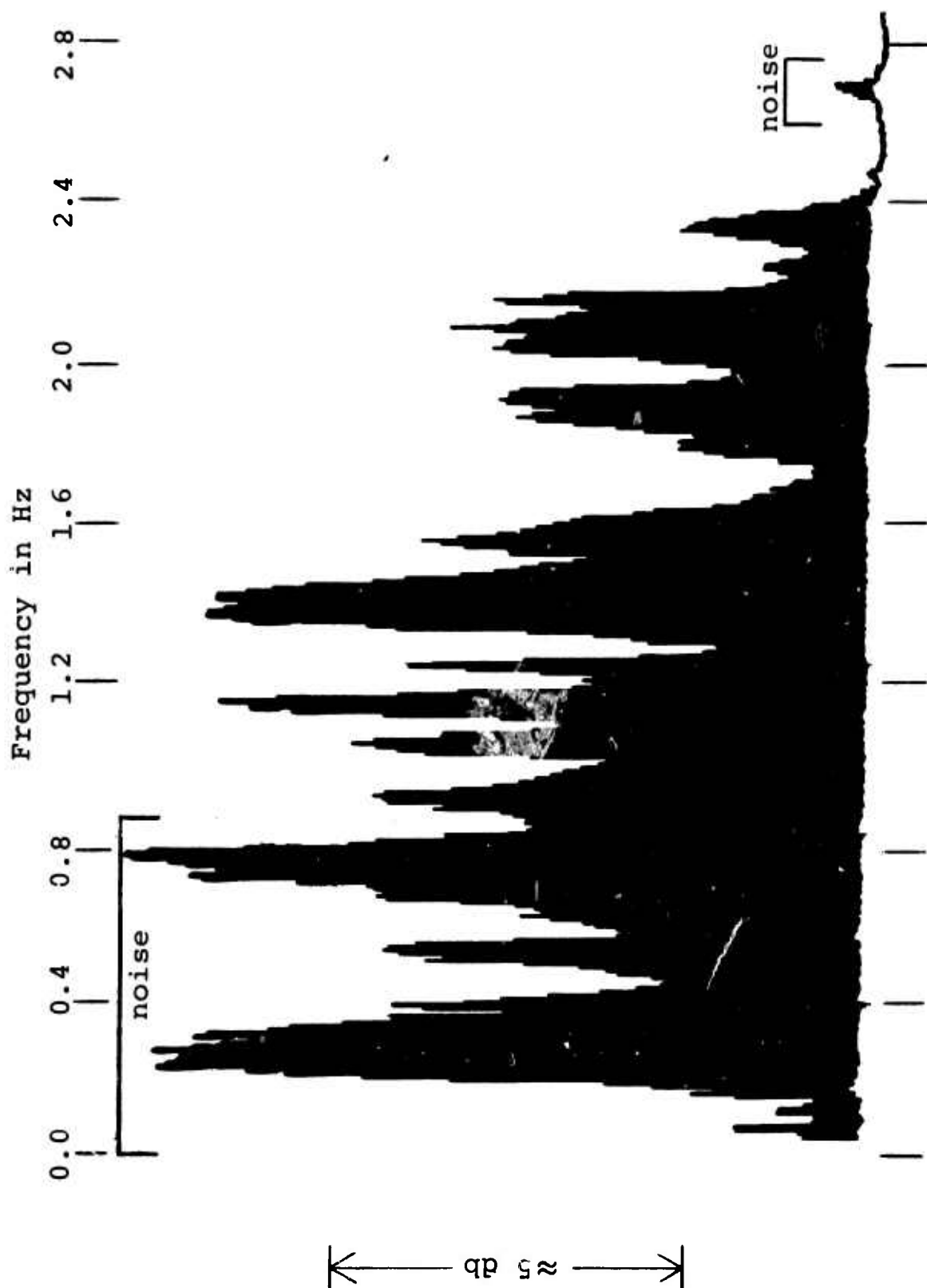


Figure (12)

Spectral analysis of seismic
signal generated by CHASE VII
detonation as received at
Mould Bay, Northwest Territories.
Range - 4968 km.

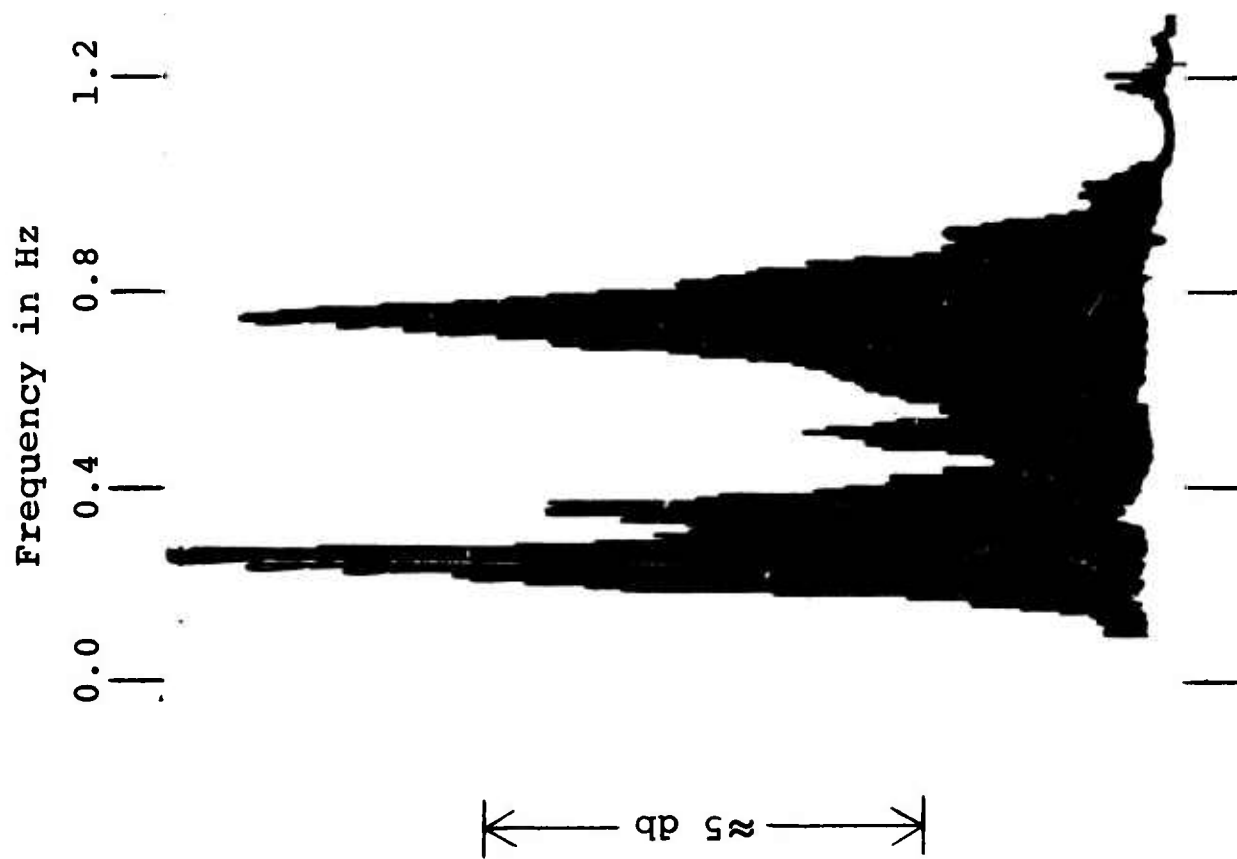


Figure (13)
Spectral analysis of back-
ground noise preceding
signal analyzed in Figure (12).

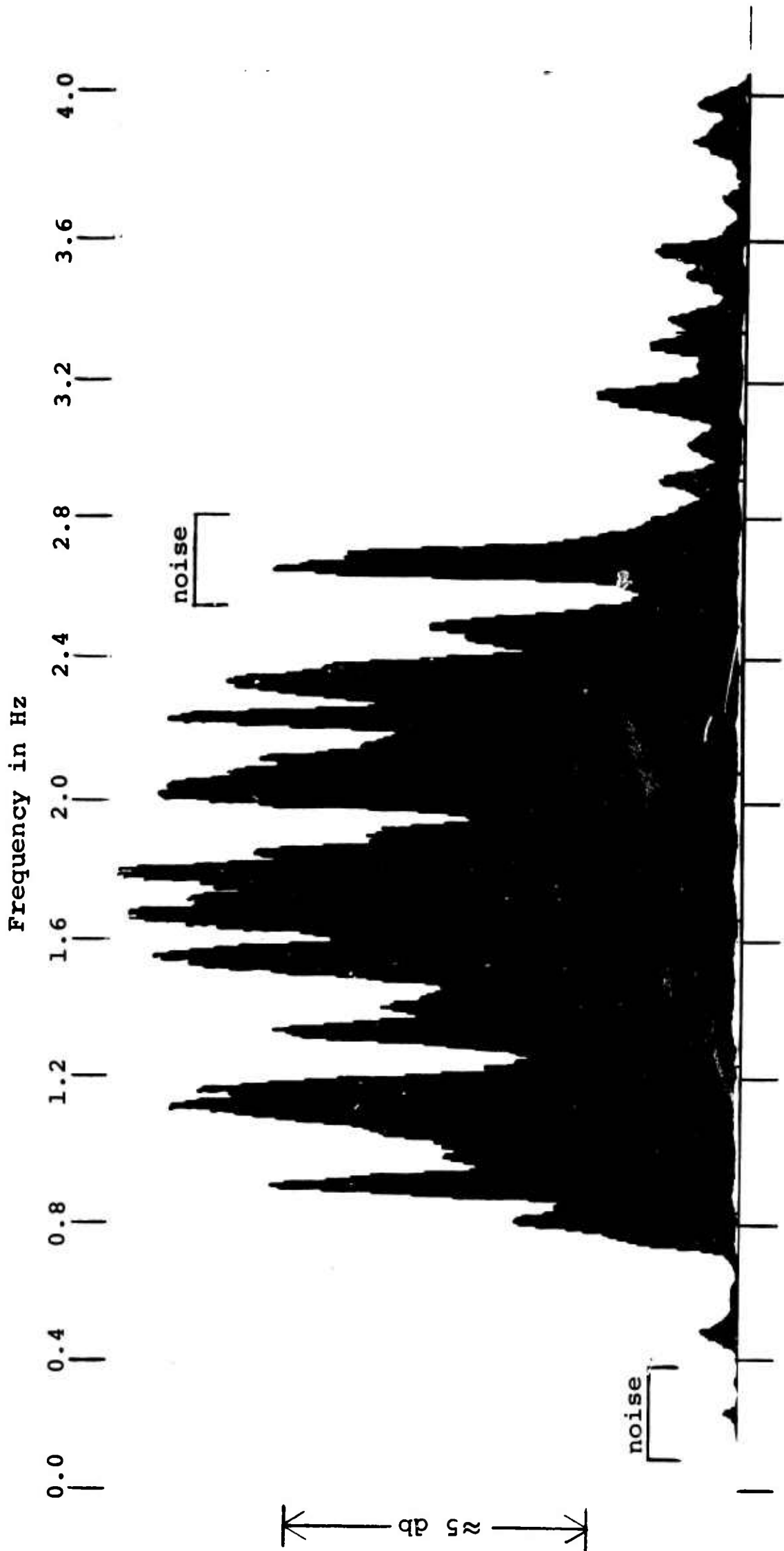


Figure (14)

Spectral analysis of seismic
signal generated by CHASE V
detonation as received at
Mina, Nevada. Range - 673 km.

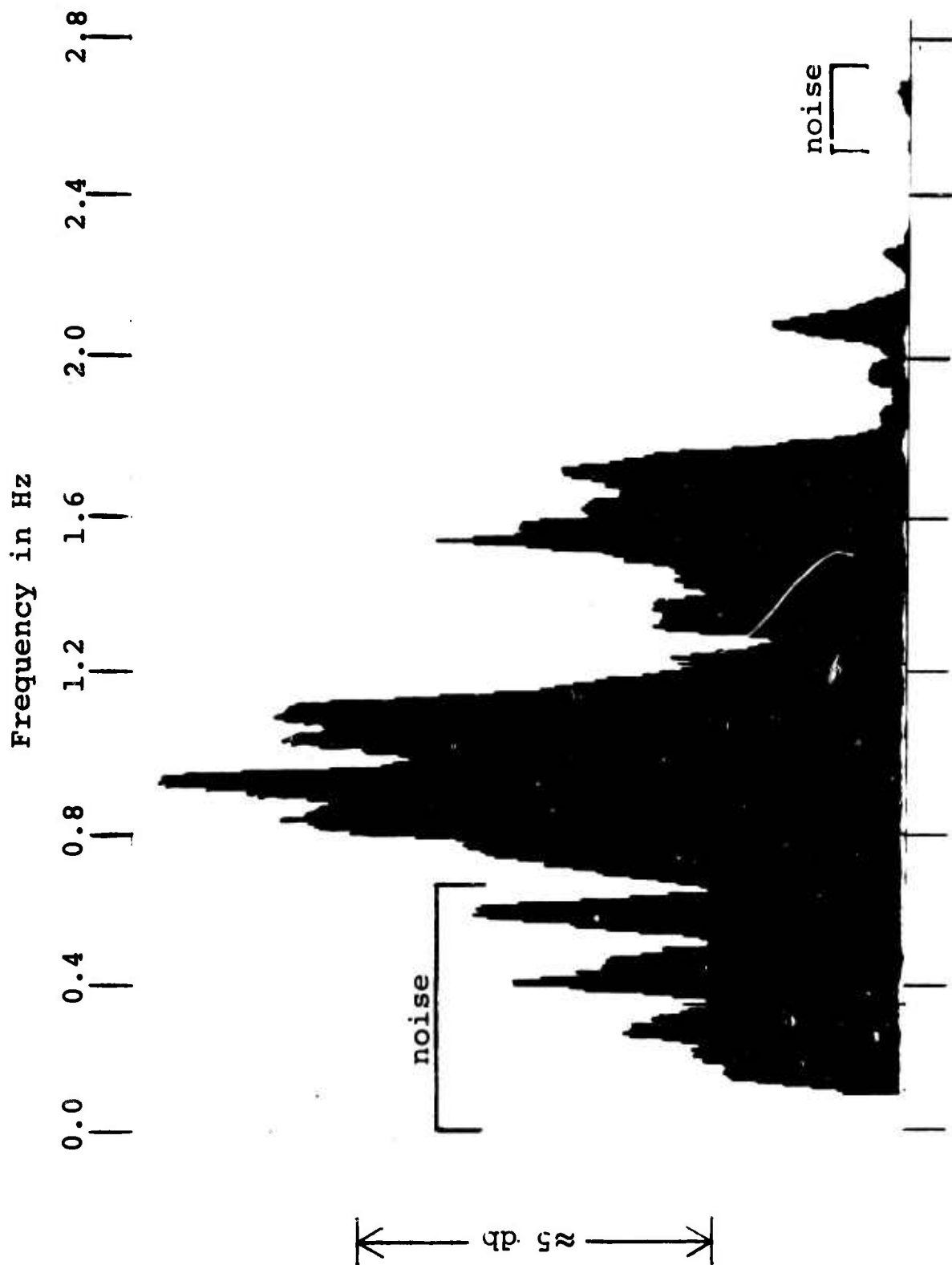


Figure (15)

Spectral analysis of seismic
signal generated by CHASE V
detonation as received at
Uinta Basin Observatory, Utah.
Range - 1390 km.

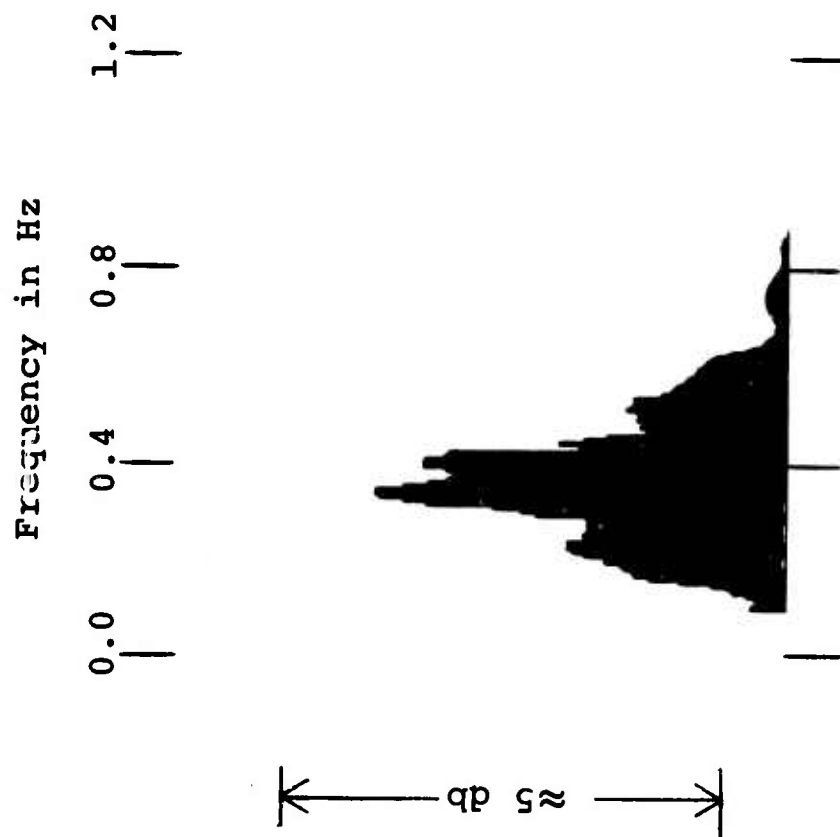


Figure (16)
Spectral analysis of
background noise pre-
ceding signal analyzed
in Figure (15).

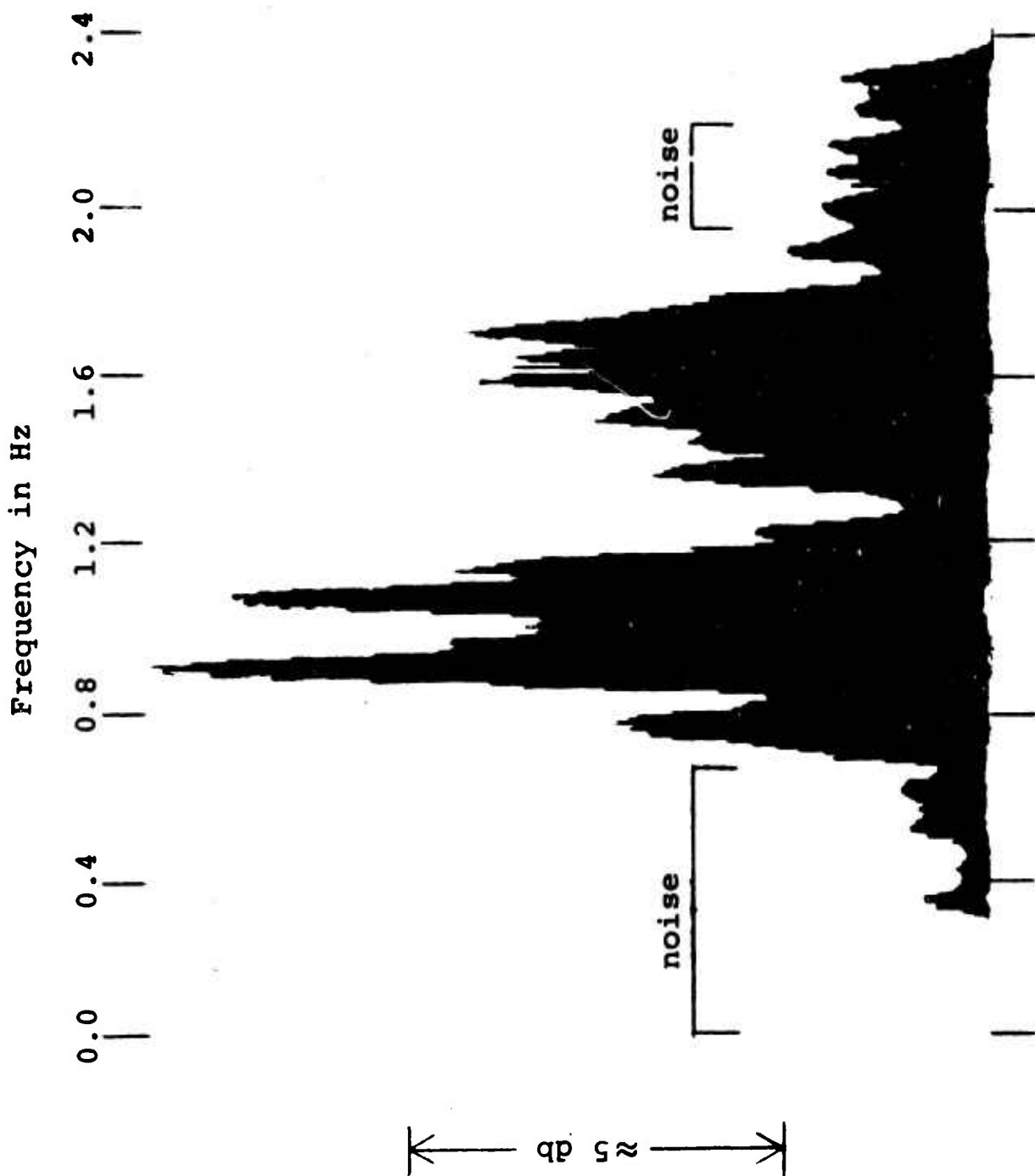


Figure (17)
Spectral analysis of seismic
signal generated by CHASE V
detonation as received at
Winner, South Dakota.
Range - 2175 km.

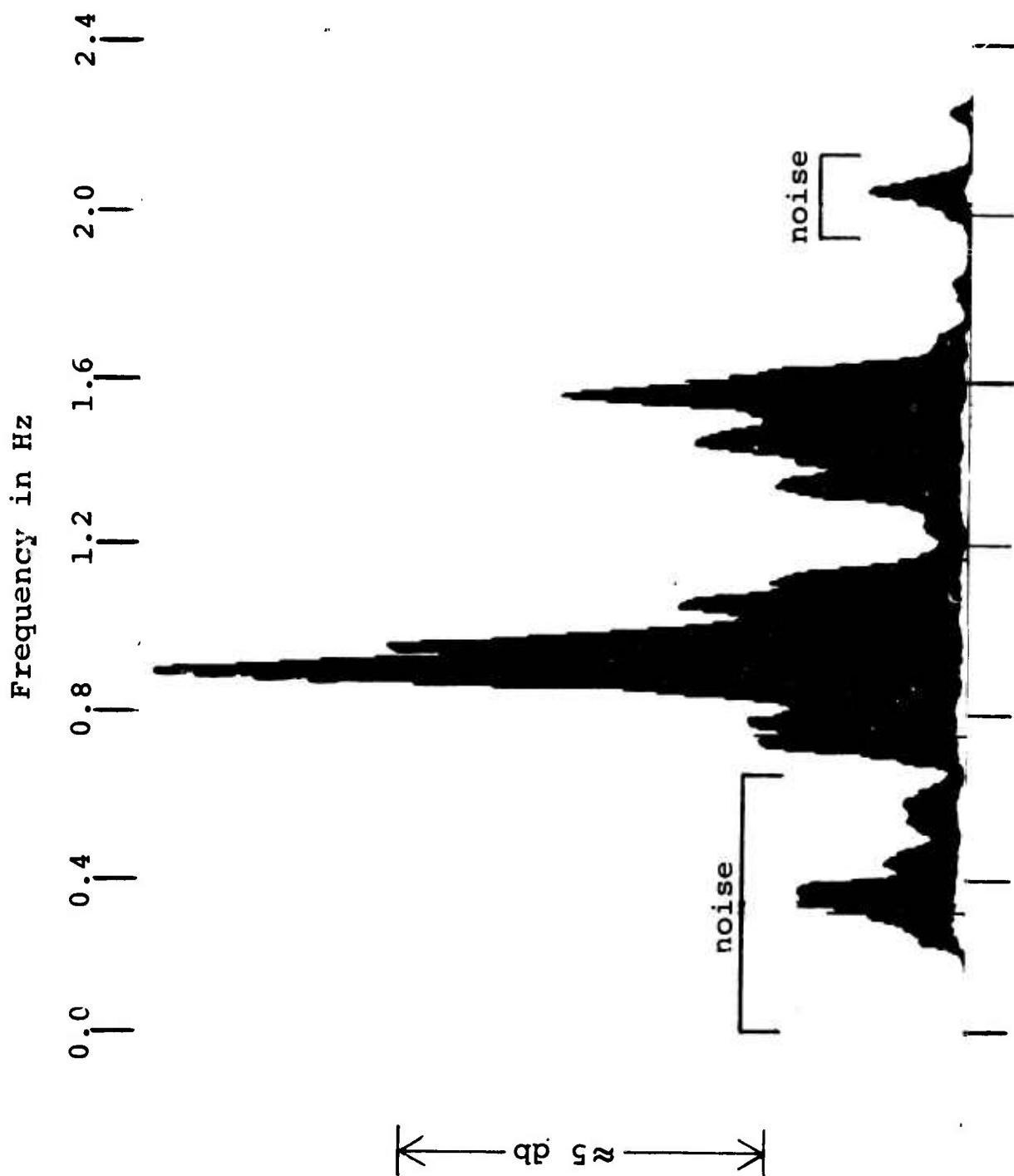


Figure (18)

Spectral analysis of seismic signal generated by CHASE V detonation as received at Wichita Mountains Observatory, Oklahoma. Range - 2466 km.

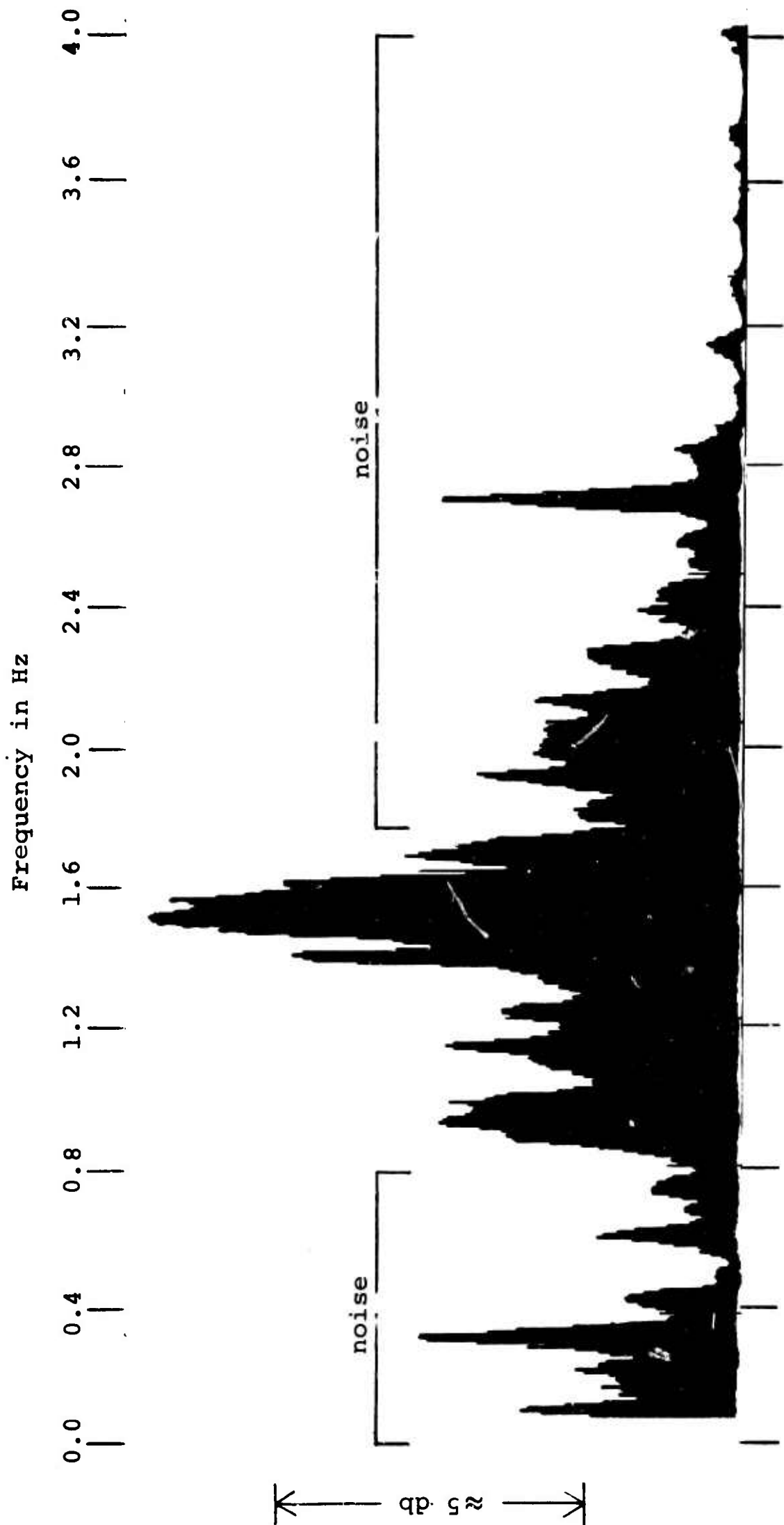


Figure (19)
Spectral analysis of seismic
signal generated by CHASE V
detonation as received at
Kansas City, Missouri.
Range - 2668 km.

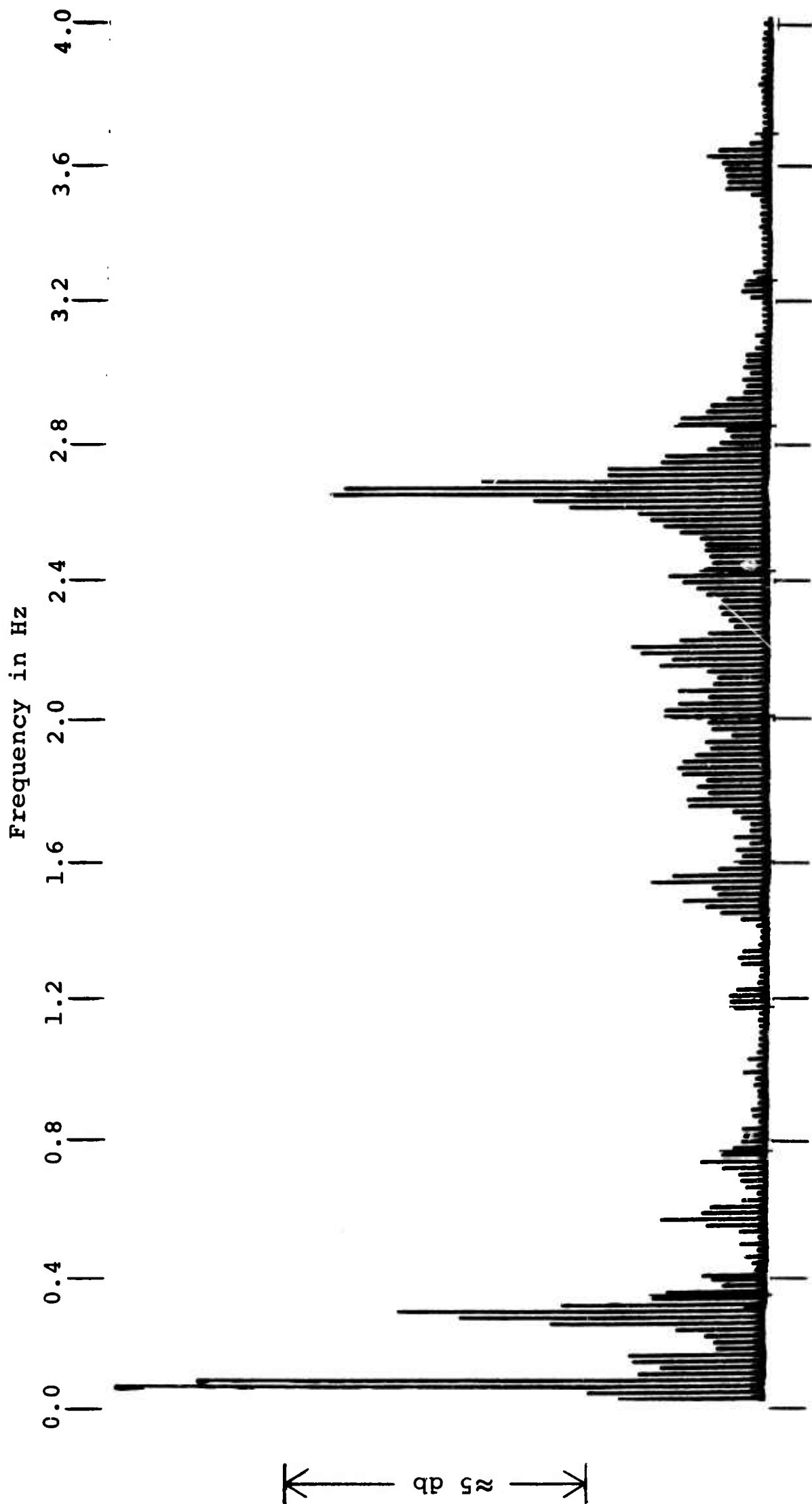


Figure (20)
Spectral analysis of back-
ground noise preceding
signal analyzed in
Figure (19).

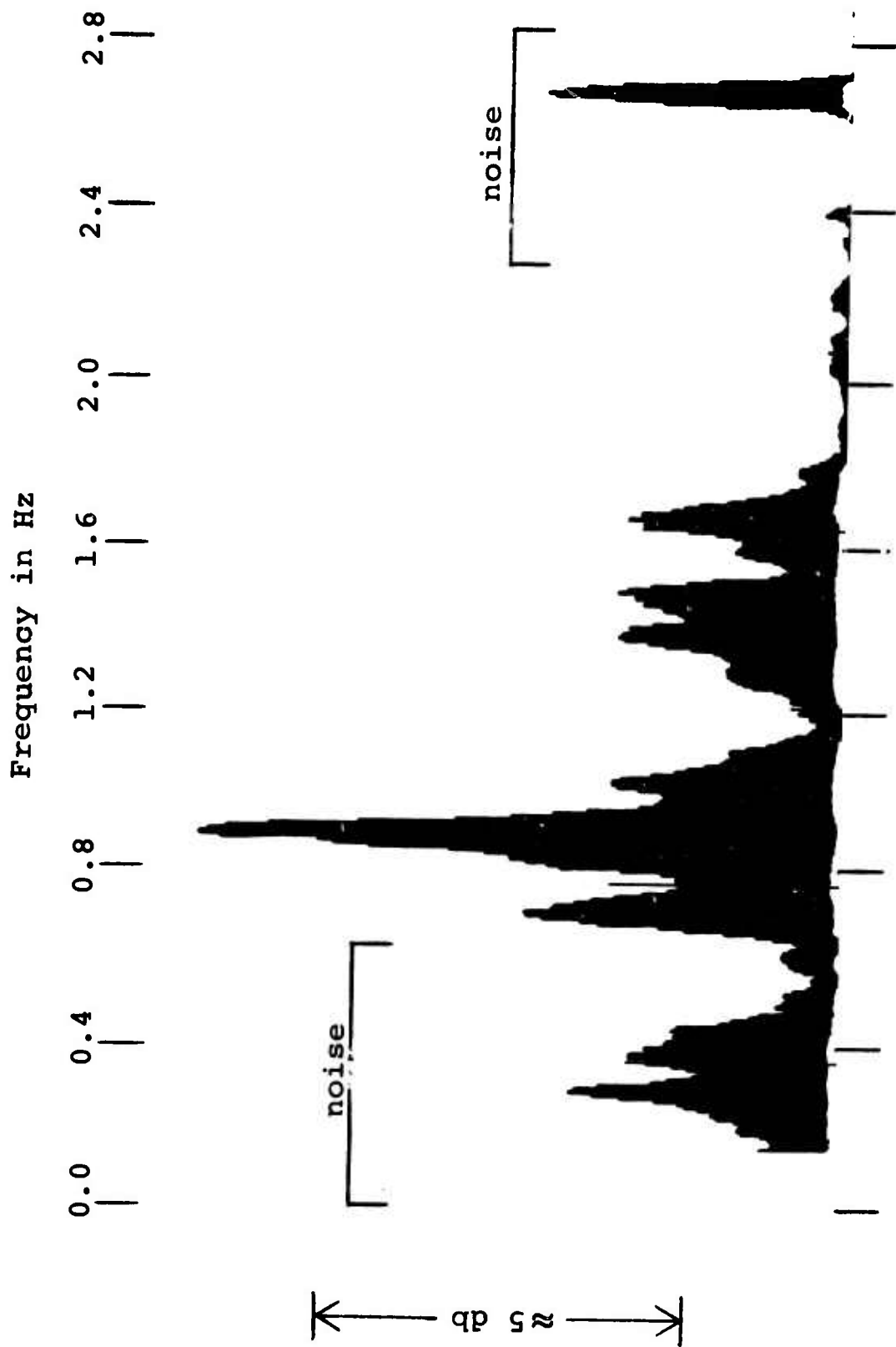


Figure (21)
Spectral analysis of seismic
signal generated by CHASE V
detonation as received at
Red Lake, Ontario.
Range - 2797 km.

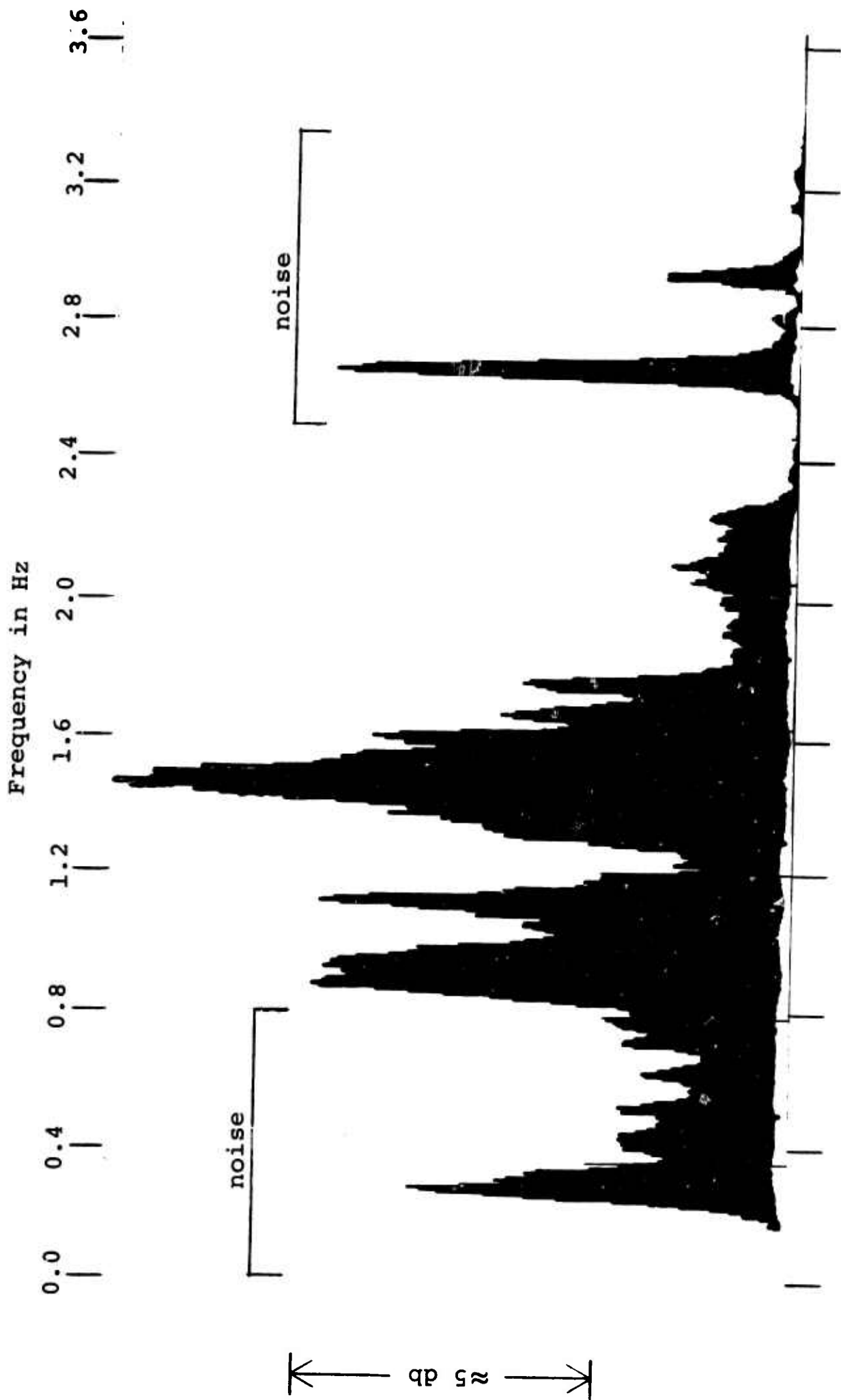


Figure (22)
Spectral analysis of seismic
signal generated by CHASE V
detonation as received at
Alexander City, Alabama.
Range - 3618 km.

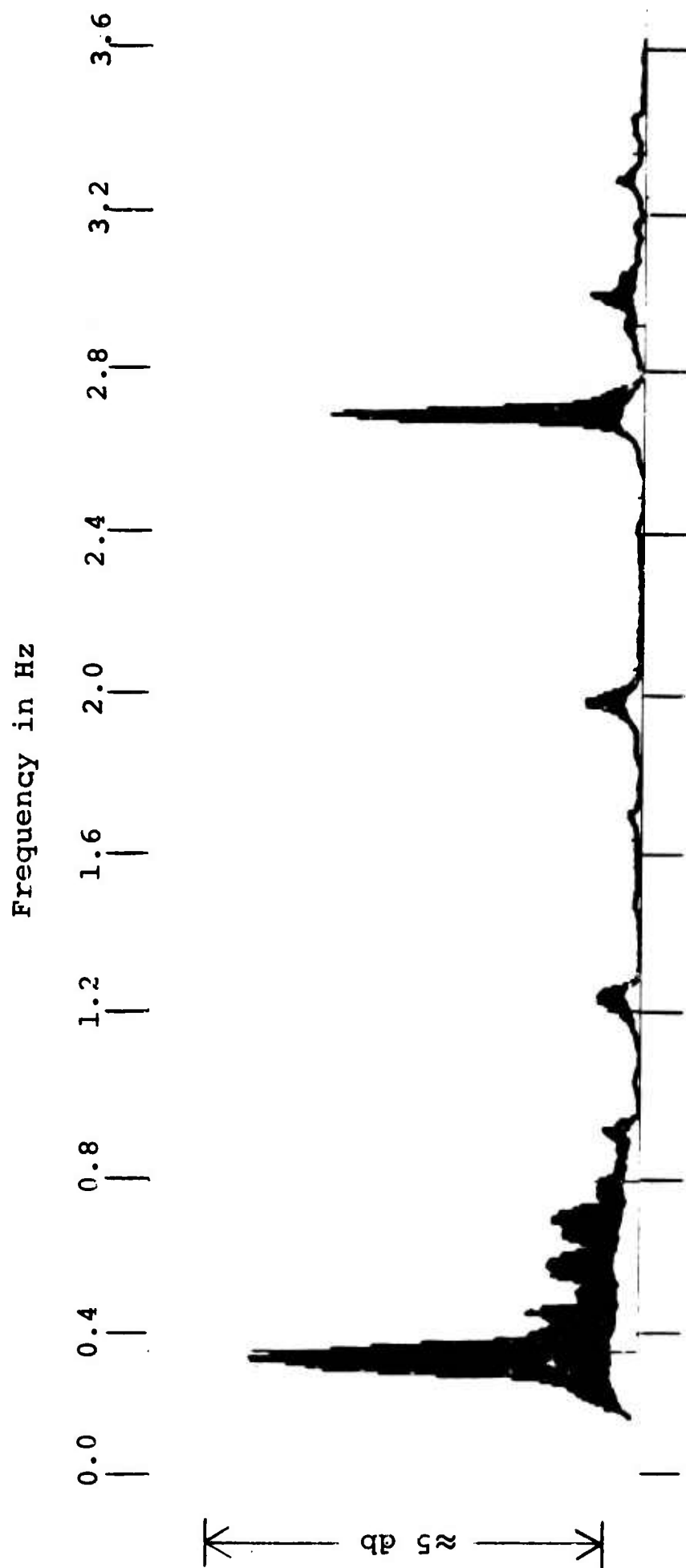


Figure (23)
Spectral analysis of
background noise pre-
ceding signal analyzed
in Figure (22).

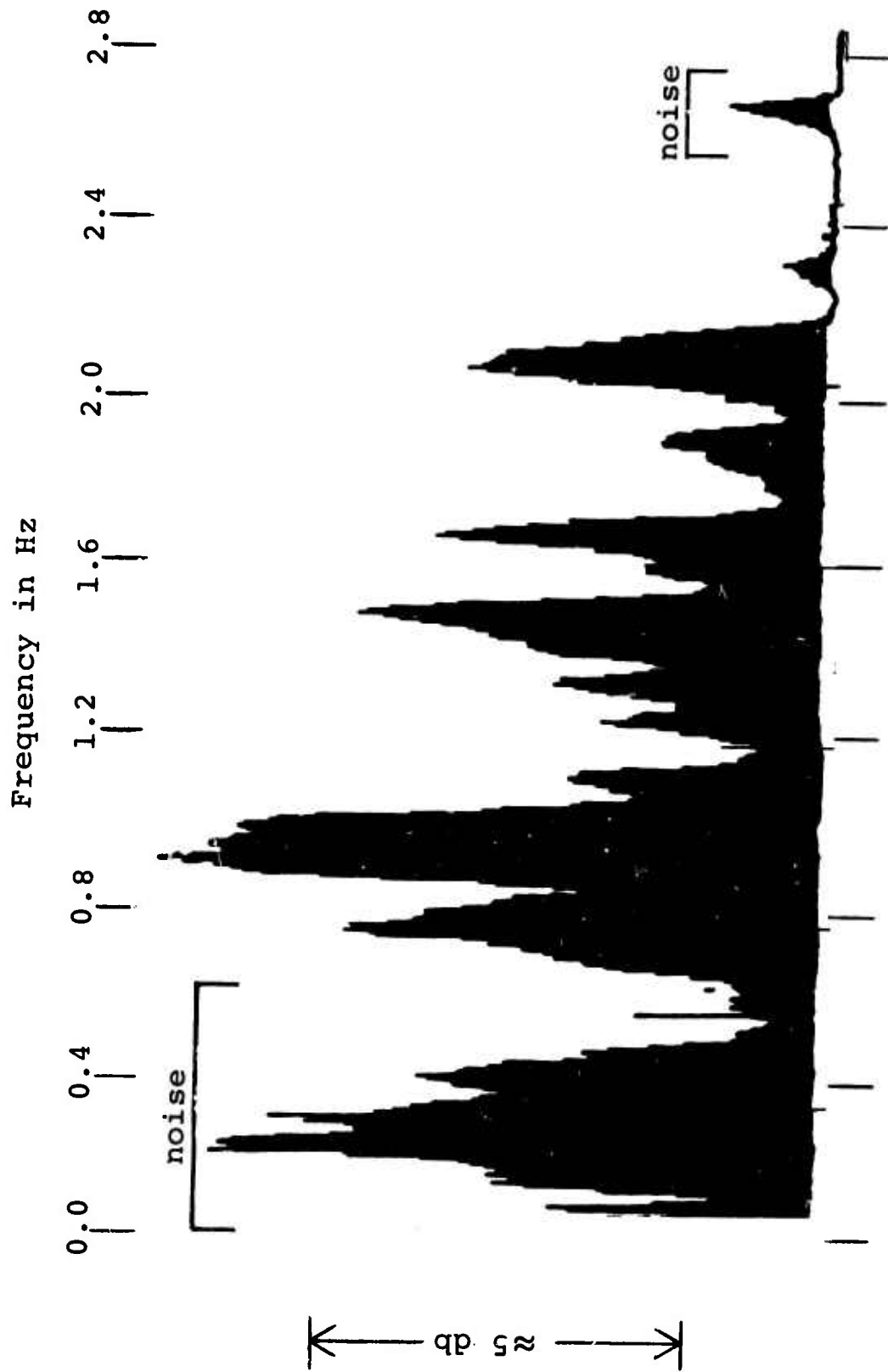


Figure (24)

Spectral analysis of seismic
signal generated by CHASE V
detonation as received at
Mould Bay, Northwest Territories.
Range - 4113 km.

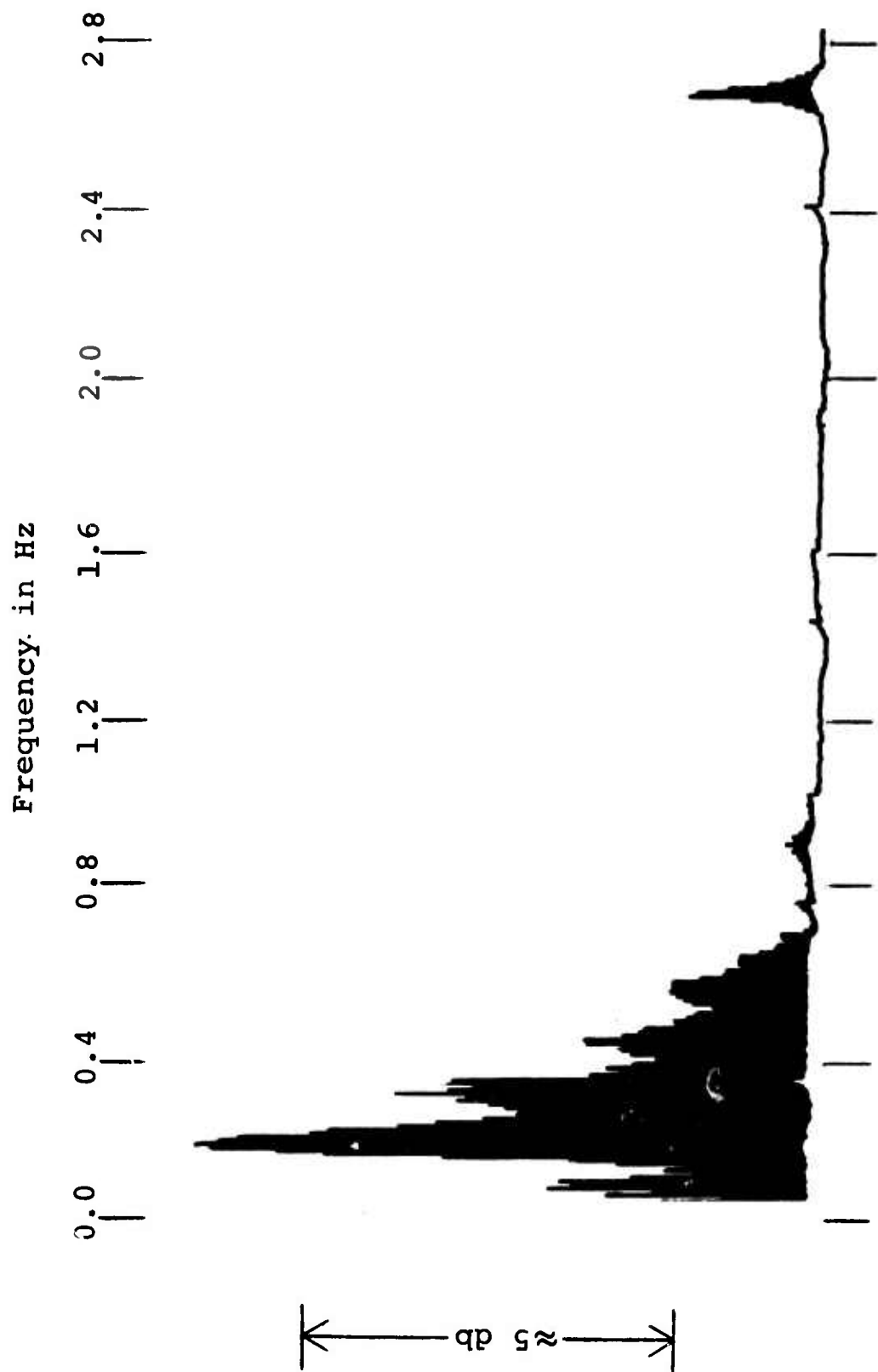


Figure (25)
Spectral analysis of
background noise pre-
ceding signal analyzed
in Figure (24).

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13. ABSTRACT			
The CHASE VII event consisted of the underwater explosion of 400 tons TNT equivalent at a nominal detonation depth of 3000 feet. The CHASE V event had a yield of 1000 tons and was detonated at a nominal depth of 4000 feet. Narrow band spectra of the seismic signals generated by these events as received at a number of LRSM stations and Vela observatories are presented. Source-receiver distances of selected stations range from approximately 700 to 5000 kilometers. From the results obtained, it is concluded that: (1) The odd harmonic series due to the detonation depth is readily identified in a majority of the spectra obtained for both the CHASE V and CHASE VII events. (2) The bubble pulse frequency is not identified for either the CHASE V or CHASE VII event. (3) Harmonic series falling in the complete integer set, as yet unexplained, are revealed in the records obtained for both the CHASE V and CHASE VII events. (4) An odd harmonic series interpreted as being generated by sub-bottom layering at the source is observed in the CHASE VII spectra. This series is not observed in the CHASE V records. (5) A comparison of spectra obtained from several seismic stations is essential to valid spectral interpretation.			

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underwater explosion TNT equivalent nominal detonation depth narrow band spectra odd harmonic series bubble pulse frequency sub-bottom layering						

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