World-Wide Standard Station Seismic Measurements

Project 173-7

ANTLER

September 15, 1961

Prepared

by

Seismology Division

under

ARPA Project VELA-UNIFROM

U. S. Department of Commerce
Coast and Geodetic Survey
Washington 25, D. C.

June 1963

This shot report is issued on behalf of the Advanced Research Projects Agency, Department of Defense, to provide information which may prove of value in the study of data from nuclear tests.

The data contained in this report are preliminary and subject to later revision as may be necessary.

CONTENTS

TABLES

FIGURES

ANTLER

NOUGAT SERIES

EVENT DESCRIPTION

DATE: September 15, 1961

TIME OF ORIGIN: 17:00:00.1Z

MAGNITUDE: $m_b = 4.4 \pm 0.4$

LOCATION:

Site: Area U12eo3a

Geographic Coordinates:	Lat. 37°11'17" N Long. 116°12'28" W
Nevada Grid Coordinates:	N 887 716.89 feet E 633 676.25 feet

ENVIRONMENT:

Geological Medium: Tuff
Shot Depth: 1319 feet
Surface Elevation: 7483 feet
Shot Elevation: 6164 feet

COMPUTED EPICENTER DATA:

Geographic Coordinates: Lat. 37°11'01.0" N, Long. 116°14'34.1" W

Time of Origin: 16:59:59.5Z
Station Used: See Table 8

COLLAPSE: None Observed

UNITED STATES

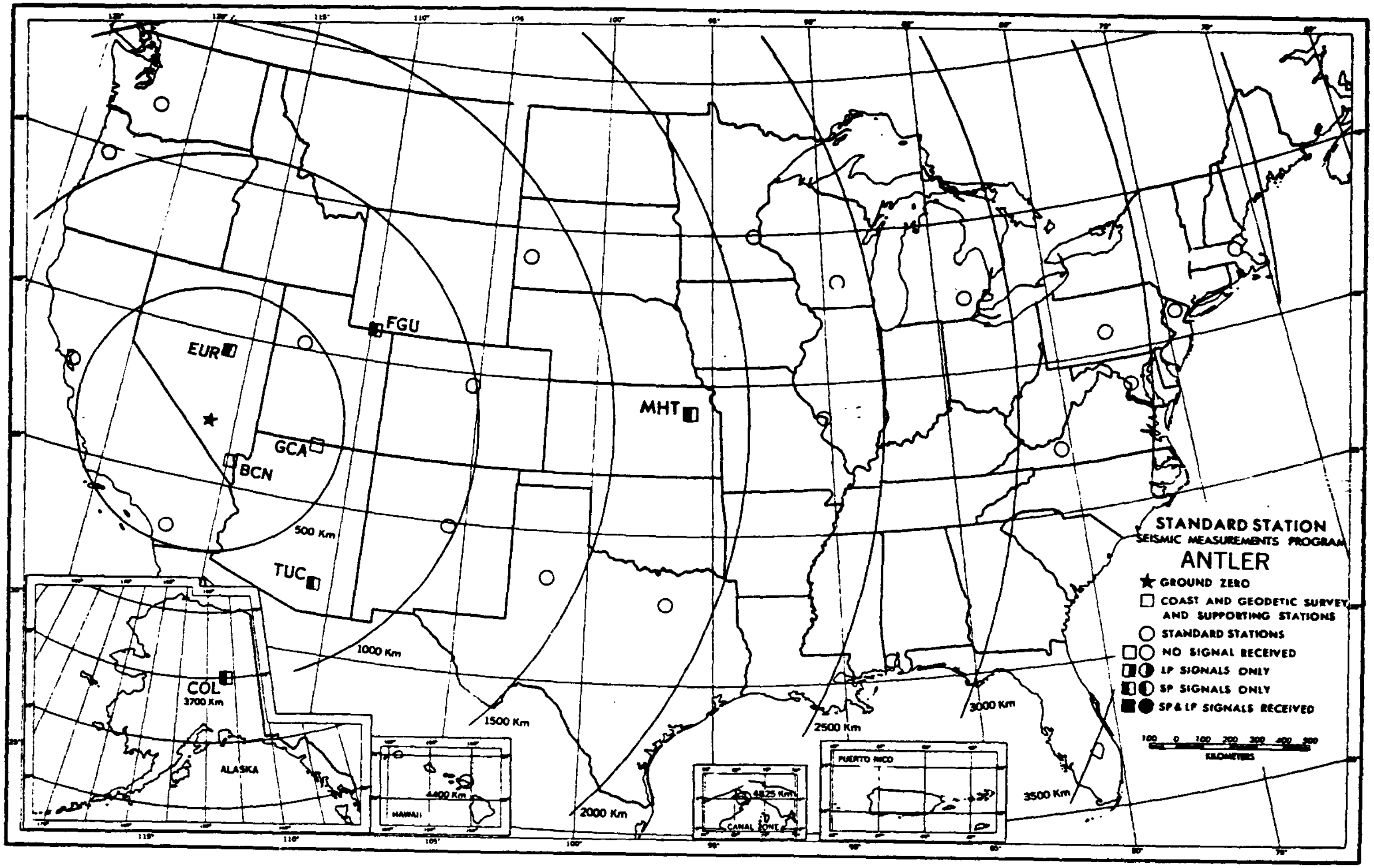


Figure 1. Map showing recording stations within the United States and signals received from ANTLER

INTRODUCTION

A World-Wide Network of Standardized Seismograph Stations (WWNSS) is being established under VELA-UNIFORM Project to provide standardized short and long period instruments for recording seismic data. This program was initiated to provide improved instrumentation for recording world-wide seismic activity and to eliminate, as far as possible, uncertainties in the analysis of seismic data due to differences in instrumentation.

This report comprises an analysis of seismic data recorded from the ANTLER event at the Nevada Test Site (NTS) by Coast and Geodetic Survey and other stations. These, and other data, will be used by VELA-UNIFORM participants for studies directed toward the development of methods for distinguishing between explosion and earthquake seismic sources.

INSTRUMENTATION

The Coast and Geodetic Survey stations used in this report have either Benioff variable reluctance or Benioff moving coil instruments: Recording techniques differ as shown below:

Flaming Gorge, Utah	35 mm film
Eureka, Nevada	photographic paper recording
Tucson Telemeter, Arizona	photographic paper recording
College, Alaska	photographic paper recording

Reference time is placed on the records at Coast and Geodetic Survey stations as follows:

Flaming Gorge	- a separate film is used to record a radio time signal.
Eureka	- operator manually impresses a radio time signal, such as WWV.
Tucson Telemeter	- operator manually impresses a radio time signal, such as WWV.
College	- operator manually impresses a radio time signal, such as WWV.

The horizontal instruments of each station used in this report have N-S and E-W orientation.

DATA AND RESULTS

Figure 1 shows the station locations within the United States and indicates stations which recorded the event. Table 1 summarizes signal reception and instrument availability; Table 2 contains instrument peak magnifications; Table 3 shows station coordinates, elevation, epicenter to station azimuth, and instrument foundation.

Table 4 summarizes the measurements made of the principal phases from the ANTLER event. Included are P_n and P, P_g, and L_g arrival times. First motion conforming to Technical Working Group II (TWG II) criteria is noted (see Appendix II). A second column included in Table 4 gives first motion as it might be listed by a working seismologist in routine analysis of seismograms, not necessarily meeting TWG II signal to noise specifications.

Table 5 shows the travel times, periods, maximum ground displacement in mμ, and maximum amplitude/period in mμ/sec for P_n and P. These data are measured on the short period vertical instruments. Arrival times and periods are read to the nearest ± 0.1 sec and amplitudes are measured to ± 0.5 mm. Four Coast and Geodetic Survey stations with the required instrumentation recorded ANTLER. Also shown in Table 5 are the unified magnitudes (m_b), based on either P_n or P trace displacements and the AFTAC extension of the Gutenberg and Richter technique of "Q" values. The average magnitude value of 4.4 shown in Figure 5 is apparently low since College, Alaska has been closer to the average value in previous reports. A second stronger arrival at MHT is plotted by an open square in both Figures 2 and 5.

Travel times, periods, maximum ground displacements, and maximum amplitude/period of P_g taken from the short period vertical instruments are given in Table 6. Travel times are measured to the beginning of the phase and do not indicate the time at which maximum amplitude is recorded. Recordings of P_g were observed at two stations.

In Table 7 are listed the travel times, periods, maximum ground displacements, and maximum amplitude/period of L_g phase. The following criteria were used in the identification of the L_g phase: (1) the relation of the vertical amplitude to the horizontal amplitude; (2) observed travel time; (3) initial period; and (4) reverse dispersion. The L_g phase was recognized at only one station.

Figures 2 and 3 show plots of the energy attenuation (amplitude/period) versus distance for P_n and P, and P_g respectively. A reference line proportional to the inverse cube of the epicentral distance has been visually fitted through the observed P and P_g points and a fourth power line through the P_n points. In Figure 4 are shown the travel time residuals of P_n and P based on a constant P_n velocity of 8.1 km/sec.

COMPUTER DATA REDUCTION

Useful signals from ANTLER were recorded out to a distance of 3717 (College, Alaska). Input data for the computer program are tabulated in Table 8. In Table 9 are tabulated the computer determined travel time residuals, azimuths, and distances based on the known coordinates, origin time, and assuming a depth on the surface of the reference sphere. A hypocenter determination was made (not shown) which resulted in a depth value 12 km above the reference sphere and errors of 1 km N and 2 km E in epicenter coordinates. In Table 10 is shown the epicenter computation obtained by holding the depth fixed on the surface of the reference sphere. This computation resulted in an epicenter coordinate error of 0.5 km S and 3.9 km W.

REFERENCES

Carder, D. S., and L. F. Bailey, (1958), "Seismic Wave Travel Times from Nuclear Explosions," Bulletin Seismological Society of America, Vol. 48, pp. 377-398.

Gunst, R. H., and E. R. Engdahl, (1962), "Progress Report of USC&GS Hypocenter Computer Program," Earthquake Notes, Vol. 33, No. 4, p. 93.

Gutenberg, B., and C. F. Richter, (1956), "Magnitude and Energy of Earthquakes," Annali di Geofisica, Vol. 9, p. 1.

Jeffreys, H., and K. E. Bullen, (1958), "Seismological Tables," British Association for the Advancement of Science, Burlington House, W. 1, London, England.

Lehmann, I., (1962), "The Travel Times of the Longitudinal Waves of the Logan and Blanca Atomic Explosions and their Velocities in the Upper Mantle," Bulletin Seismological Society of America, Vol. 52, No. 3, p. 519.

Romney, Carl, (1959), "Amplitudes of Seismic Body Waves from Underground Nuclear Explosions," Journal of Geophysical Research, Vol. 64, No. 10, pp. 1489-1501.

Table 1. ANTLER

Station Status Report

Sta.	Abbr.	Dist. km	SPZ	SPN	SPE	LPZ	LPN	LPE
Eureka, Nev.	EUR	256	+	x	x	x	x	x
Flaming Gorge, Utah	FGU	722	+	+	+	x	x	x
Tucson Telemeter, Ariz.	TUT	736	+	x	x	x	x	x
College, Alaska	COL	3717	+	x	x	x	x	x

+ Received signal
x No instrument

Table 2. ANTLER

Station Distance and Magnification

Sta.	Dist. km	SPZ	Instrument Magnification in K SPN	SPE	LPZ	LPN	LPE
EUR	256	425	x	x	x	x	x
FGU	722	63	-	-	x	x	x
TUT	736	200	x	x	x	x	x
COL	3717	425	x	x	x	x	x

x No instrument
- Magnifications not known

Table 3. ANTLER

Station Site Information

Sta.	Geographic N. Lat. ° ' "	Geographic W. Long. ° ' "	Elev. km	Azi. Epi-Sta. °	Foundation
EUR	39 29 00	115 58 12	2.18	4.6	Dolomite
FGU	40 55 36	109 23 10	1.98	52.8	Limestone
TUT	32 14 49	110 50 01	0.20	135.4	Granite
COL	64 54 00	147 47 36	0.16	336.1	Granite

Table 4. ANTLER

Principal Phases

Sta.	Dist. km	Inst.	Phase	GMT	TWG II FM*	FM**
EUR	256	SPZ	iP_n	17:00:39.9	C	C
TUT	736	SPZ	eP_n	17:01:39.4		
		SPZ	eP_g	17:02:03.6		
FGU	722	SPZ	eP_n	17:01:39.8		
		SPZ	eP_g	17:02:13.2		
		SPZ	eL_g	17:03:25.5		
MHT	1731	SPZ	eP	17:03:44.0		
		SPZ	e	17:03:58.9		
COL	3717	SPZ	eP	17:06:42.3		

e Emergent
i Impulsive
C Compression
D Rarefaction
* See Appendix II
** As it may be picked in routine analysis, but not meeting TWG II specifications

Table 5. ANTLER

Periods and Amplitudes of P_n and P

Sta.	Dist. km	T-T* sec	Per. sec	Ampl.** mμ	Ampl./Per. mμ/sec	m_b
EUR	256	39.8	-	-	-	-
FGU	722	99.7	0.6	12.1	20.2	4.8
TUT	736	99.3	0.6	3.0	5.0	4.1
MHT	1731	223.9	0.8	5.3	6.6	3.9
COL	3717	402.2	0.9	11.3	12.6	4.8

* Observed travel time from short period vertical seismogram
** Maximum ground displacement in mμ (single amplitude)
\- Excessive amplitude

Table 6. ANTLER

Periods and Amplitudes of P_g

Sta.	Dist. km	T-T* sec	Per. sec	Ampl.** mμ	Ampl./Per. mμ/sec	Comp.
FGU	722	133.1	0.6	10.6	17.7	SPZ
TUT	736	123.5	0.9	3.5	3.8	SPZ

*Observed travel time
**Maximum zero to peak ground displacement

Table 7. ANTLER

Periods and Amplitudes of L_g

Sta.	Dist. km	T-T* sec	Per. sec	Ampl.** mμ	Ampl./Per. mμ/sec	Comp.
FGU	722	205.4	0.6	8.3	13.8	SPZ

*Observed travel time
**Maximum zero to peak ground displacement

Table 8. ANTLER

Computer Input Data

Sta.	Phase	GMT
MN1	iP_n	17:00:34.4
EUR	iP_n	17:00:39.9
WDY	iP_n	17:00:43.3
BF1	iP_n	17:00:49.1
RVR	iP_n	17:00:53.1
PAS	iP_n	17:00:55.0
HAY	iP_n	17:00:55.3
KRC	iP_n	17:00:55.6
FM1	iP_n	17:00:58.3
MHC	iP_n	17:01:07.9
CP1	iP_n	17:01:08.3
BE1	iP_n	17:01:09.0
FS1	iP_n	17:01:10.5
VIN	e	17:01:13.2
SLC	eP_n	17:01:13.6
SFC	e	17:01:25.8
TUT	eP_n	17:01:39.4
FGU	eP_n	17:01:39.8
DR1	eP_n	17:01:40.7
LAR	iP	17:02:18.2
LC1	eP	17:02:19.5
MHT	eP	17:03:44.0
COL	eP	17:06:42.3

Table 9. ANTLER

Travel Time Residual Data*

Sta.	Dist. km	Azi. °	Res.** sec
MN1	220	309.6	1.0
EUR	256	4.6	0.2
WDY	289	235.9	0.8
BF1	292	235.1	-4.5
RVR	369	197.0	1.3
PAS	381	208.4	0.9
HAY	390	172.2	1.8
KRC	378	238.0	0.1
FM1	417	56.0	2.3
WI1	475	347.2	1.2
MHC	482	273.7	1.1
CP1	495	181.8	2.3
BE1	498	297.3	1.9
FS1	500	116.6	0.7
VIN	464	265.5	-6.8
SLC	548	42.2	3.7
SFC	553	278.5	-8.0
TUT	736	135.4	1.6
FGU	722	52.8	-0.4
DR1	747	85.1	2.1
LAR	1024	60.2	-1.0
LC1	1026	118.3	-1.8
MHT	1731	76.6	-1.6
COL	3717	336.1	0.1

*The exact origin time and hypocenter coordinate data were used to compute distance, azimuth, and travel time residual for each observation.

**TIME RESIDUAL = Jeffreys-Bullen travel time - Observed travel time + Ellipticity and station elevation corrections

Table 10. ANTLER

Epicenter Computation*

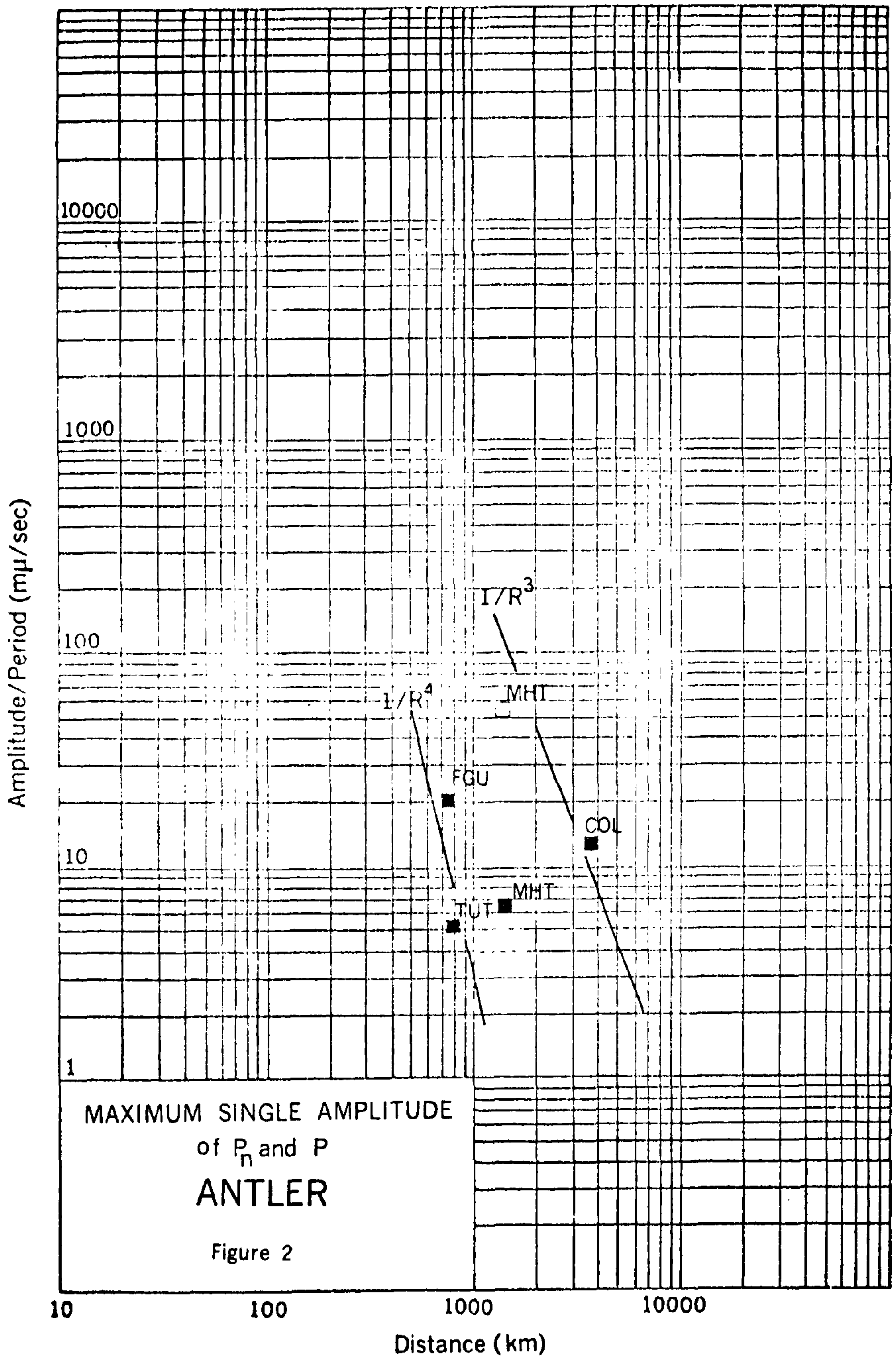
	Computed	Error
Ø =	37°11'01.0" N	0.5 km S
λ =	116°14'34.1" W	3.9 km W
H =	16:59:59.5Z	-.6 sec

Sta.	Dist. km	Azi. °	Res.** sec
MN1	222	310.2	0.1
EUR	256	5.3	-0.3
WDY	289	235.6	-0.1
RVR	367	196.5	0.6
PAS	378	208.0	0.0
HAY	389	171.7	1.2
KRC	378	237.8	-0.9
WI1	478	347.6	0.6
MHC	478	273.7	0.1
FS1	500	116.4	0.4
SLC	556	42.4	3.4
TUT	734	135.2	1.3
FGU	723	52.9	-0.6
LAR	1023	60.2	-1.2
LC1	1034	118.2	-2.1
MHT	1735	76.6	-1.8
COL	3714	336.1	-0.6

Sta.	Dist. km	Azi. °	Res.** sec
BF1	289	234.8	-5.5
FM1	423	56.2	2.1
CP1	489	181.4	1.6
BE1	500	297.5	1.0
VIN	456	265.5	-7.8
SFC	545	278.6	-9.0
DR1	745	85.1	1.9

*The epicenter coordinates and origin time were computed holding the depth at 00 km using the first 17 stations listed. Residuals were computed for all stations.

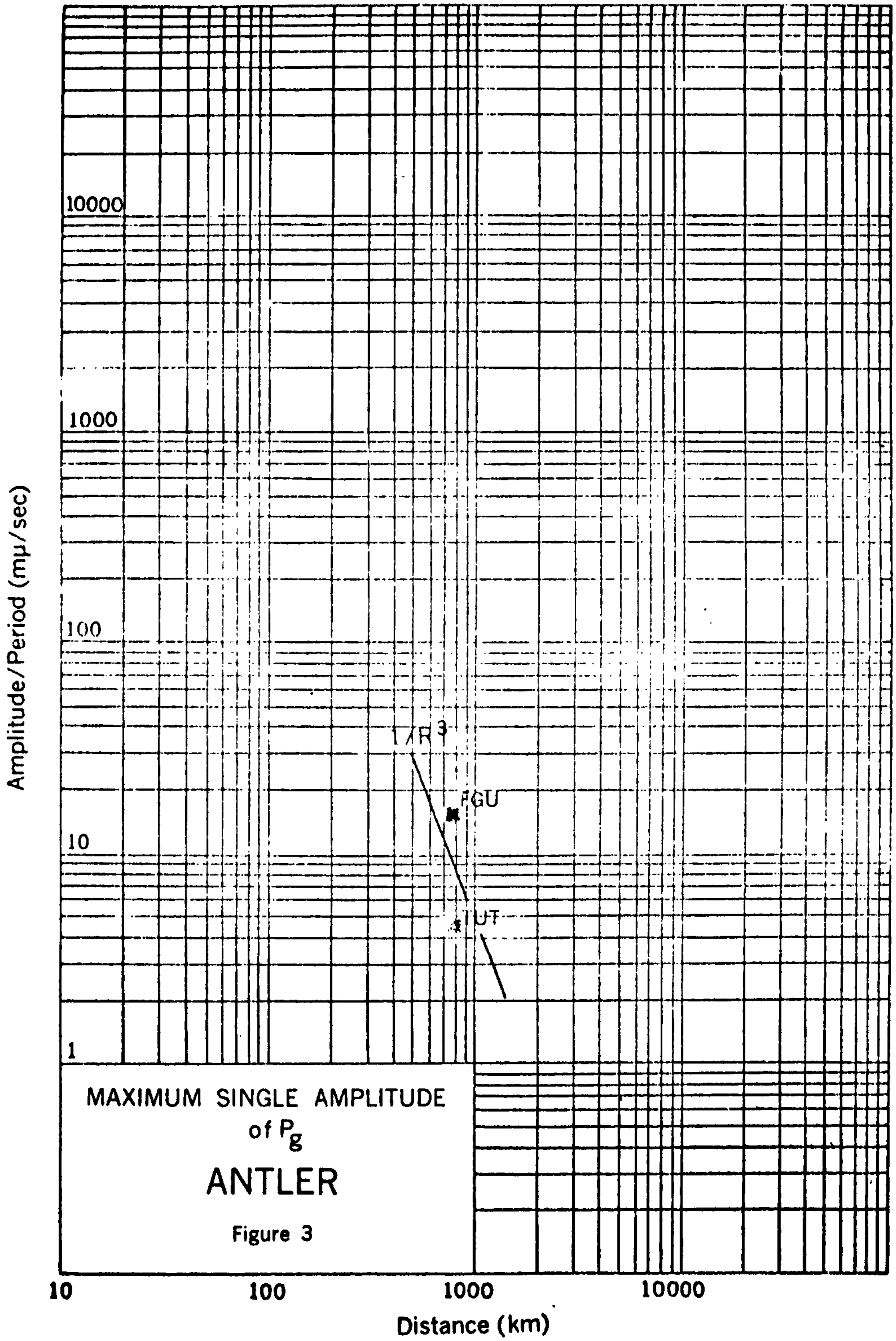
**TIME RESIDUAL = Jeffreys-Bullen travel time - Observed travel time + Ellipticity and station elevation corrections



MAXIMUM SINGLE AMPLITUDE of P_n and P

ANTLER

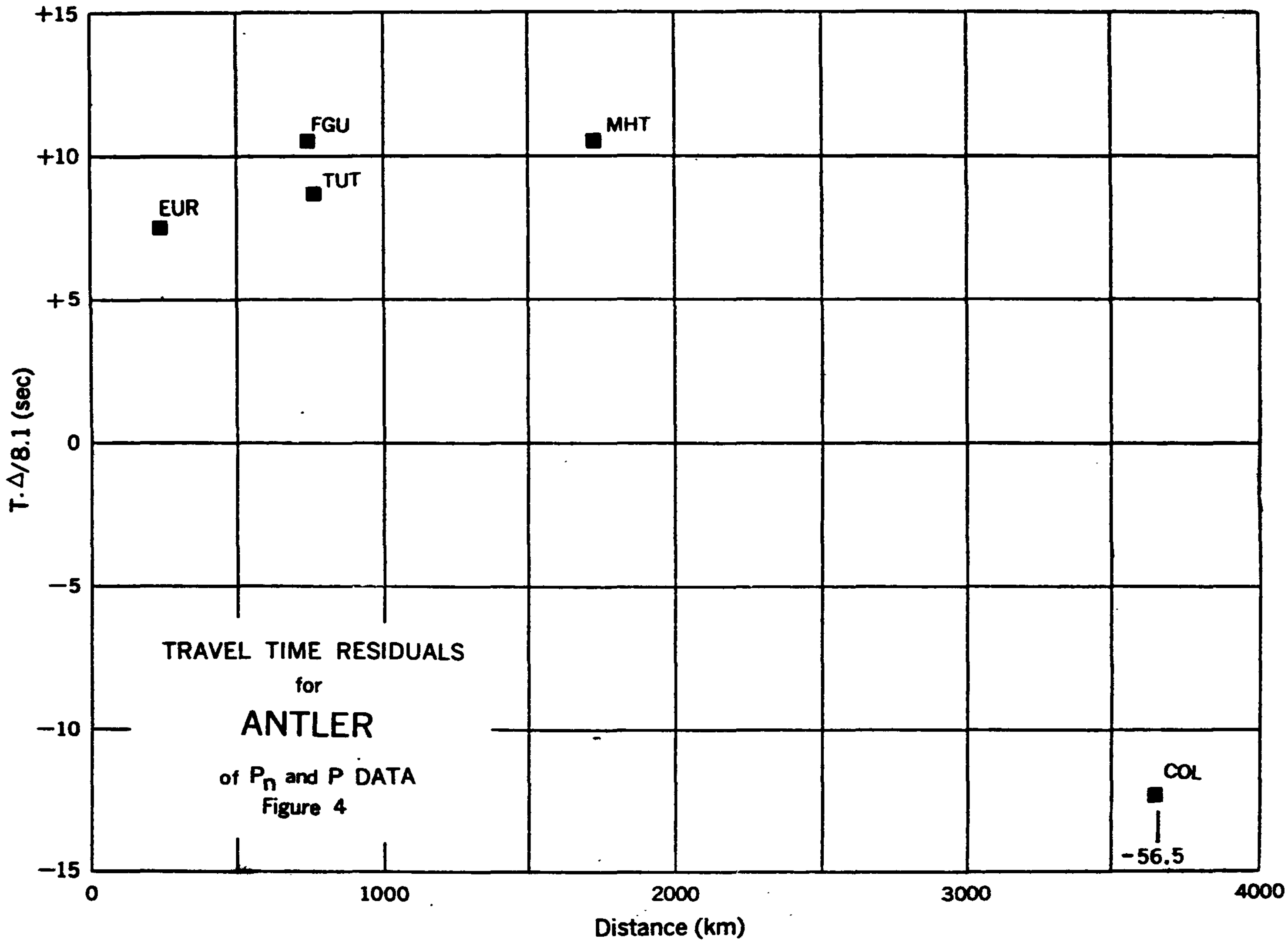
Figure 2



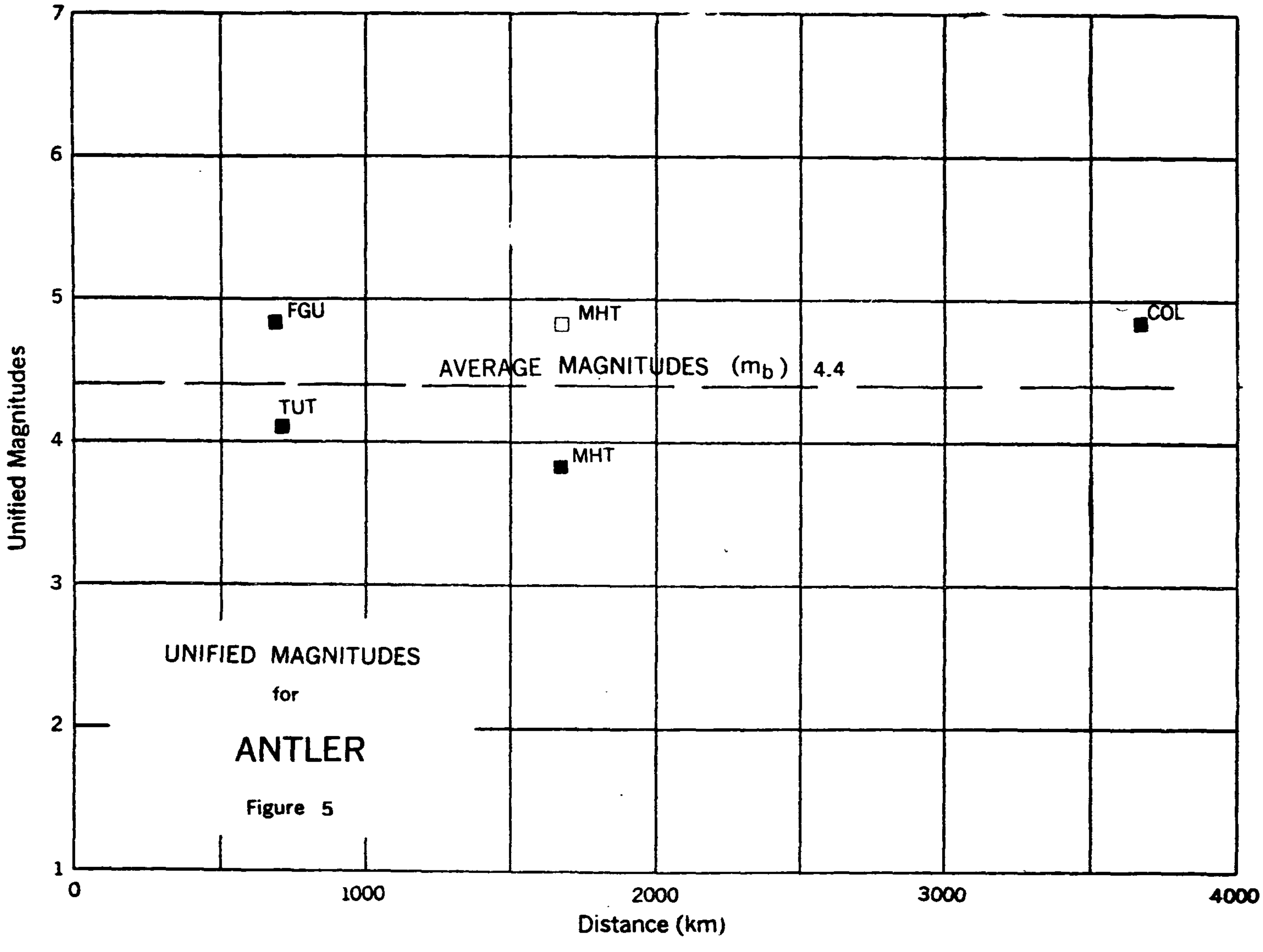
MAXIMUM SINGLE AMPLITUDE of P_g

ANTLER

Figure 3



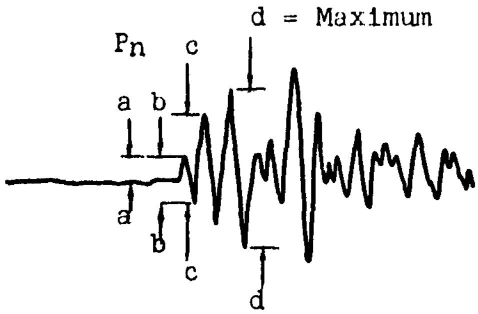
TRAVEL TIME RESIDUALS
for
ANTLER
of P_n and P DATA
Figure 4

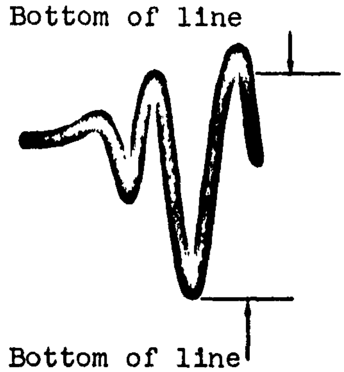


UNIFIED MAGNITUDES
for
ANTLER
Figure 5

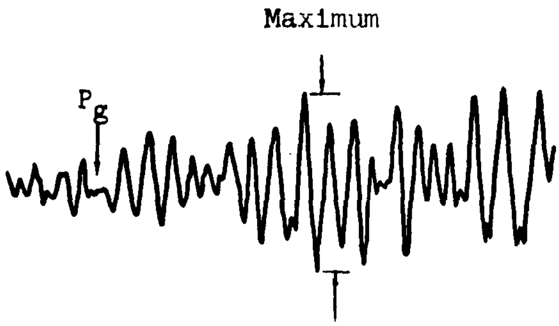
SEISMIC ANALYSIS DIAGRAM

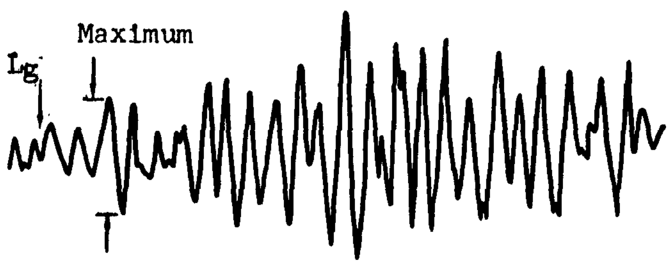
APPENDIX I





DETAIL SHOWING ALLOWANCE FOR LINE WIDTH





Pick time of P_n at beginning of "a" half-cycle.

Pick amplitude of P_g as maximum "d/2" within 2 or 3 cycles of "c".

Pick amplitude of P_g and L_g at maximum of corresponding motion.

APPENDIX II

FIRST MOTION CRITERIA
TECHNICAL WORKING GROUP II (TWG)

Excerpt from Appendices to Hearings before the Special Subcommittee on Radiation and the Subcommittee on Research and Development of the Joint Committee on Atomic Energy; 86th Cong., 2d Sess.; April 19-22, 1960; on Technical Aspects of Detection and Inspection Controls of a Nuclear Weapons Test Ban; Part 2 of 2 Parts, pp 632-633:

"2. Identification of Earthquakes

A located seismic event shall be ineligible for inspection if, and only if, it fulfills one or more of the following criteria:

a. Its depth of focus is established as below 60 kilometers;

b. Its epicentral location is established to be in the deep open ocean and the event is unaccompanied by a hydroacoustic signal consistent with the seismic epicenter and origin time;

c. It is established within 48 hours to be a foreshock by the occurrence of a larger event of at least magnitude 6 whose epicenter coincides with that of the given event within the accuracy of the determination of the two epicenters. The eligibility of the second event for inspection must be determined separately.

d. The directions of clearly recorded first motions define a pattern which strongly indicates a faulting source. First motions recorded at distances between 1100 kilometers and 2500 kilometers will not be used. First motions beyond 3500 kilometers will not be used for events of magnitude smaller than 5.5. The apparent direction of first motion must also meet both the following minimum conditions to be considered to be clearly recorded:

(1) The amplitude of the half-cycle of apparent first motion is at least two (2) times as large as any half-cycle of apparent noise in the preceding few minutes, and

(2) The largest of the amplitudes of the half-cycle of apparent first motion and the two immediately following half-cycles.

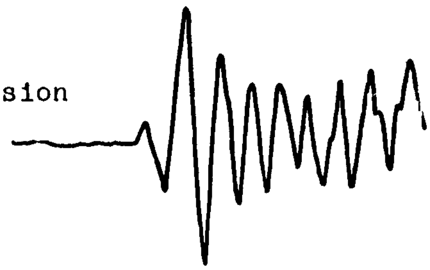
(a) at epicentral distances less than 700 kilometers is twenty (20) times larger than any half-cycle of noise in the preceding few minutes;

(b) at epicentral distances more than 700 kilometers is forty (40) times larger than any half-cycle of noise in the preceding few minutes.

A pattern of clearly recorded first motions strongly indicates a faulting source if the observed motions, extended backward to a small sphere about the focus, can be separated into alternate quadrants by two orthogonal great circles drawn on the small sphere, with the requirement that two opposite quadrants combined (i) contain at least 4 clearly recorded rarefactive first motions and (ii) contain not more than 15% compressions among the clearly recorded first motions."

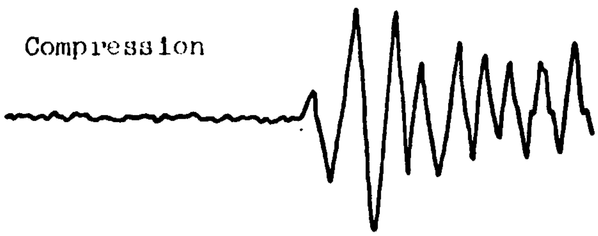
APPENDIX II

1. Compression



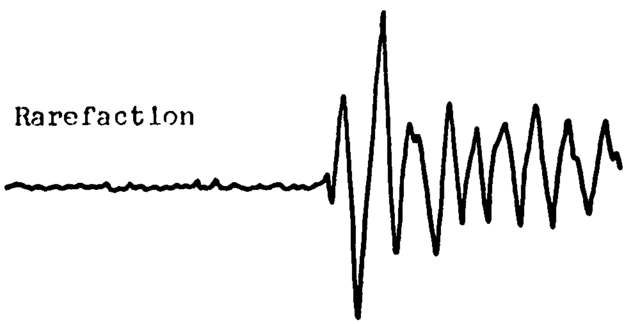
$700 < \Delta < 1100$ km

2. Compression



$\Delta < 700$ km

3. Rarefaction

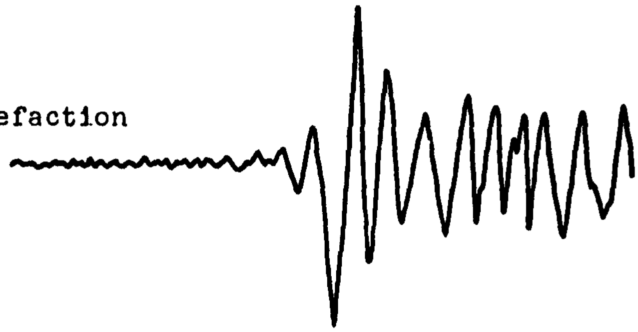


$\Delta < 700$ km. Example shows what may be interpreted to be earlier signal; however, motion is less than 2 times the motion level and may be interpreted as noise.

APPENDIX II

Application of the TWG II Criteria

4. Rarefaction



$\Delta < 700$ km.
Similar to example 3

5. Not applicable

Δ 700 km. Amplitude of first half-cycle is less than 20 times noise.

APPENDIX III

COMPUTATION OF AZIMUTH AND EPICENTRAL DISTANCE

Standard formulas of spherical trigonometry are used in computing azimuth and distance from epicenter to station. As required by the Jeffreys-Bullen travel time curves, the formulas are referred to a spherical earth equal in volume to the Hayford-Bowie spheroidal earth. This requires a sphere of radius 6371.14 km.

The geographic coordinates of the station and epicenter must be converted to geocentric coordinates. Use is then made of direction-cosines of the line joining the Earth's center to the epicenter and of the line joining the Earth's center to the station. By this method the formula obtained for the epicentral distance is as follows:

$$\cos \Delta = \sin \phi \sin \phi' + \cos \phi \cos \phi' (\cos \gamma \cos \gamma' + \sin \gamma \sin \gamma').$$

Where

ϕ = geocentric latitude of epicenter
γ = longitude of epicenter
ϕ' = geocentric latitude of station
γ' = longitude of station
Δ = angular distance from epicenter to station

The azimuth, which is the angle measured from north through east between the meridian line through the epicenter and the arc line from epicenter to recording station, is obtained by use of the following formula from spherical trigonometry:

$$\cos Z = \frac{\sin \phi' - \cos \Delta \sin \phi}{\cos \phi \sin \Delta}.$$

Printout of both Z and Δ is rounded off to the nearest 0.1 deg. It is expected then that an error of $\pm$ 5.5 km. due to rounding may exist in our quoted epicentral distance. This rounding error is reflected in neither the epicentral computation nor the published travel time residuals.

APPENDIX IV

Unified Magnitudes from P_n or P Waves

Unified Magnitude: $m = \log_{10} (A/T) + B$

where

A = zero to peak ground motion in millimicrons

$= \frac{(mm)(1000)}{K}$

T = signal period in seconds

B = distance factor (see Table below)

mm = record amplitude in millimeters zero to peak

K = magnification in thousands at signal frequency

Table of Distance Factors (B) for Zero Depth

Dist. (°)	B	Dist. (°)	B	Dist. (°)	B
0	-	20	3.0	40	3.4
1	-	21	3.1	41	3.5
2	2.2	22	3.2	42	3.5
3	2.7	23	3.3	43	3.5
4	3.1	24	3.3	44	3.5
5	3.4	25	3.5	45	3.7
6	3.6	26	3.4	46	3.8
7	3.8	27	3.5	47	3.9
8	4.0	28	3.6	48	3.9
9	4.2	29	3.6	49	3.8
10	4.3	30	3.6	50	3.7
11	4.2	31	3.7	51	3.7
12	4.1	32	3.7	52	3.7
13	4.0	33	3.7	53	3.7
14	3.6	34	3.7	54	3.8
15	3.3	35	3.7	55	3.8
16	2.9	36	3.6	56	3.8
17	2.9	37	3.5	57	3.8
18	2.9	38	3.5	58	3.8
19	3.0	39	3.4	59	3.8

Dist. (°)	B	Dist. (°)	B	Dist. (°)	B
60	3.8	75	3.8	90	4.0
61	3.9	76	3.9	91	4.1
62	4.0	77	3.9	92	4.1
63	3.9	78	3.9	93	4.2
64	4.0	79	3.8	94	4.1
65	4.0	80	3.7	95	4.2
66	4.0	81	3.8	96	4.3
67	4.0	82	3.9	97	4.4
68	4.0	83	4.0	98	4.5
69	4.0	84	4.0	99	4.5
70	3.9	85	4.0	100	4.4
71	3.9	86	3.9	101	4.3
72	3.9	87	4.0	102	4.4
73	3.9	88	4.1	103	4.5
74	3.8	89	4.0	104	4.6
				105	4.7