Report of Investigations 8892

Airblast and Ground Vibration Generation and Propagation From Contour Mine Blasting

By Virgil J. Stachura, David E. Siskind,
and John W. Kopp

UNITED STATES DEPARTMENT OF THE INTERIOR
William P. Clark, Secretary

BUREAU OF MINES
Robert C. Horton, Director

UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

cu yd	cubic yard	in/s	inch per second
dB	decibel	lb	pound
deg	degree	lb/in^2	pound per square inch
ft	foot	MΩ	megaohm
ft/lb	foot per pound	pct	percent
GΩ	gigaohm	s	second
Hz	hertz	yr	year
in	inch		

Library of Congress Cataloging in Publication Data:

Stachura, Virgil J

Airblast and ground vibration generation and propagation from contour mine blasting.

(Bureau of Mines report of investigations ; 8892)

Bibliography: p. 11.

Supt. of Docs. no.: I 28.23:8892.

1. Blasting. 2. Blast effect—Measurement. 3. Coal mines and mining—Appalachian Region. I. Siskind, D. E. II. Kopp, John W. III. Title. IV. Series: Report of investigations (United States. Bureau of Mines) ; 8892.

TN23.U43 [TN279] 622s [622'.334] 84-600051

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AIRBLAST AND GROUND VIBRATION GENERATION AND PROPAGATION FROM CONTOUR MINE BLASTING

By Virgil J. Stachura,[1] David E. Siskind,[2] and John W. Kopp[3]

ABSTRACT

The Bureau of Mines studied airblast and ground vibrations produced by surface coal mine blasting in Appalachia to determine the topographic or other region-specific effects on generation and propagation. Arrays of seismographs were used to measure blast effects in both rolling-terrain and steep-slope contour coal mining areas. Comparisons were then made with previous blasting data from studies of midwest coal mines located in flat areas.

Airblasts were found to have both higher average levels and higher spectral frequencies, consistent with expectations of less efficient blast confinement on the slopes. Topographic channeling of airblast was also observed, leading to more efficient propagation along the hollows or valleys. These two effects produced observed airblast levels higher by 1.9 to 4.4 dB than predicted from previous studies.

Ground vibration levels, by contrast, were lower than found in flat-area coal mines. This is consistent with lesser degrees of confinement and the resulting greater blast relief. No specific topographic effect on ground vibration amplitudes was observed.

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INTRODUCTION

Blasting is used in surface coal mines for rock fragmentation and, in some cases, casting or displacement of overburden. Some amount of ground vibration and airblast produced by blasting is normal. However, two special problems exist in the steep-slope contour mines in Appalachia, affecting the generation and propagation of airblast, and to a lesser degree ground vibration. Blasting on such slopes often leads to insufficient confinement of the blast energy, producing airblast of undesirably high frequency and level. In addition, the narrow valleys, known as hollows, create topographic conditions affecting both the intensity and direction of airblast propagation. Because of these problems, prediction curves derived from strip mines in relatively flat terrain cannot be assumed to apply accurately to contour mining, but can be used only as general and sometimes conservative estimators. This report describes Bureau of Mines research on the vibrations and airblast resulting from production blasting in Appalachian contour coal mines and includes analysis of the propagation of such energy down the steep-walled valleys typical of the Appalachian mining region. These investigations were intended, in part, to determine if a physical basis existed for seemingly disproportionate number of complaints of poor blasting in Appalachia (1-2).[4]

Results from the Bureau's contour blast monitoring program were compared with the Bureau's midwest area mining measurements, and with the results of analytical and experimental military studies of airblast propagation from airborne explosions over steep-walled valleys. Other problems associated with Appalachian blasting were beyond the scope of this study. One example of such problems would be site-specific geologic channeling of ground vibration; another would be flyrock behavior in contour mine blasting.

An understanding of the blasting characteristics of the Appalachian coal region rock is essential for efficient mining with minumum adverse environmental impact. The industry needs technical data on rock fragmentation by blasting, including the generation and propagation of blast-produced vibration and noise, both for prediction and for design control of such effects. This study investigated some special problems in Appalachian blasting and reviewed prediction schemes applicable to the region.

ACKNOWLEDGMENTS

The authors acknowledge the assistance of local government agencies, engineering consultants, powder companies, seismograph manufacturers, homeowners, and mine operators. Much of the fieldwork and data reduction was done by student employees Stephen Lepp, Michael P. Sethna, Kevin King, Thomas Armitage, David Gartner, and Michael J. Stevens. Special thanks go to G. Robert Vandenbos, Twin Cities Research Center, Bureau of Mines, for designing and maintaining the specialized equipment for this study.

PREVIOUS RELATED RESEARCH

MODELING OF AMPLIFICATION OF NUCLEAR BLASTS

Previous research that relates most closely to airblast propagation from contour mining is modeling of nuclear blast data and its channeling effects (3-5). The average pressure at the bottom of the different valleys can be estimated from data presented by Kaplan (3) for flat-bottom, V-bottom, and converging valleys. The channeling effect would be most

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[4] Underlined numbers in parentheses refer to items in the list of references preceding the appendixes.

pronounced when the direction of propagation was within 20° of the axis of the valley (3).

Using the overpressure relationship established by Kaplan between flat terrain and valleys, it is possible to estimate channeling effects for hollows. For example a 30° slope, which would be common in the coal mining areas of Appalachia, would produce a combined slope angle of 60°, which would yield an airblast increase of 2.2 dB for flat-bottom valleys and about 3.2 dB for V-bottom or converging valleys. These studies (3-5) of channeling effects were tests conducted for the military using small charges (1/4-lb) in model valleys 12 to 15 ft long. There were instances of 6- to 9.5-dB pressure increases in the model studies, but these were for small-scaled distances (e.g., 2.5 to 18 ft/lb$^{1/3}$) and high aerial bursts. The 2.2- and 3.2-dB increases are for almost the entire length of the valleys. Figure 1 can be used as a first prediction for airblast channeling from mine blasts.

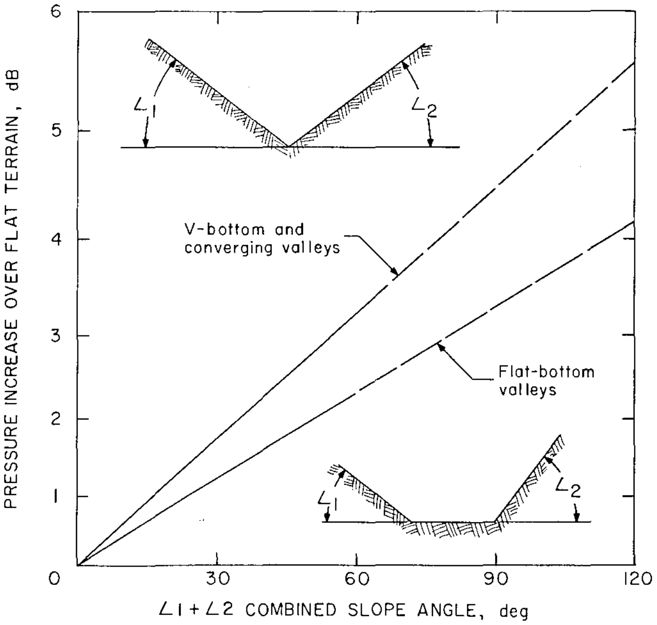

FIGURE 1. - Airblast channeling effects from model nuclear blasts (3).

PROPAGATION OF AIRBLAST

The propagation of airblast from surface mine blasting can be quantified by attenuation per doubling of distance. Typical examples from previous research are listed in tables 1 and 2.

Table 1 represents mostly near- or above-surface sources from non-Bureau studies. They are close to the theoretical -6 dB per distance doubling from pure geometrical spreading (6). This means that for every doubling of distance between receiver and blast, the airblast amplitude decreases by 6 dB. Table 2 shows actual Bureau of Mines airblast propagations in flat terrain. While there is a -3.1 to -10 dB range of attenuations because of differences in both source spectra and propagation conditions, most mining values were close to -5 dB per distance doubling. Since lower frequencies predominate in mining airblast values (11), -5 dB would be considered typical.

TABLE 1. - Airblast attenuations from other studies

Study	Attenuation, dB per doubling of distance
Vortman (7)............	-6.6
Schomer (8)............	-6.6
Kamperman and Nicholson (9)..........	[1]-6
Snell and Oltmans (10)..	-7.2

[1] 20 dB per decade.

Since the atmosphere is a dispersive propagation medium, the airblast attenuation rate is also related to frequency content. This effect and its practical consequences are discussed in the next section.

AIRBLAST FREQUENCY CHARACTERISTICS

In previous Bureau research (11-12), particular types of airblast displayed certain ranges of frequencies. Type I airblasts were characterized by having much of their energy in a band of frequencies ranging from 5 to 25 Hz where

TABLE 2. - Airblast attenuations from Bureau of Mines RI 8485 (11)

Type of blast	Equation[1]	Attenuation, dB per doubling of distance
Coal highwall:		
0.1 Hz	$AB = 0.162\ (D/W^{1/3})^{-0.794}$	-4.8
5 Hz	$AB = 0.087\ (D/W^{1/3})^{-0.725}$	-4.4
Coal parting:		
0.1 Hz	$AB = 169\ (D/W^{1/3})^{-1.623}$	-9.8
5 Hz	$AB = 194\ (D/W^{1/3})^{-1.666}$	-10.0
Metal mine: 0.1 Hz	$AB = 0.401\ (D/W^{1/3})^{-0.713}$	-4.3
Quarry:		
0.1 Hz	$AB = 0.246\ (D/W^{1/3})^{-0.711}$	-4.3
0.1 Hz[2]	$AB = 0.979\ (D/W^{1/3})^{-1.120}$	-6.7
0.1 Hz[3]	$AB = 0.056\ (D/W^{1/3})^{-0.515}$	-3.1
0.1 Hz[4]	$AB = 1.317\ (D/W^{1/3})^{-0.966}$	-5.8

[1] AB = airblast, pound per square inch; D = distance, ft; W = charge weight, lb.
[2] Charges propagating toward gage station.
[3] Gage station behind free face.
[4] Gage station in front of free face.

structures readily respond (11). Type II airblasts have most of their energy below 5 Hz and typically produce less structural response.

In general, an airblast with higher spectral frequencies will have greater attenuation, typically exceeding 6 dB per doubling of distance. Blasts with lower spectral frequencies will have attenuations less than 6 dB per doubling of distance. Hence, the high attenuation observed for the relatively poorly confined parting blasts. For mining applications, this would indicate that well-confined blasts would have both low frequencies and low attenuations and unconfined blasts would have high frequencies and high attenuations. Therefore a shot that has vented would be expected to start at a higher airblast level but would drop relatively quickly to lower levels with greater distance. This was found to be the case by previous Bureau airblast studies (11).

Blasting in steep-slope areas was expected to be poorly confined as compared to flat-area mining. The measurements bear this out since the steep-slope contour shots contain higher frequencies, similar to those found with parting shots. In terms of airblast, parting shots had been typically found to be the most troublesome mining blasts because of their poor confinement (11).

MONITORING PROGRAM IN APPALACHIA

INSTRUMENTATION AND MEASUREMENT TECHNIQUES

Several types of measurement and recording systems were used for this study, including FM tape recorders with separate transducers for structure response measurements, and seismographs with an additional channel for airblast for propagation studies in the steep-sloped valleys. The structure response measurements taken during this project were reported previously (11).

Measurements for the contour mine blast propagation studies were made with a Berger Safeguard Seismic Unit II and several Dallas Instrument model ST-4 seismographs.[5] These recorded airblasts as well as ground vibrations. Technical data for these are given in RI 8506 (12) and RI 8508 (13).

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[5] Reference to specific products does not imply endorsement by the Bureau of Mines.

The airblast channels for these instruments were modified for better low-frequency response. The standard microphones were replaced by Validyne differential pressure transducers or Bruel and Kjaer sonic boom microphones. The system was then calibrated by recording a signal from an acoustic calibrator on the seismograph tape recorder.

Later in this study, the standard microphones of the Dallas Instruments ST-4 self-triggered seismographs were modified to improve the low-frequency response from 5 to 0.2 Hz. This was accomplished by increasing the RC (resistor-capacitor) time constant in the microphone preamplifier circuit, which determines the low-frequency response of this microphone system. The resistance value of the RC circuit was changed from 66 MΩ to 3 GΩ. This changed the time constant from 0.03 s to 1.5 s and lowered the frequency response from 5 Hz to 0.1 Hz. In actual practice, the low-frequency responses were in the range of 0.2 to 0.3 Hz because these microphones were not precision instruments intended for sealed use. There was some unpredictable amount of leakage of the overpressure around the microphone diaphragm.

Some long-term monitoring was done at several field sites in Kentucky using ST-4 self-triggered seismographs. While the Appalachian blasts often had a high airblast-to-ground vibration ratio, the vibrations were often too weak to trigger the seismograph. To record such shots, the seismographs were modified to also trigger from the airblast channel. However, it was also found that radiofrequency intereference could cause spurious signals that would trigger the recorder, resulting in rapid depletion of the recorder tape and a tape full of useless "events". An attempt was made to correct this by shielding the instrument with 3-mil-thick aluminum foil. This method was successful when care was taken to ensure that no gaps were left in the foil shielding. Figure 2 shows a shielded instrument.

FIGURE 2. - Seismograph shielded against RF interference with aluminum foil.

FREQUENCY ANALYSIS OF CONTOUR MINE AIRBLASTS AND GROUND VIBRATIONS

One measure of the annoyance or damage potential from blasts is the frequency content. Frequency analyses of airblast records were made with a Spectral Dynamics SD 350 Digital Signal Processor, a true fast fourier spectrum analyzer.

For comparisons, the airblasts were tabulated two ways according to frequencies whose amplitudes were within both 3 dB and 20 dB of the spectral peak (fig. 3). Those within 3 dB can be considered essentially equivalent in amplitude, and events more than 20 dB below the peak would be essentially nonexistent.

The general trend in figure 3 shows that frequencies encountered in steep-slope contour mine airblasts were very similar to those found in coal "parting" flat-area blasts. Parting blasts were relatively troublesome in previous Bureau research because of the resulting strong structure responses (11). This same problem, therefore, could apply to contour mine blasts. Parting and steep-slope contour mine blasts both have relatively poor confinement and characteristically higher frequency spectra. (With the parting blasts this is due to the thin parting layers often found between coal seams; with the contour mine blasts it is due to the sloping geometry giving too much relief.) The contour mine blasts had a wider spectral spread, possibly from the varied geometries between sites. In the Bureau tests for this report, contour mine blasts in rolling terrain were found to have higher frequency spectra because measurements were made at shorter distances. The rolling-terrain contour mines are located in higher population density areas than the flat-area and steep-slope contour mines, and therefore the blasts are nearer to homes.

The frequency spectra of the ground vibration at the contour mines tested were not greatly different from spectra of other forms of mining. The most significant trends were that rolling-terrain contour mine blasts had frequency spectra very similar in range to those found in flat-area coal mines, while blasts in test hollow 1 and steep-slope contour mines had frequency spectra between those found in quarries and flat-area coal mines. The frequency ranges encountered

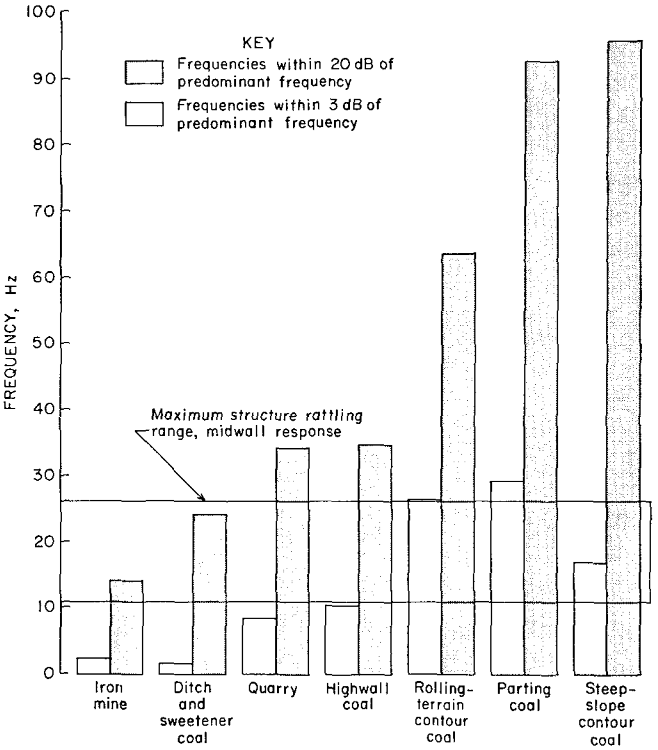

FIGURE 3. - Airblast histogram by mine type.

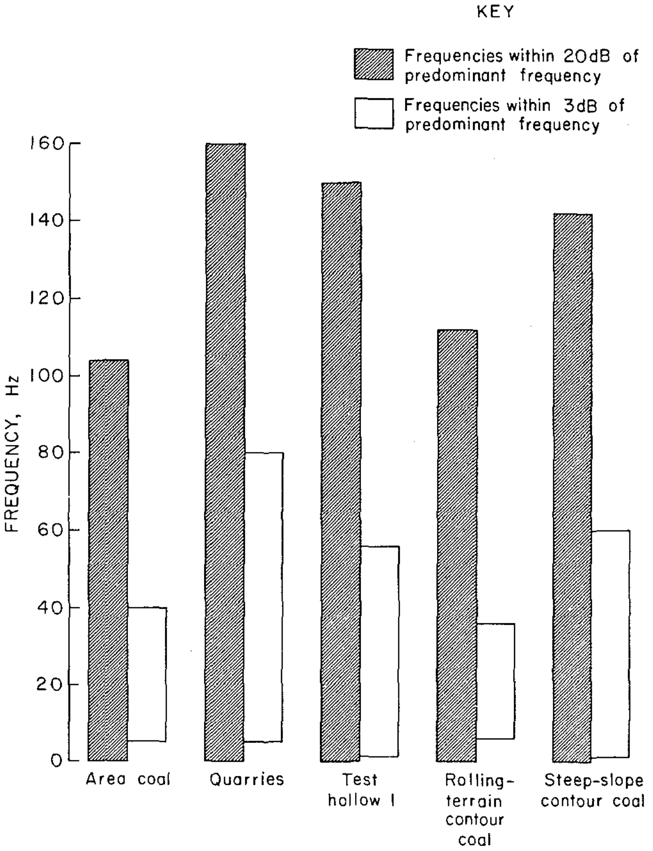

FIGURE 4. - Ground vibrations histogram by mine type.

on different Bureau test sites are shown in figure 4. The histograms in appendix A contain more detail on the frequency ranges and distributions.

PROPAGATION

Arrays of seismographs were placed down three eastern Kentucky hollows (valleys) to monitor the generation and propagation of airblast and ground vibration from steep-slope contour mine production blasts. Topographic maps, longitudinal sections, and cross-section views for the three test hollows are shown in appendix B. Detailed blast design, noise, and vibration data for this study are located in appendix C.

Airblast Propagation

Understanding propagation of airblast from steep-slope contour mines was a major goal of this research. Of the types of blasts previously studied by the Bureau and reported in RI 8485 (11), the results of steep-slope contour mine blasts most closely resembled those of flat-area thin-layer parting blasts. They both contain unusually high frequencies and have similar overall spectra. Airblast measurement parameters and results for the three test hollows are given in table 3. Measured attenuations were all found to be less than for the parting blasts of RI 8485, which averaged -9.8 dB per doubling of distance.

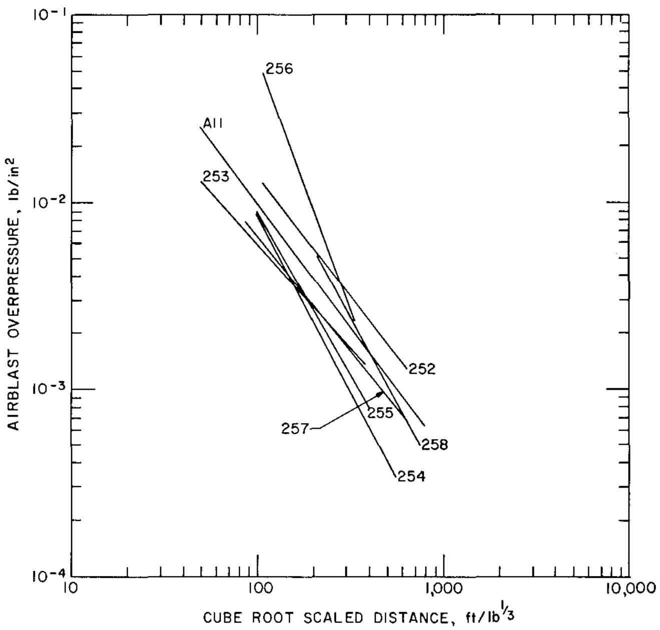

FIGURE 5. - Test hollow 1 shots 252-258, airblast, 0.1-Hz high pass.

The propagation curves for seven blasts monitored in hollow 1 are shown in figure 5. The summary line (labeled All) is the total-data regression and has a slope corresponding to an attenuation of -7.9 dB per distance doubling. This attenuation is 1.9 dB less than that of parting blasts with similar spectra and is consistent with the figure 1 model by Kaplan (3), which gives a theoretical difference of approximately 2.0 dB for a valley of this shape compared to flat terrain. Statistical data for figure 5 appear in appendix D.

TABLE 3. - Measured airblasts in three steep-slope contour mine valleys compared to parting blasts at area mines

Valley	Combined slope angle, deg	Valley bottom	Measured attenuation, dB per doubling of distance	Number of measurements
Hollow 1............	45	Flat.....	-7.9	10 shots, 34 stations.
Hollow 2............	53	V........	-6.4	1 shot, 2 stations.
Hollow 3............	55	Rounded V	-5.4	1 shot, 5 stations.
Parting blasts (11).	NAp	NAp......	-9.8	19 shots, 19 stations.

NAp Not applicable.

Only two successful airblast measurements were made for hollow 2 because of equipment failure. The propagation data for these points are shown in figure 6. The attenuation value of -6.4 dB is 3.4 dB less than for flat terrain. This is again close to the figure 1 model, which predicts slightly less than 3 dB.

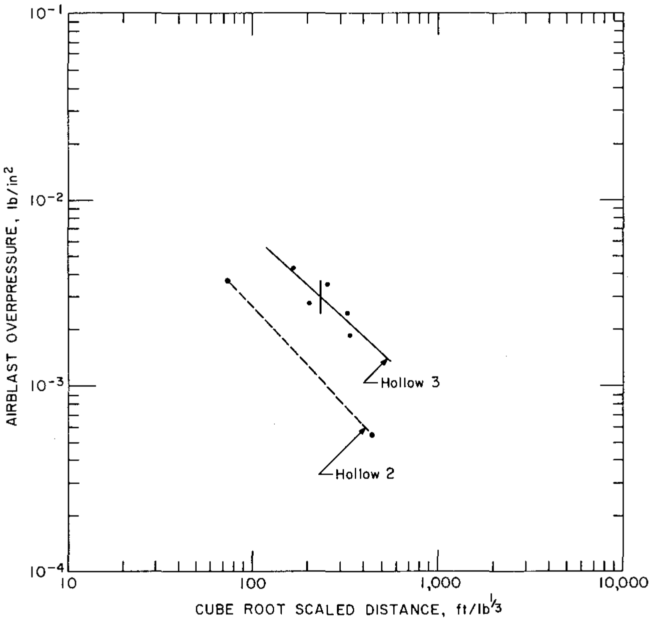

FIGURE 6. - Test hollows 2 and 3 shots, airblast, 0.1-Hz high pass.

Results from the test hollow are also given in figure 6. The measured attenuation rate of -5.4 dB is 4.4 less than for the flat-terrain parting shots. Considering the different valley cross section, this reasonably approximates both hollow 2 results and a figure 1 prediction of about 3 dB.

Two overall summaries of steep-slope contour mine airblast measurements were made for comparisons with summaries from other types of mining. Figure 7 compares contour and flat-area mine airblasts using 0.1-Hz wide-band high-pass instrumentation. The airblast data for parting, highwall, and rolling-terrain contour mine blasts were taken from RI 8485 (11). For the current study, the rolling-terrain contour mine measurements were reanalyzed from the raw data for RI 8485 (table 3). In the earlier study, they had not been analyzed separately. In the summary analysis, the slopes of the steep-slope contour and flat-area mine parting shots were similar, rather than

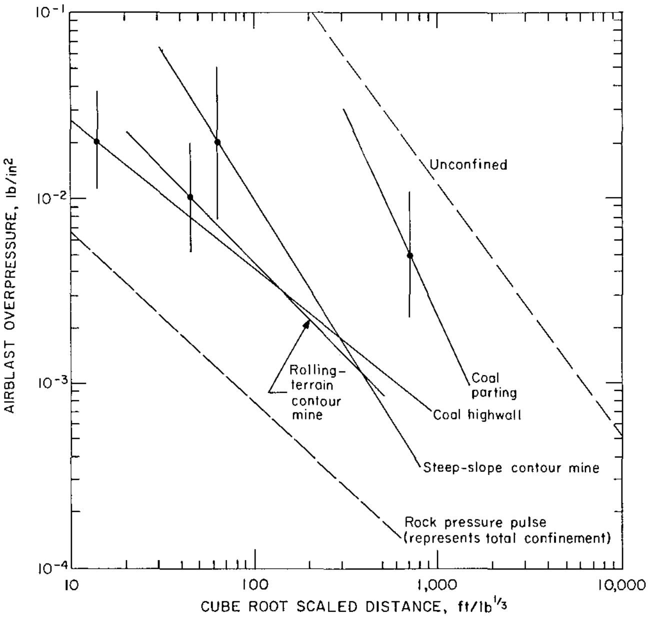

FIGURE 7. - Airblast from shots, contour and flat-area coal mines, 0.1-Hz high pass.

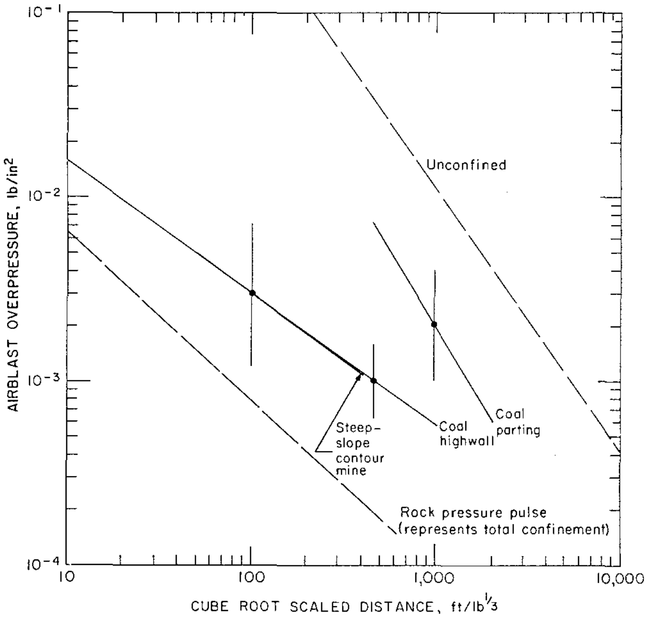

FIGURE 8. - Airblast from shots, steep-slope contour and flat-area coal mines, 5-Hz high pass.

showing the reduced attenuation found for individual valleys. This is because the instrument locations varied rather than being in an array down a hollow, which also contributes to the greater standard deviation shown. At less than 300 ft/lb$^{1/3}$ scaled distances, the steep-slope contour mine airblasts exceed other full-size mine production blasts such as coal highwall by factors of 5 to 10 (up to 20 dB). This indicates that steep-slope blasts often generate higher initial levels than other forms of surface coal mining.

A series of 5-Hz high-pass airblast measurements were also made in the steep-slope mining region, simulating commercial monitoring devices. By contrast to the three hollow studies, instruments were set up near existing structures and not systematically in bottom valley arrays. The results, shown in figure 8, were no different than previously determined 5-Hz propagations from RI 8485.

Ground Vibration Propagation

Ground vibrations were also recorded during the airblast monitoring program. Figures 9 and 10 show maximum horizontal and vertical components from the measurement of production blasts in hollow 1. Typical values were found to be lower than in previous Bureau studies of other coal mining regions by factors of up to 10, using data from RI 8507, figure 10 (14) as an overall reference. Also there was a great amount of scatter between shots. In steep-slope contour mining, much of the blast energy is lost into the atmosphere owing to insufficient confinement; hence ground vibrations tend to be lower. The only exception to the low-ground-vibrations prediction appeared to be when measurements were made on the same formation as that of the blast but on the other side of the ridge. Hollow 3 was monitored for vibrations, using five three-component stations. Results were on the high side of the spread of results from hollow 1 (fig. 11). Statistical data for figures 9, 10, and 11 are located in appendix D.

A general summary of all vibration measurements was made for comparison with coal mine vibration propagations from RI 8507 (14). The results are shown in

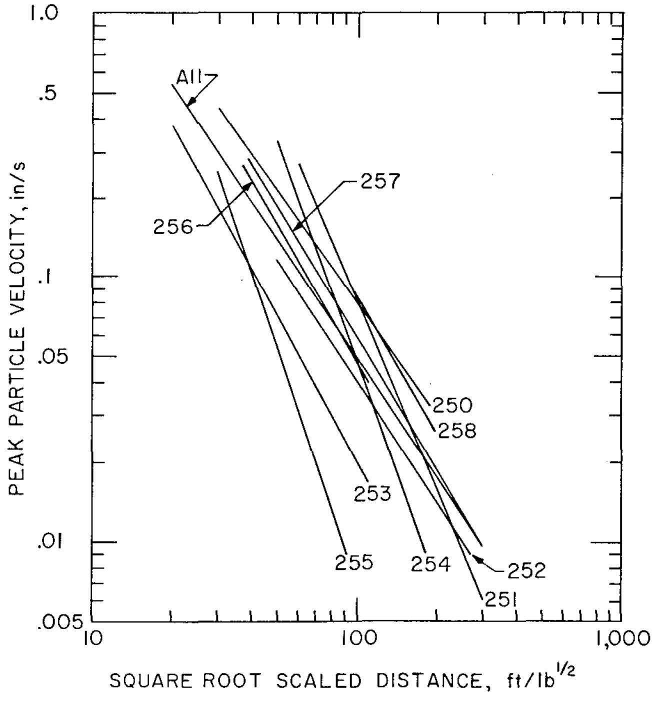

FIGURE 9. - Test hollow 1 shots 250-258, largest component of horizontal ground vibrations.

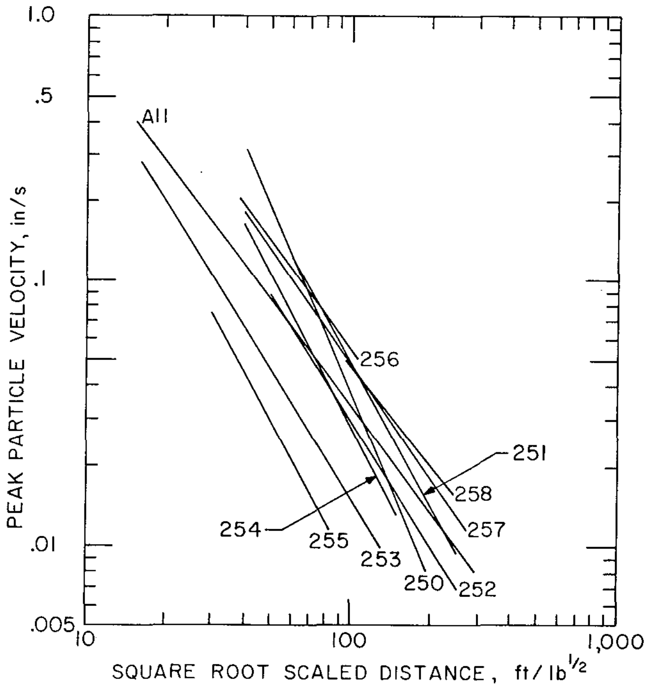

FIGURE 10. - Test hollow 1 shots 250-258, vertical ground vibration.

figure 12 for flat-area, rolling-terrain contour, and steep-slope contour coal mines. The steep-slope contour mines generated the least amplitudes at small scaled distances where vibration levels were initially the highest. At large scaled distances (more than 300 ft/lb$^{1/2}$), they are indistinguishable in level from amplitudes at flat-area coal mines.

CONCLUSIONS

Airblast and ground vibration generation and propagation from steep-slope contour mine blasting were found to differ from those in other types of surface coal mines. Increased relief and lesser rock confinement of explosive changes, due to mountainside geometry, resulted in the generation of both higher levels and higher frequencies for airblast. By contrast, ground vibration levels were lower.

Topographic influences on airblast attenuation were also observed and were consistent with experimental and theoretical models of previous research. Instead of the expected -9.8-dB attenuation per doubling of distance for high-frequency airblasts over flat terrain, values were between -5.4 and -7.9 dB. These differences appear to be enhanced propagation resulting from a channeling effect in the hilly topography.

This combination of high frequency and high source level of airblast and abnormally low attenuation within topographic valleys suggests airblast as the main cause of complaints from Appalachian blasting.

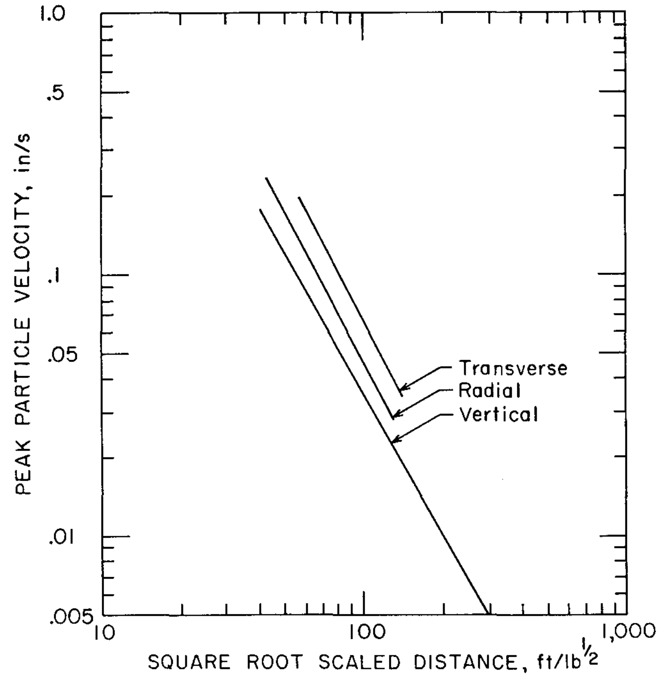

FIGURE 11. - Test hollow 3 shots, ground vibration.

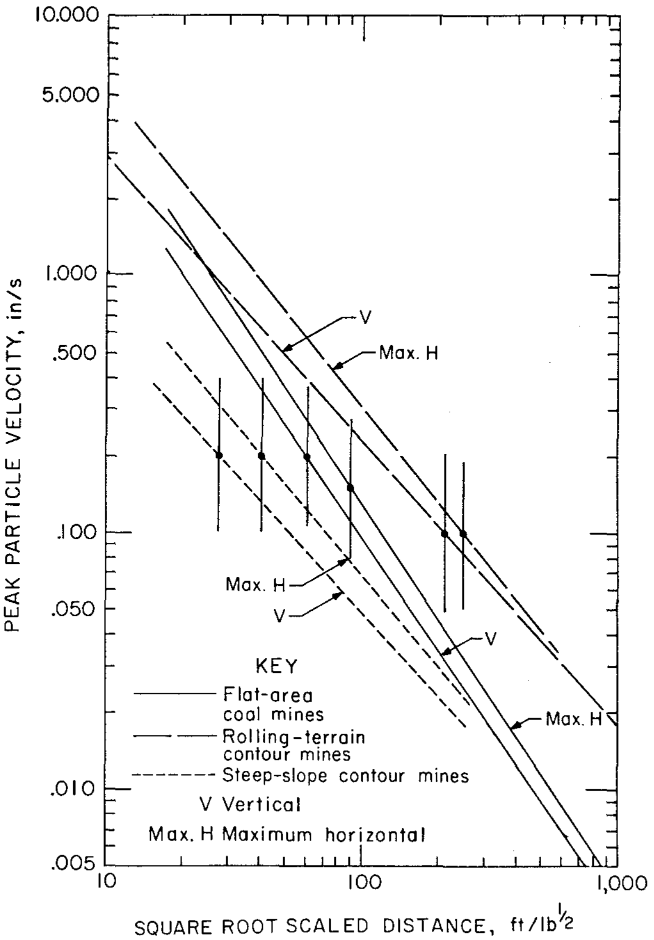

FIGURE 12. - Ground vibrations from shots, contour and flat-area coal mines.

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APPENDIX A.--FREQUENCY HISTOGRAMS

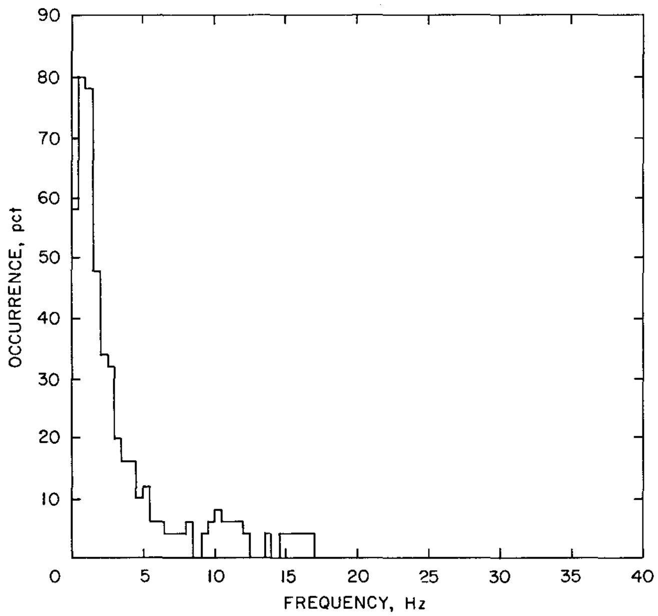

FIGURE A-1. - Steep-slope contour coal mine airblast, frequencies within 3 dB of peak spectra.

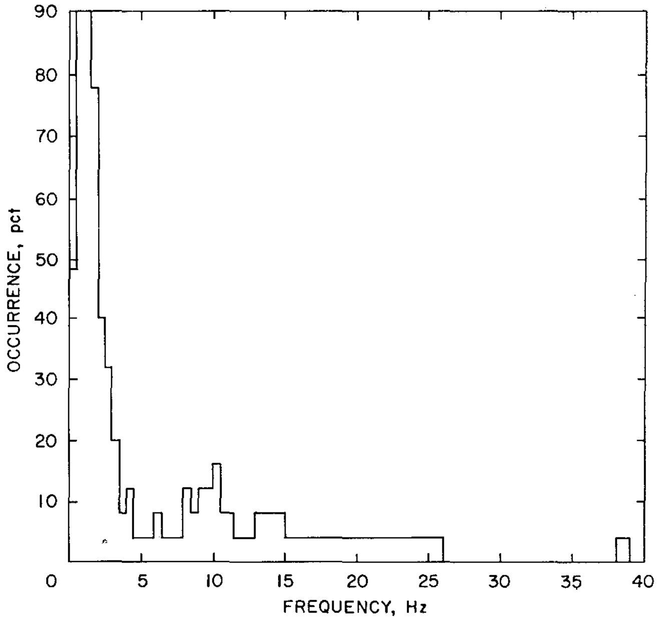

FIGURE A-2. - Rolling-terrain contour coal mine airblast, frequencies within 3 dB of peak spectra.

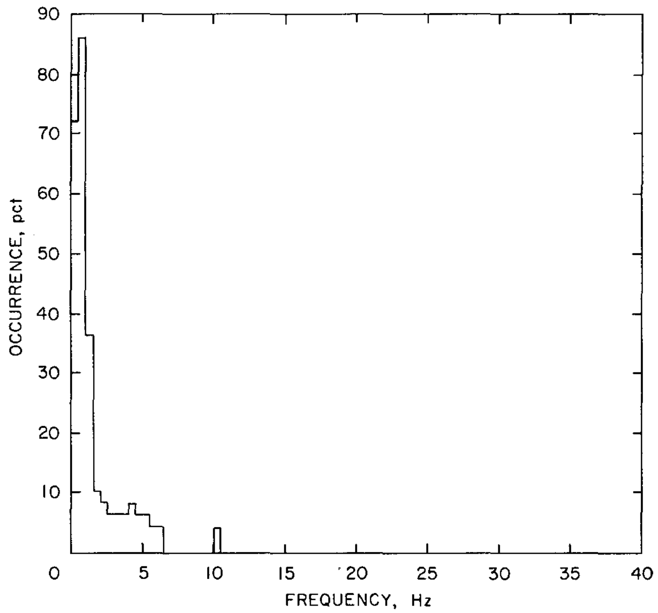

FIGURE A-3. - Flat-area coal mine, highwall airblast, frequencies within 3 dB of peak spectra.

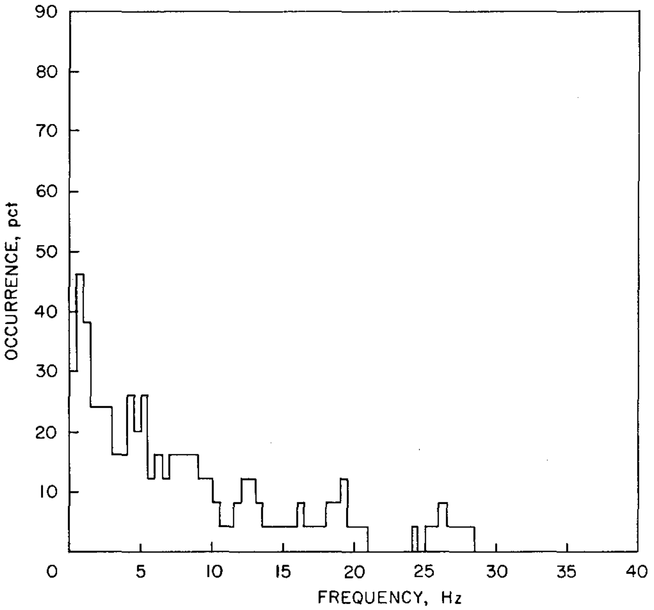

FIGURE A-4. - Flat-area coal mine parting airblast, frequencies within 3 dB of peak spectra.

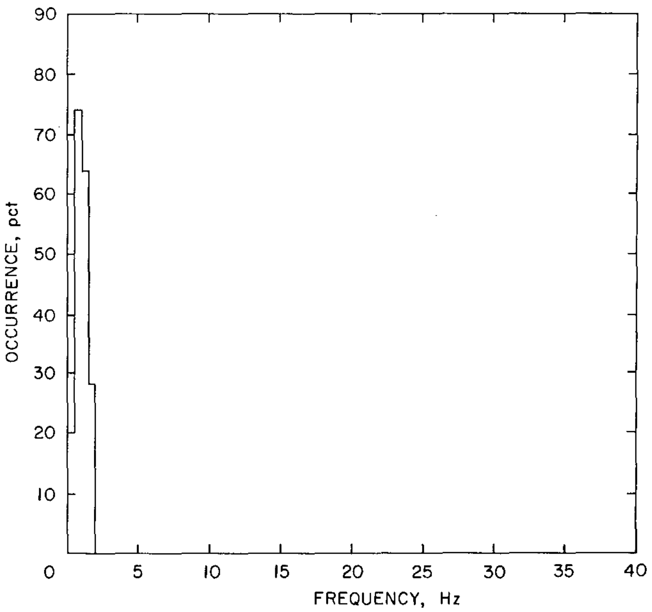

FIGURE A-5. - Flat-area coal mine ditch and sweetener airblast, frequencies within 3 dB of peak spectra.

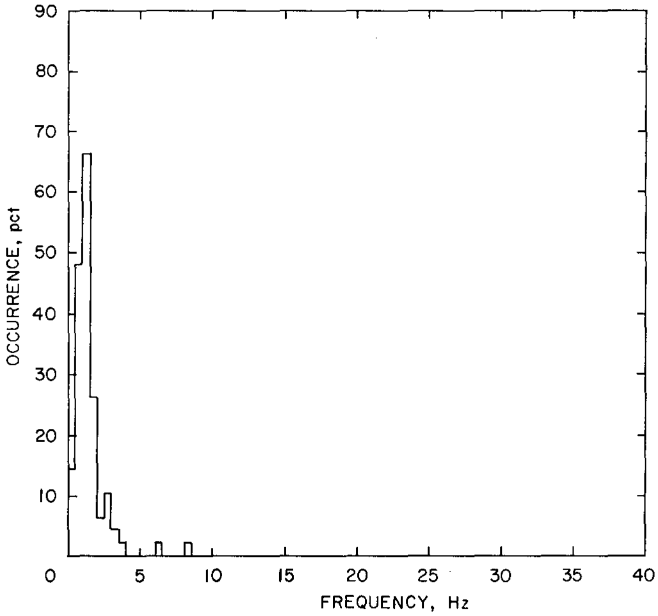

FIGURE A-6. - Quarry airblast, frequencies within 3 dB of peak spectra.

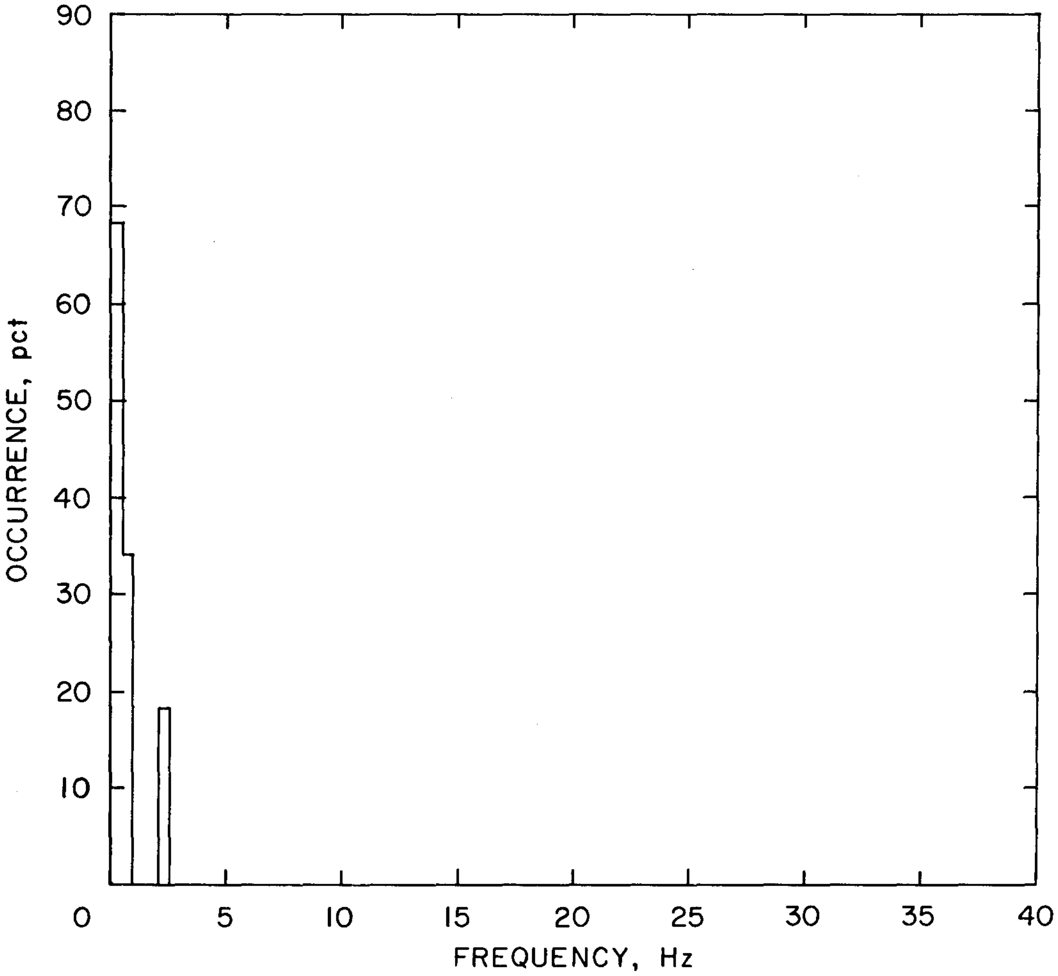

FIGURE A-7. - Metal mine airblast, frequencies within 3 dB of peak spectra.

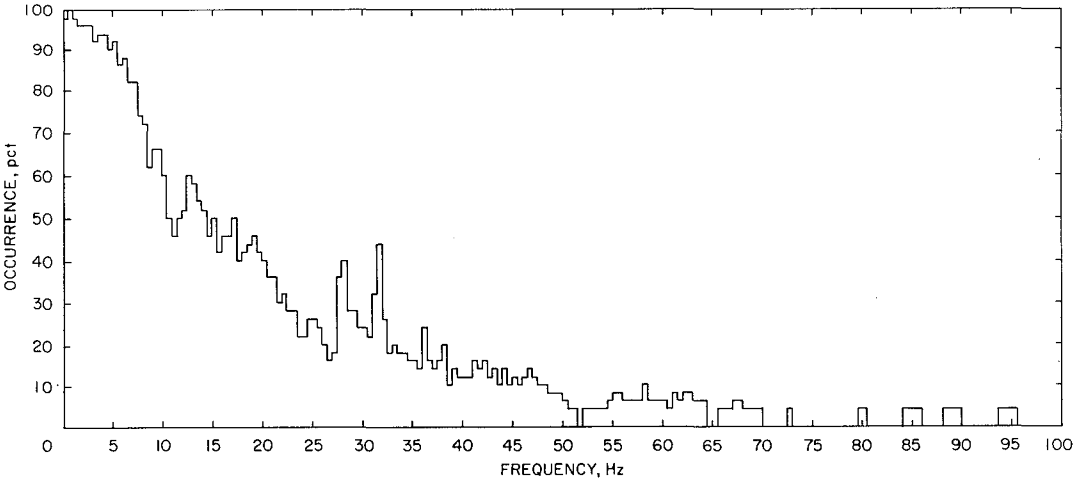

FIGURE A-8. - Steep-slope contour coal mine airblast, frequencies within 20 dB of peak spectra.

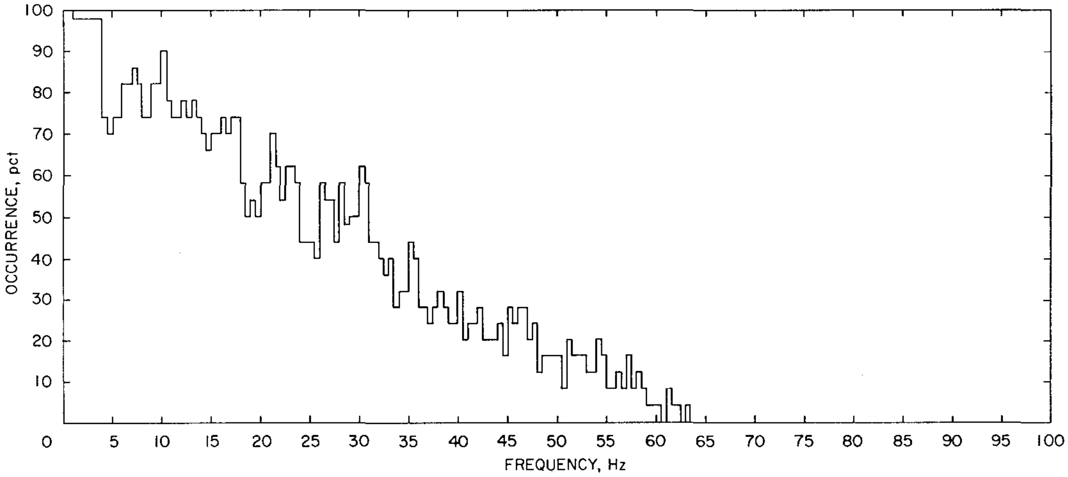

FIGURE A-9. - Rolling-terrain contour coal mine airblast, frequencies within 20 dB of peak spectra.

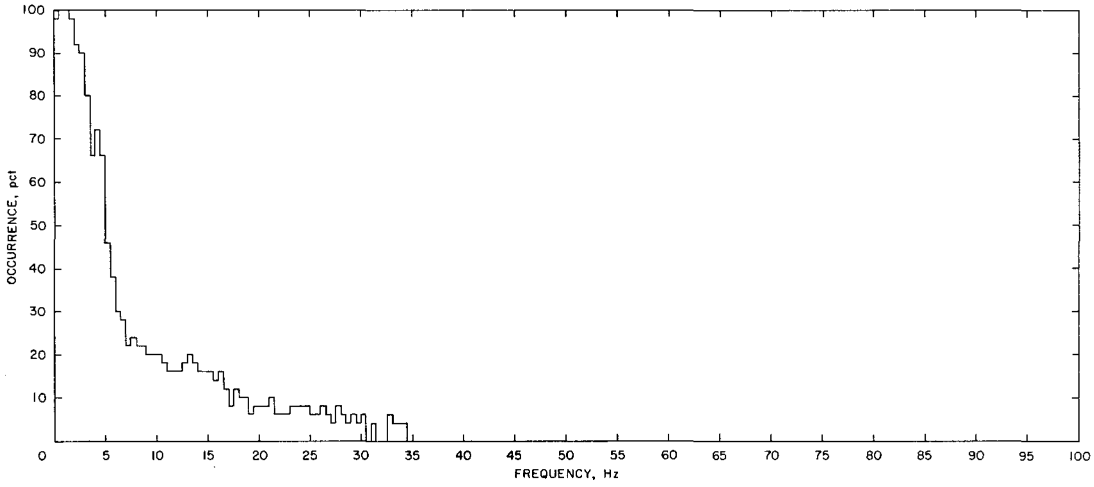

FIGURE A-10. - Flat-area coal mine highwall airblast, frequencies within 20 dB of peak spectra.

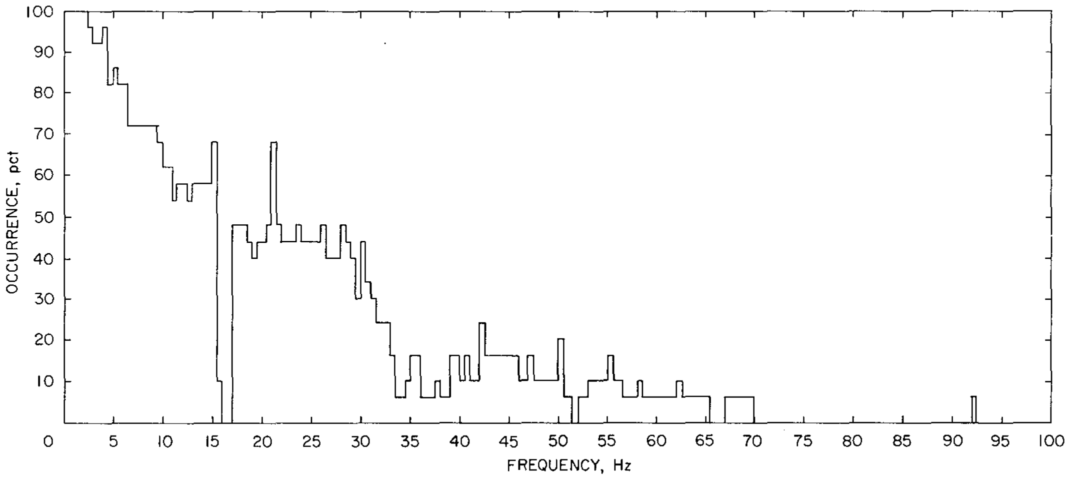

FIGURE A-11. - Flat-area coal mine parting airblast, frequencies within 20 dB of peak spectra.

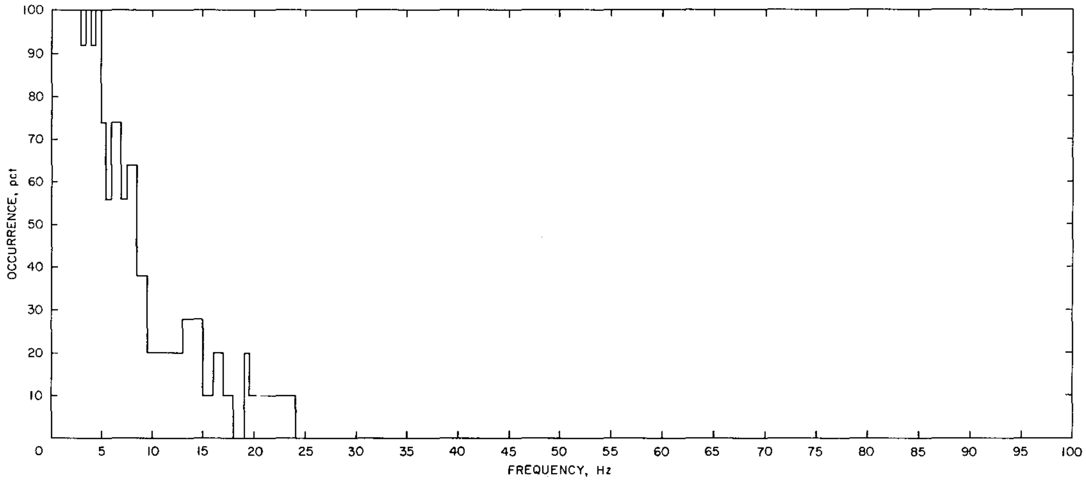

FIGURE A-12. - Flat-area coal mine ditch and sweetener airblast, frequencies within 20 dB of peak spectra.

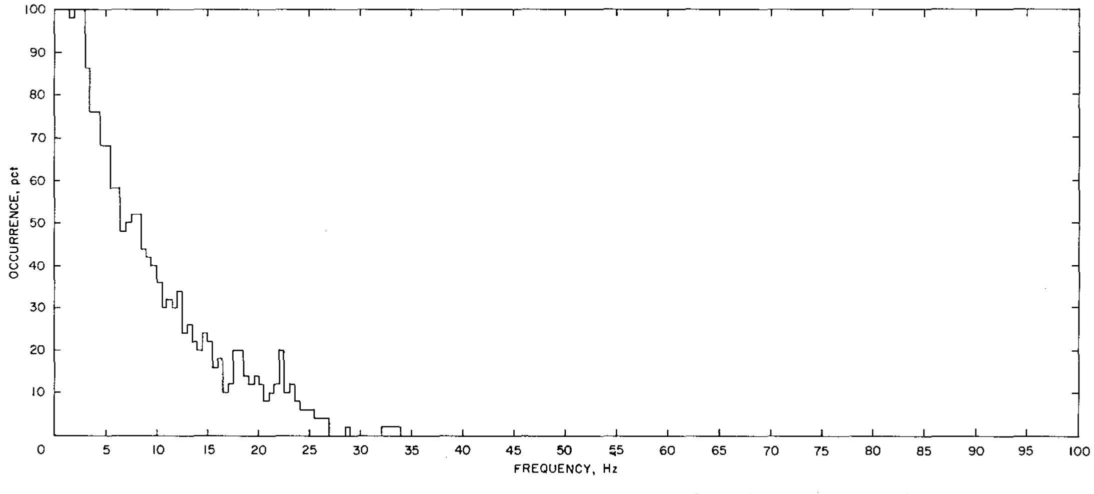

FIGURE A-13. - Quarry airblast, frequencies within 20 dB of peak spectra.

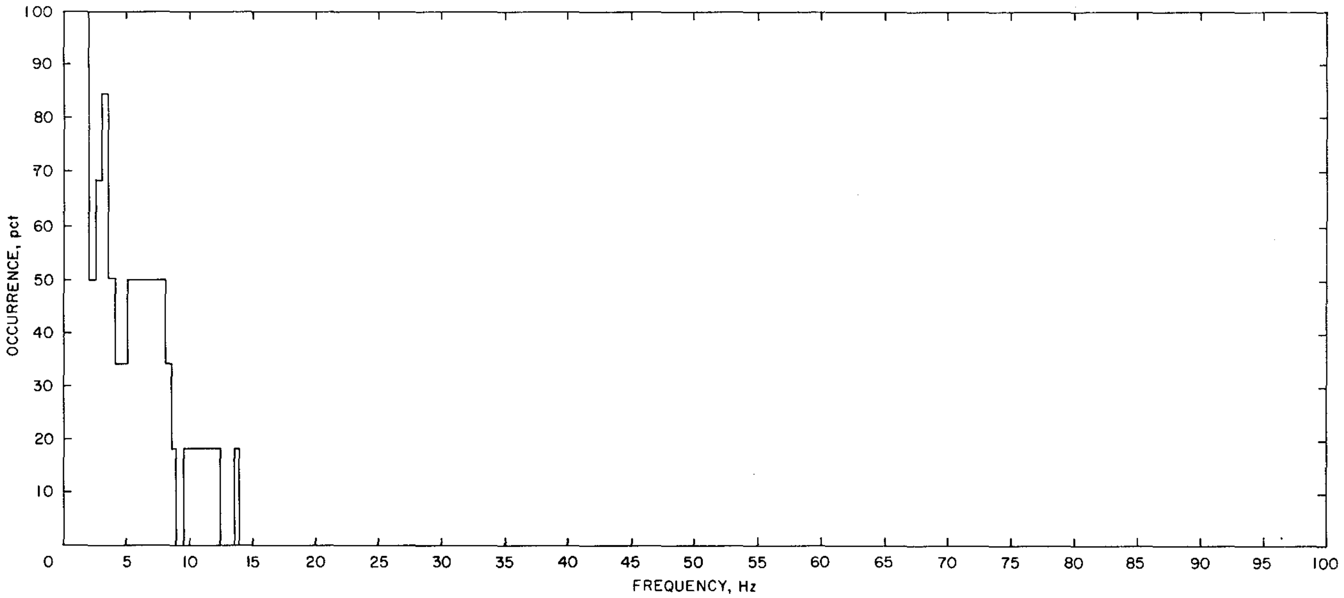

FIGURE A-14. - Metal mine airblast, frequencies within 20 dB of peak spectra.

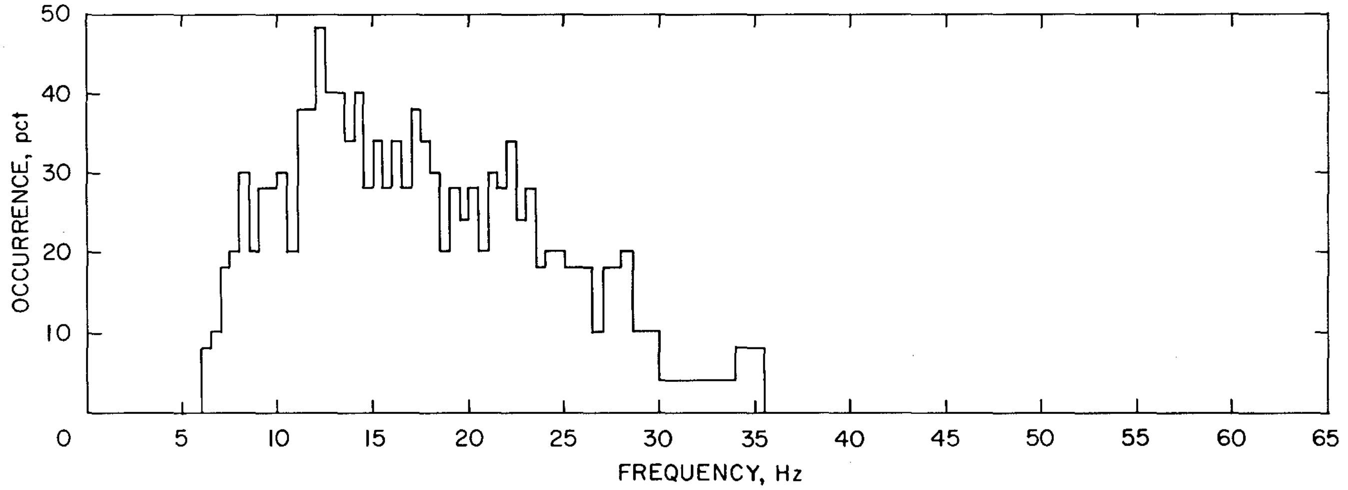

FIGURE A-15. - Steep-slope contour coal mine, ground vibrations, frequencies within 3 dB of peak spectra.

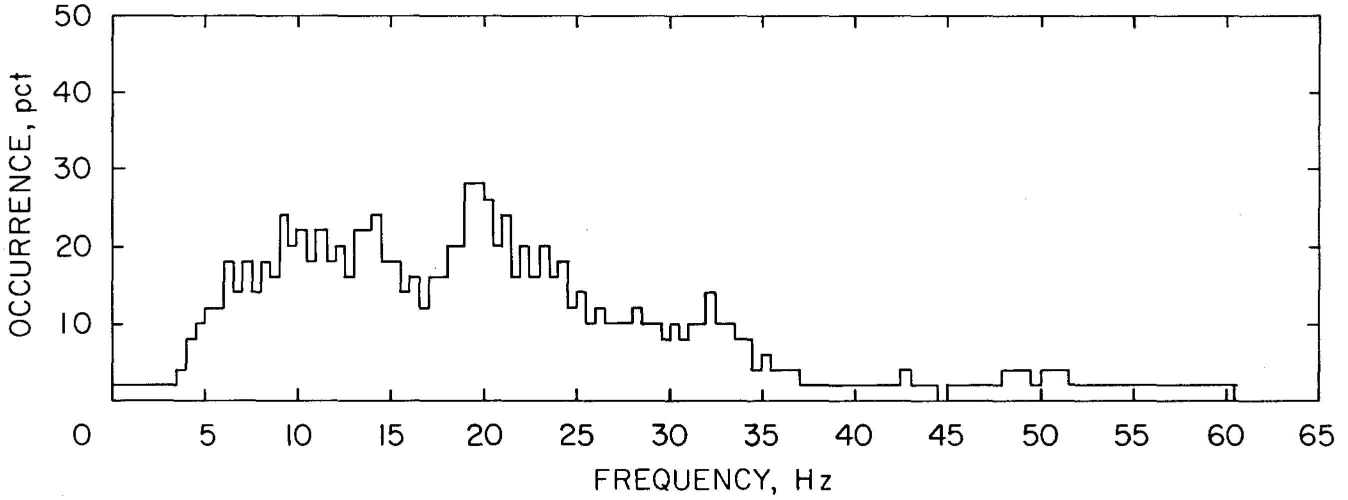

FIGURE A-16. - Rolling-terrain contour coal mine ground vibrations, frequencies within 3 dB of peak spectra.

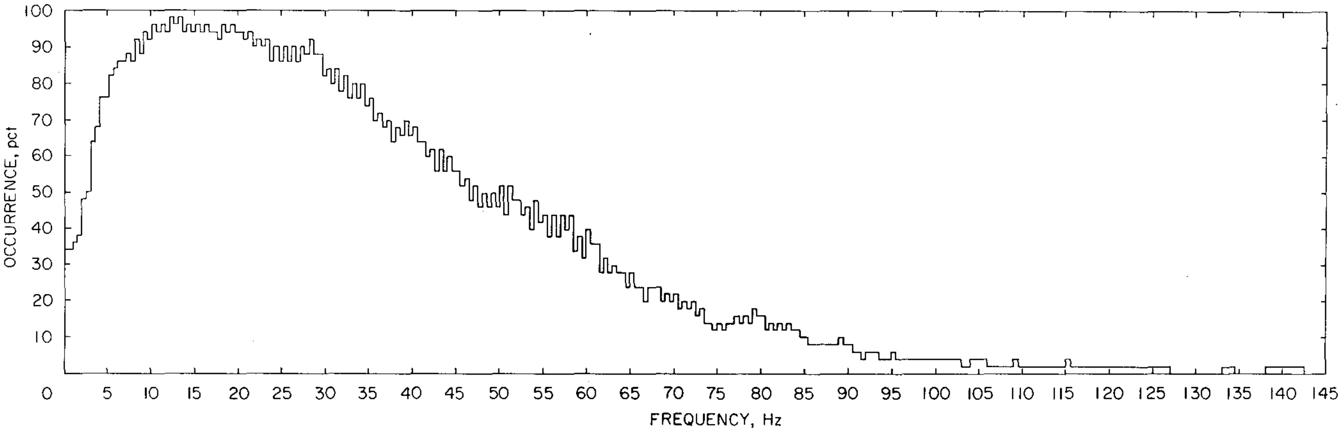

FIGURE A-17. - Steep-slope contour coal mine ground vibrations, frequencies within 20 dB of peak spectra.

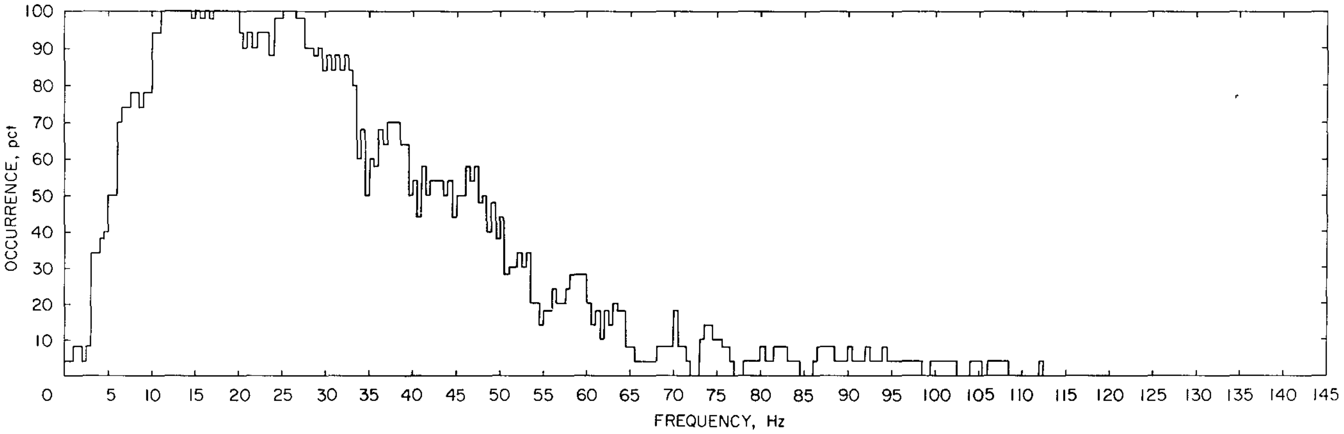

FIGURE A-18. - Rolling-terrain contour coal mine ground vibrations, frequencies within 20 dB of peak spectra.

APPENDIX B.--TOPOGRAPHIC MAP AND SECTIONS FOR TEST HOLLOWS 1-3

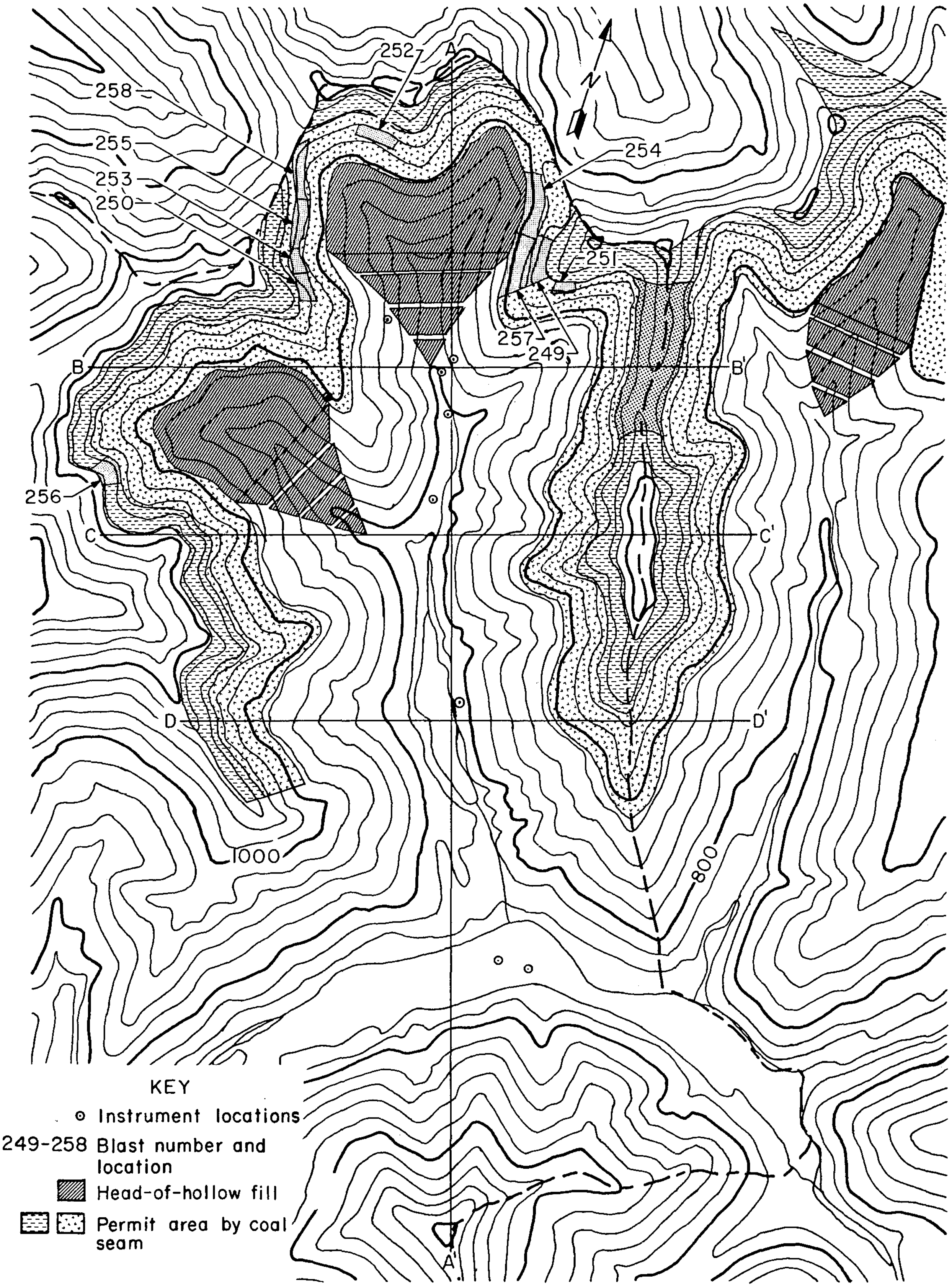

FIGURE B-1. - Test hollow 1, topographic map.

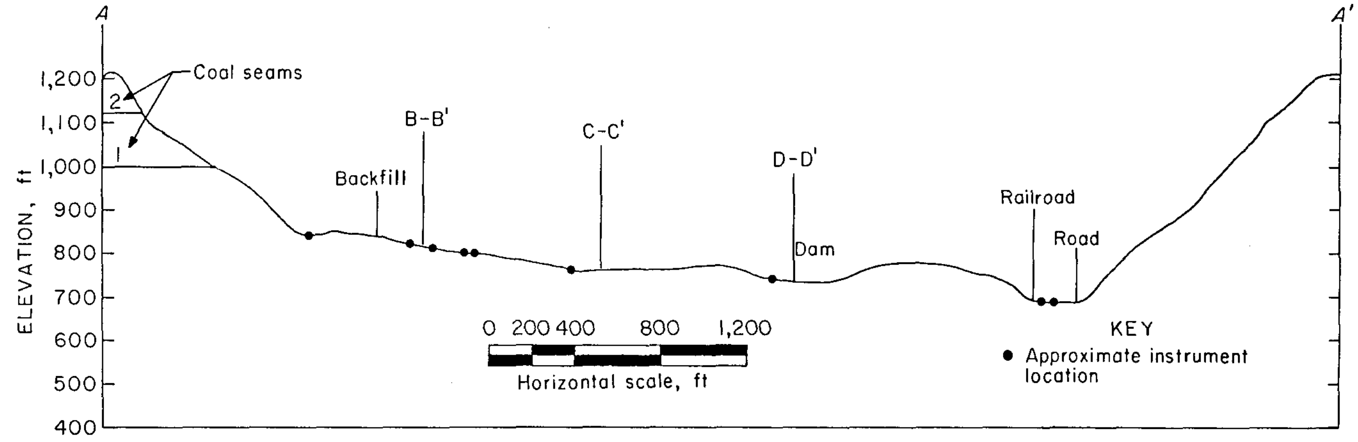

FIGURE B-2. - Test hollow 1, longitudinal section A-A' with vertical exaggeration.

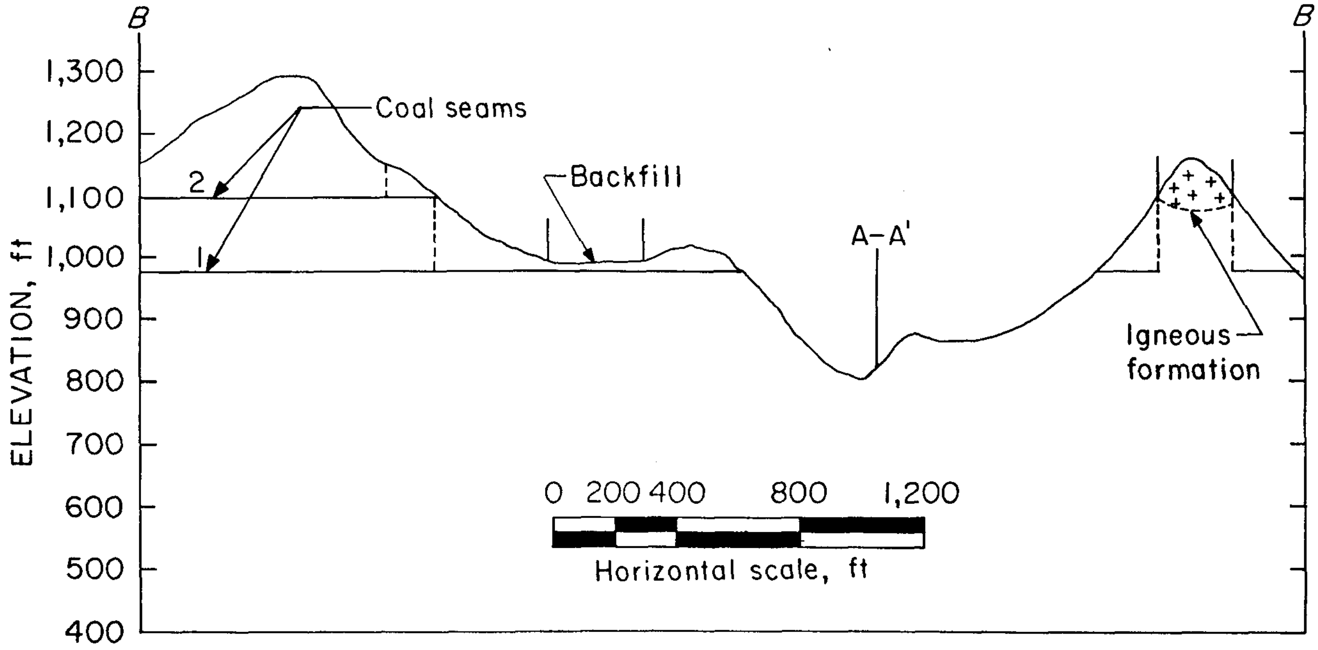

FIGURE B-3. - Test hollow 1, cross section B-B', with vertical exaggeration.

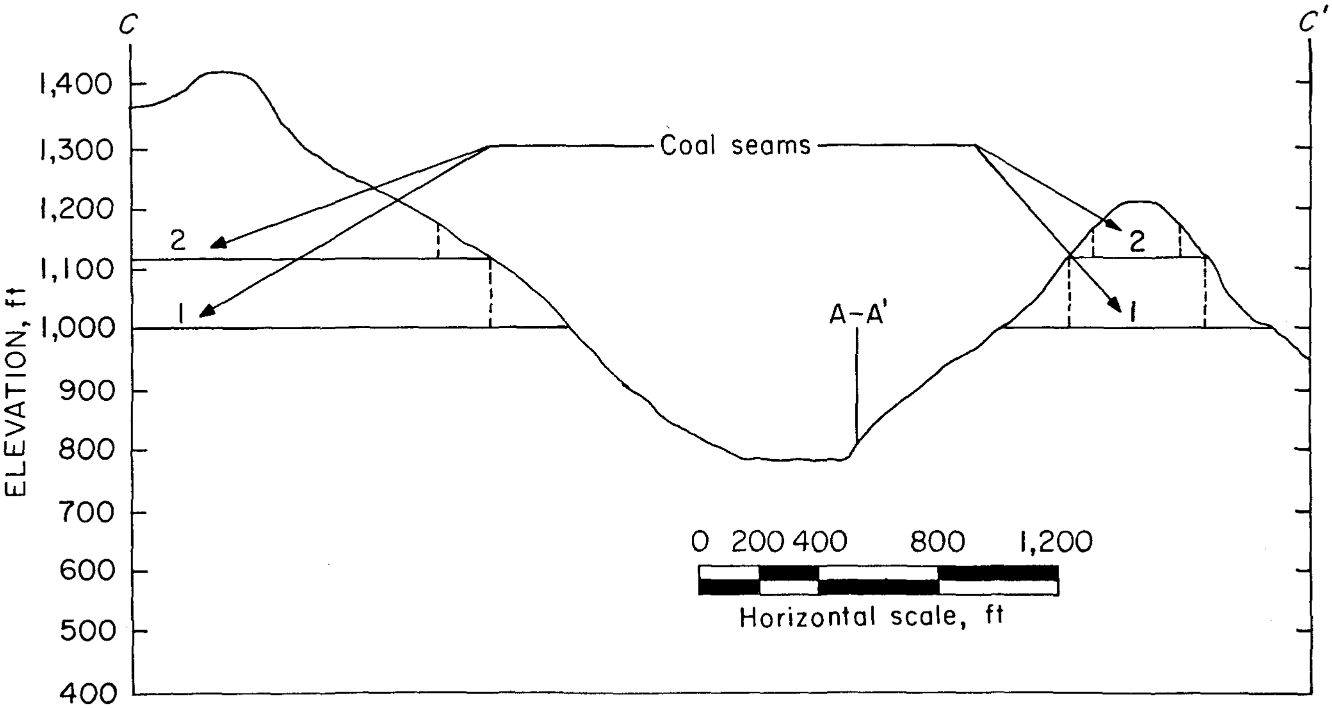

FIGURE B-4. - Test hollow 1, cross section C-C', with vertical exaggeration.

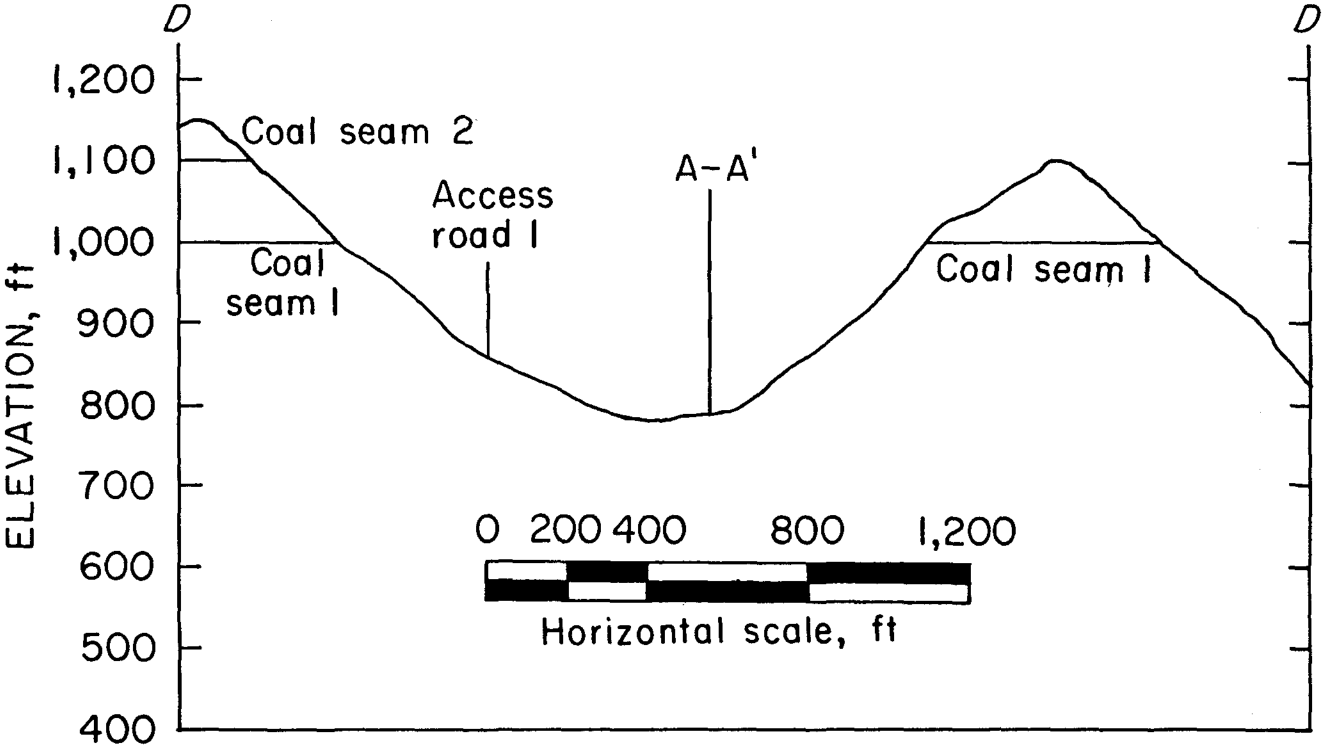

FIGURE B-5. - Test hollow 1, cross section D-D', with vertical exaggeration.

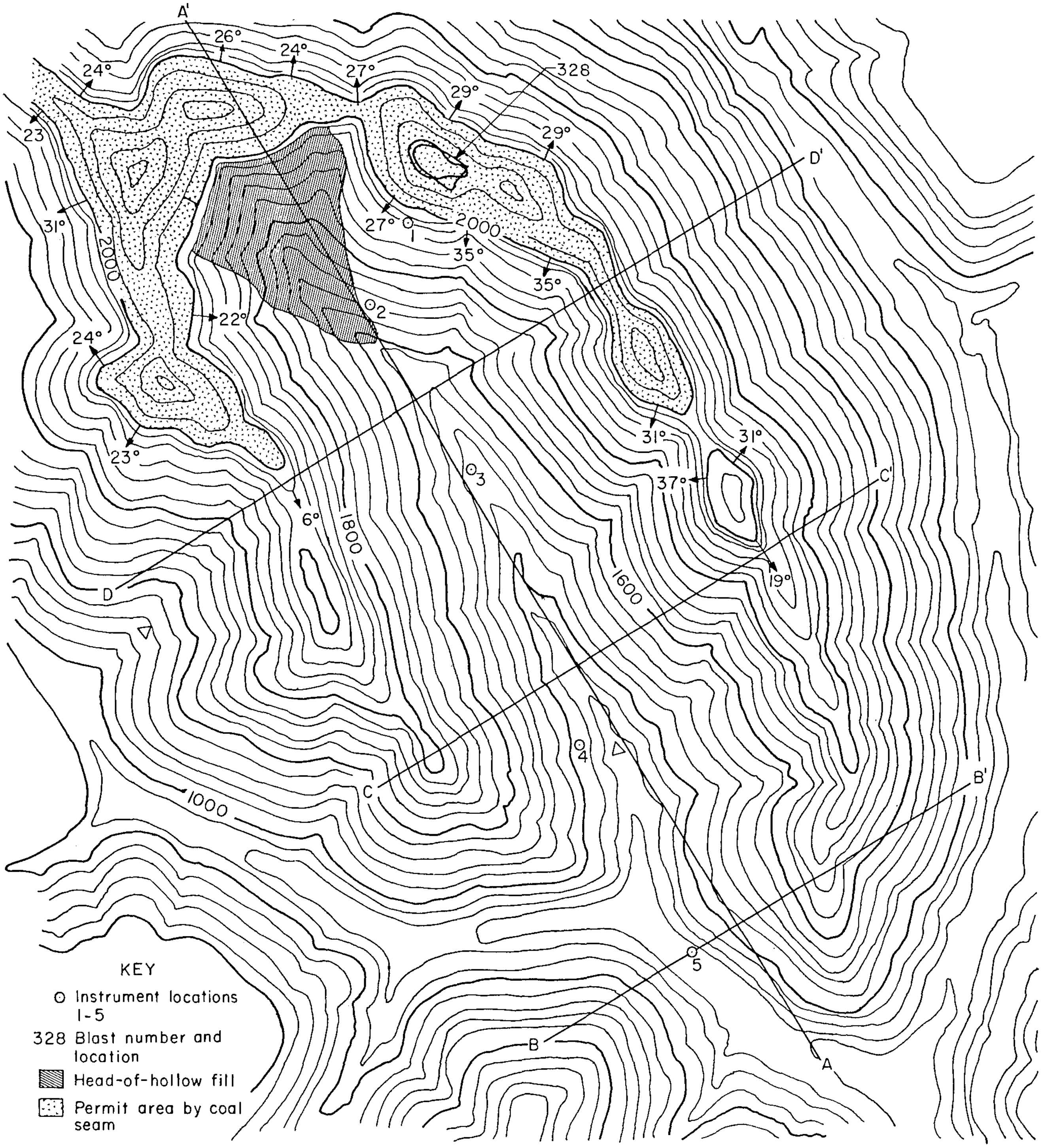

FIGURE B-6. - Test hollow 2, topographic map.

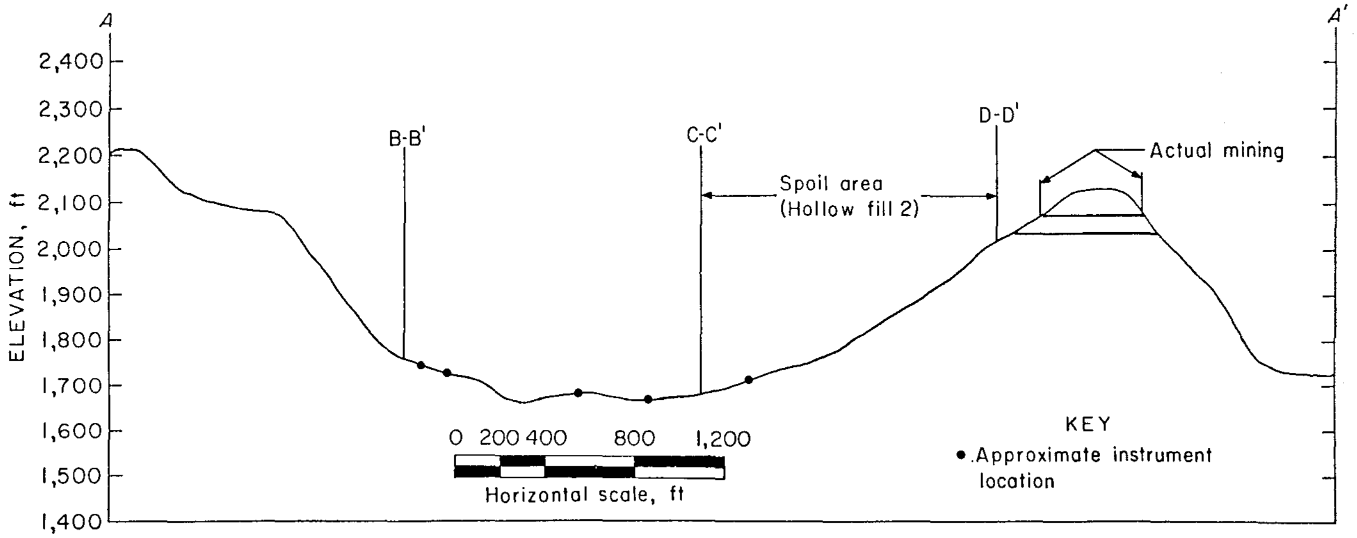

FIGURE B-7. - Test hollow 2, longitudinal section A-A', with vertical exaggeration.

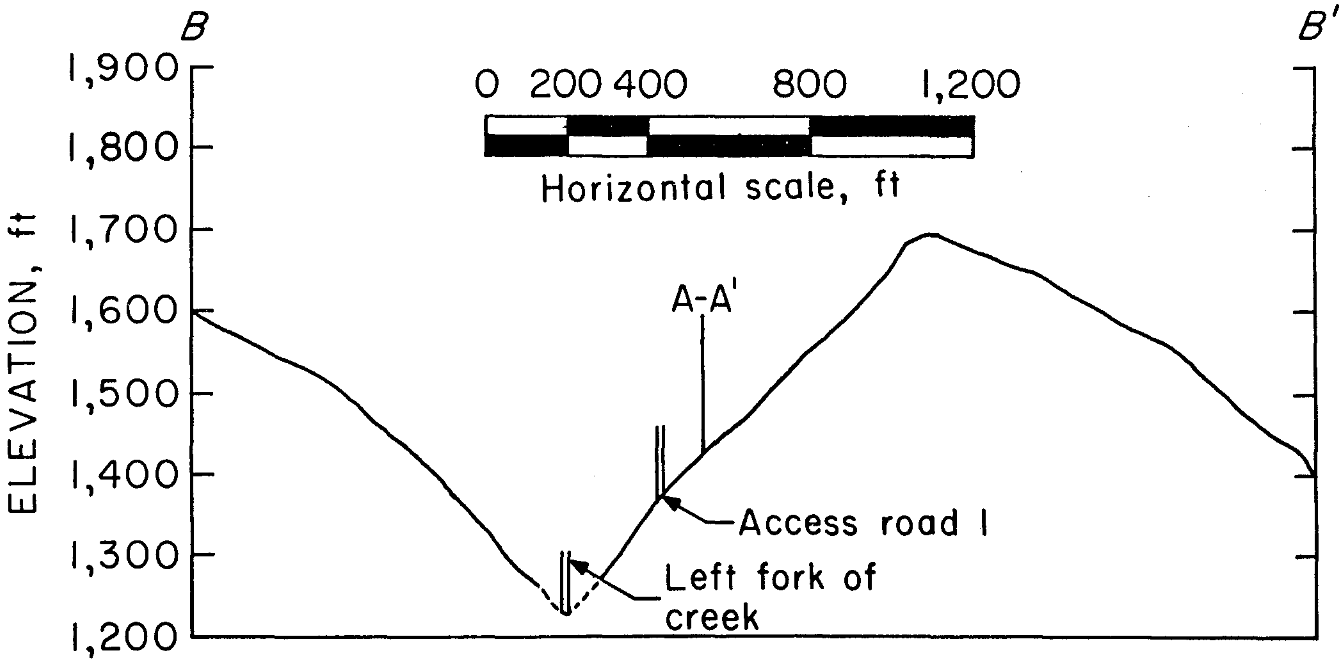

FIGURE B-8. - Test hollow 2, cross section B-B', with vertical exaggeration.

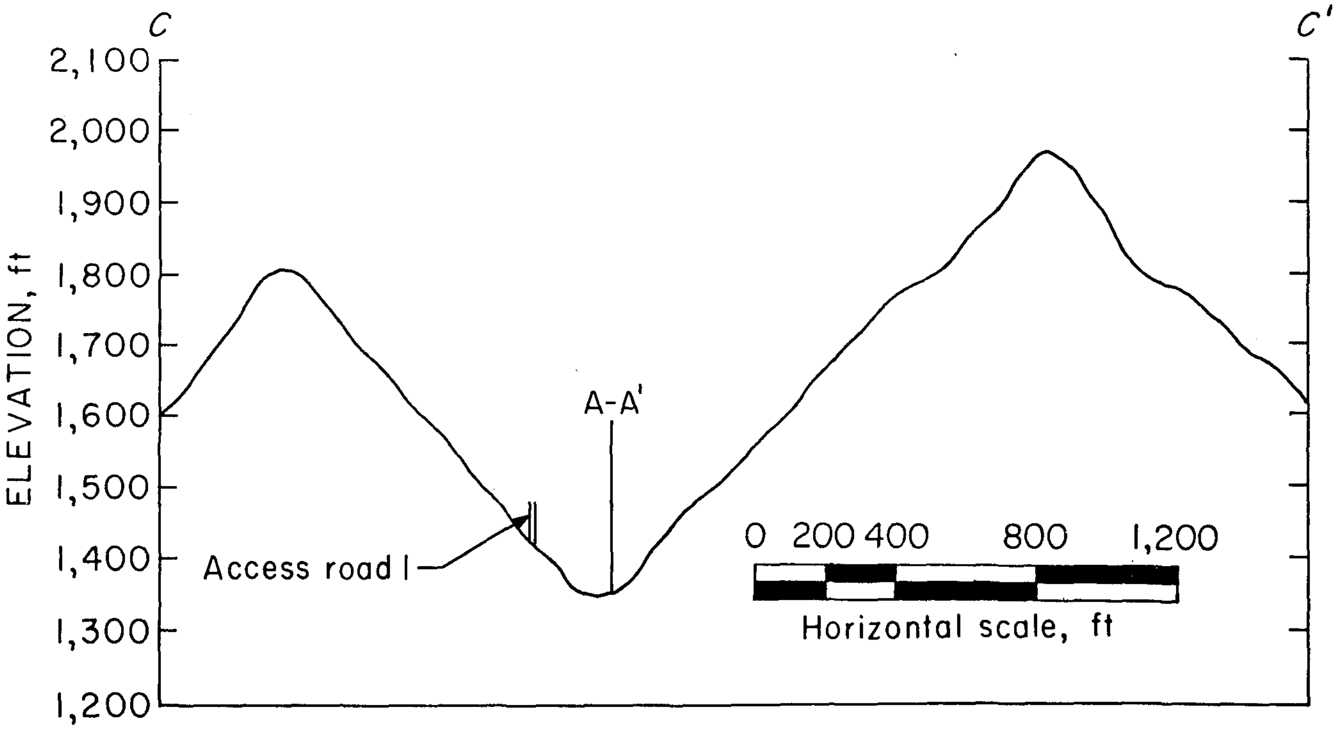

FIGURE B-9. - Test hollow 2, cross section C-C', with vertical exaggeration.

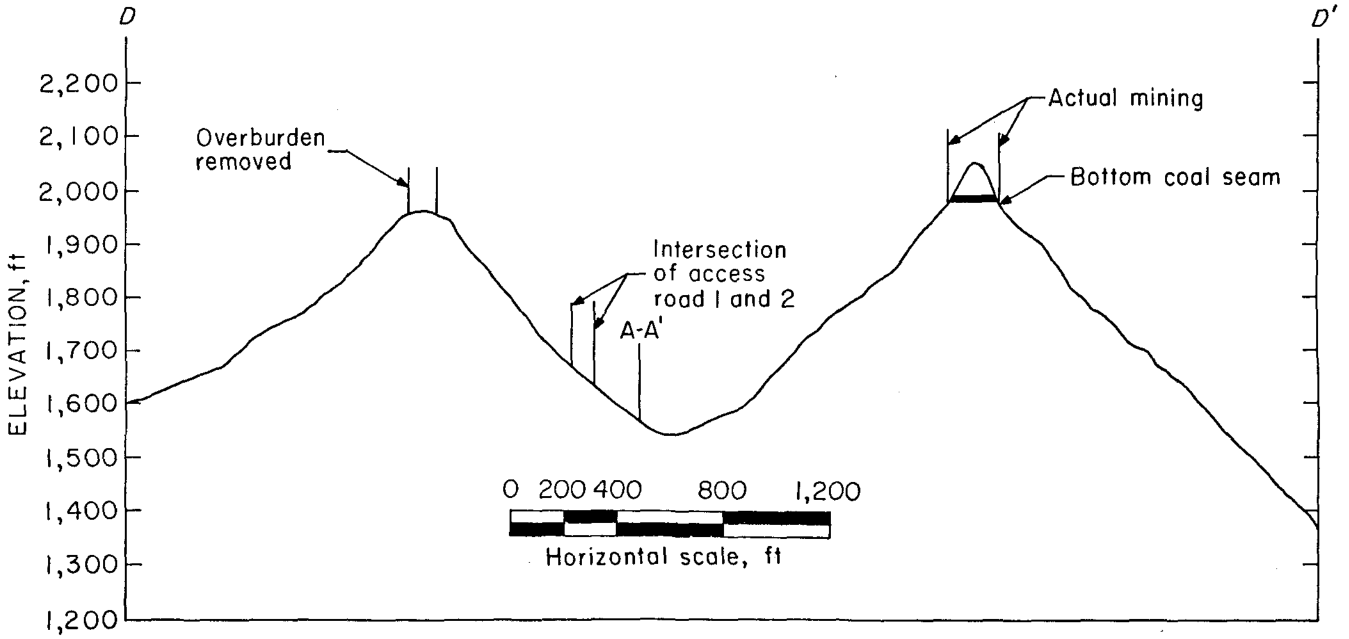

FIGURE B-10. - Test hollow 2, cross section D-D', with vertical exaggeration.

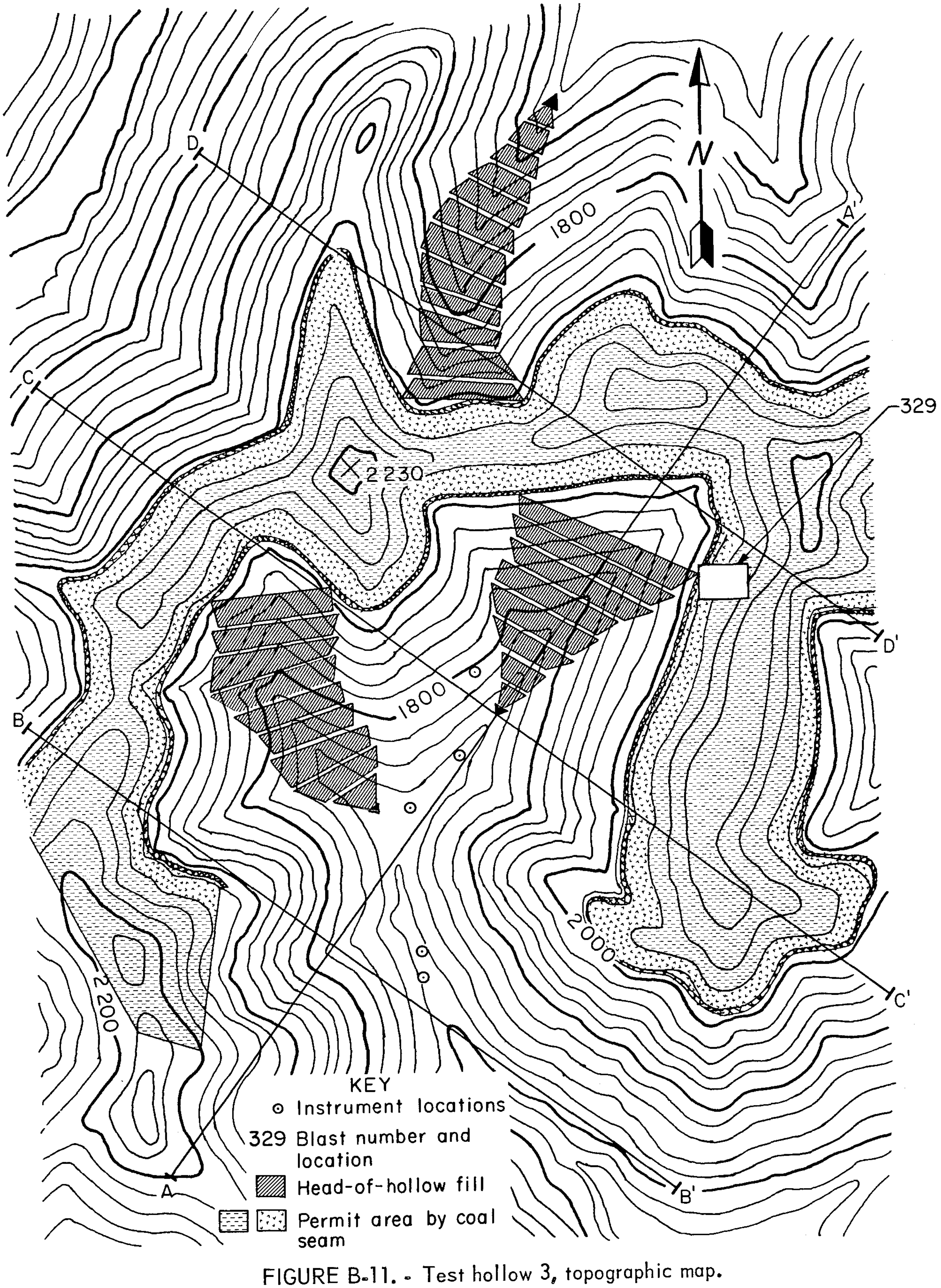

FIGURE B-11. - Test hollow 3, topographic map.

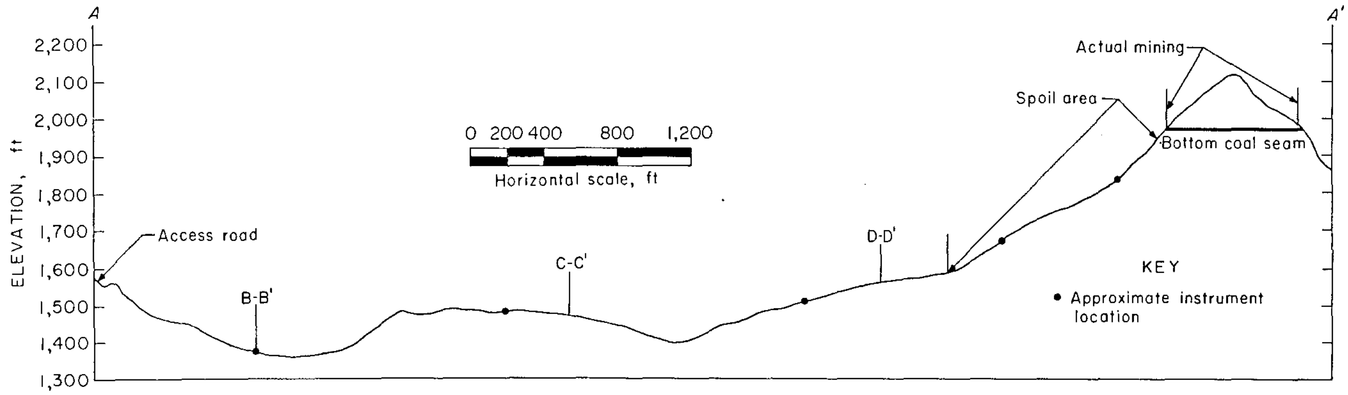

FIGURE B-12. - Test hollow 3, longitudinal section A-A', with vertical exaggeration.

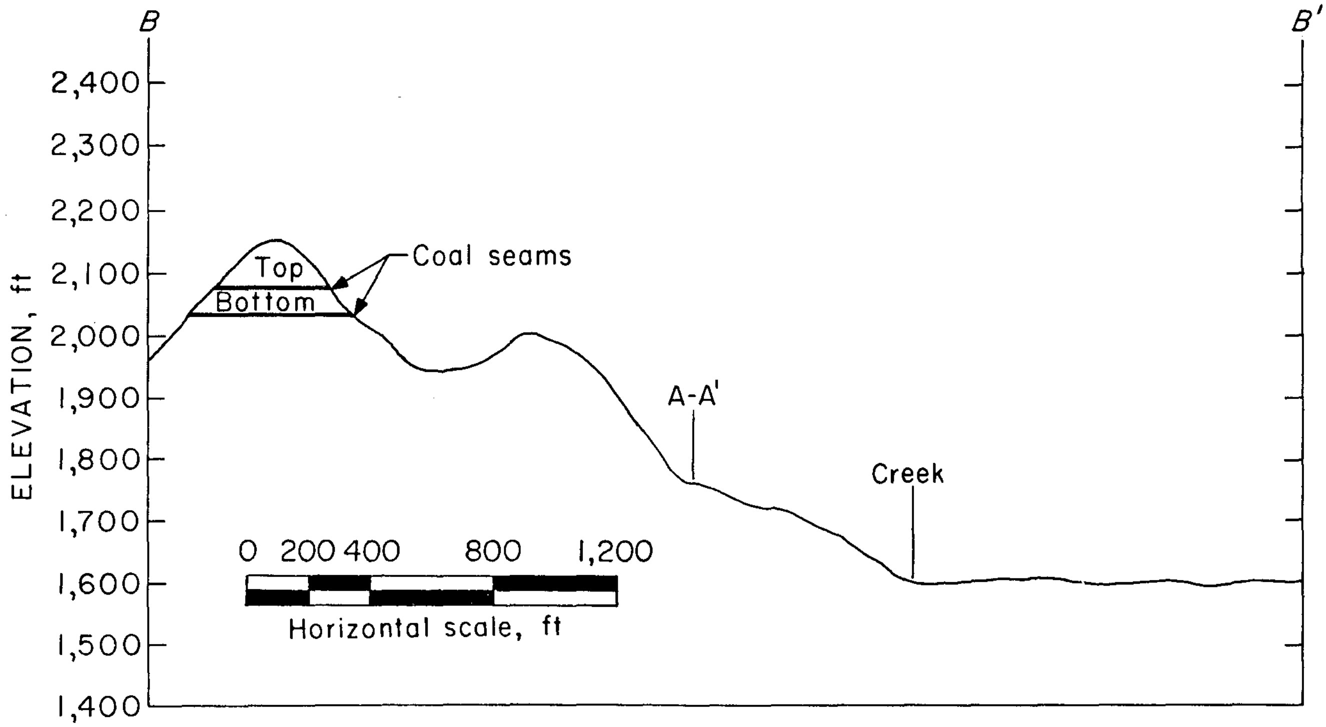

FIGURE B-13. - Test hollow 3, cross section B-B', with vertical exaggeration.

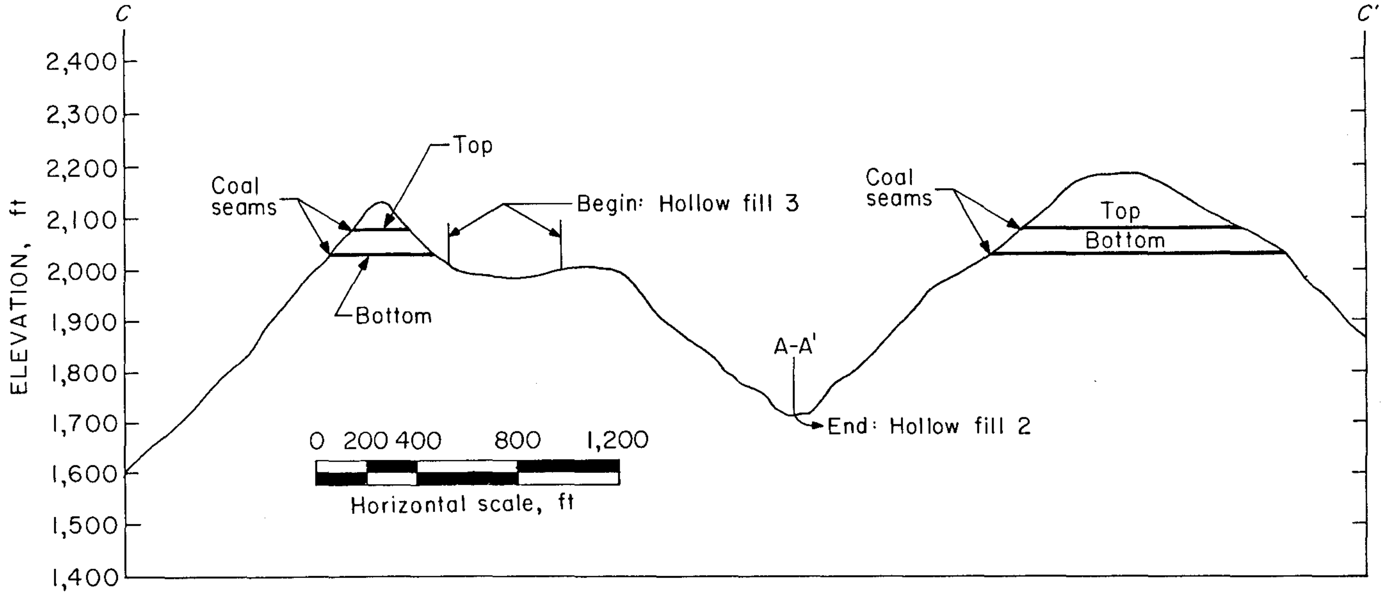

FIGURE B-14. - Test hollow 3, cross section C-C', with vertical exaggeration.

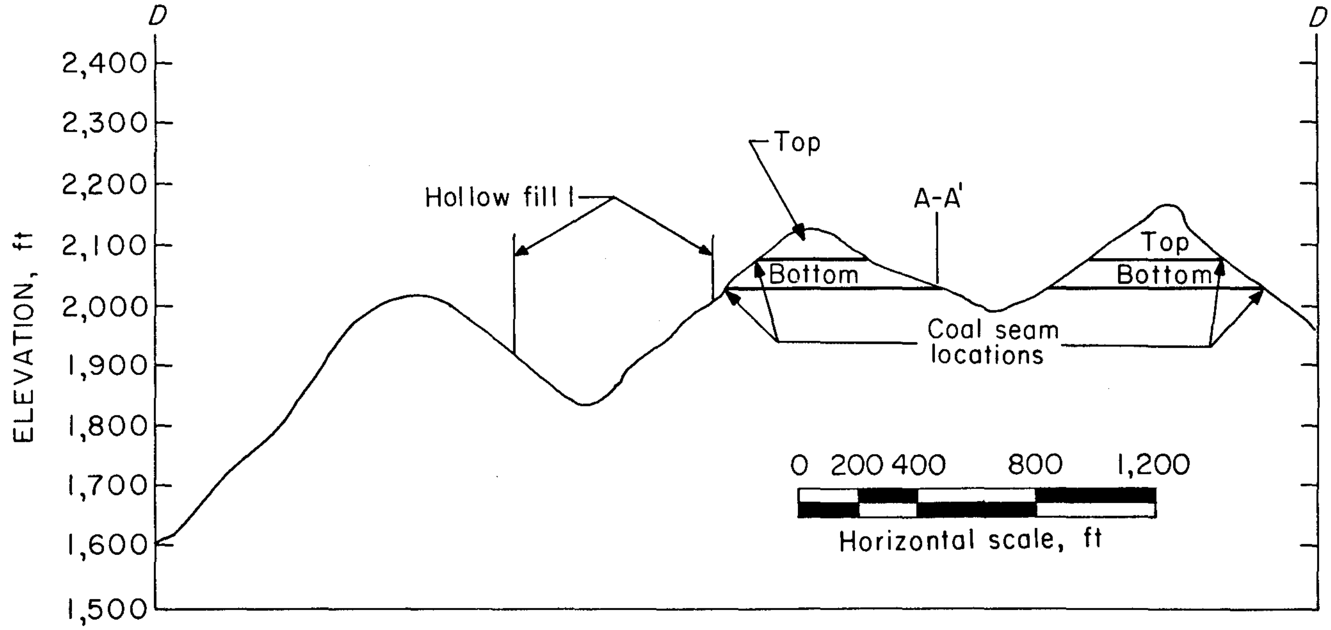

FIGURE B-15. - Test hollow 3, cross section D-D', with vertical exaggeration.

APPENDIX C.--BLAST DESIGN, NOISE, AND VIBRATION FROM CONTOUR MINES

Shots 154 through 196 are measurements made in rolling-terrain and steep-slope contour mines in Ohio and Virginia and were reported previously in Bureau of Mines RI 8485. Shots after 196 were monitored specifically for this study, with gaps being mines outside the contour mining area. Shots 154 through 329 were used for the analysis in this report.

SHOT NUMBER, DISTANCE, POUNDS PER DELAY, DEPTH, DIAMETER, STEMMING, BURDEN, SPACING, HORIZONTAL GROUND VIBRATION 1, HORIZONTAL GROUND VIBRATION 2, AIR BLAST IN PSI, VERTICAL GROUND VIBRATION, SHOT TYPE (1=HIGHWALL, 2=PARTING, 3=DITCH, 4=SWEETENER, 5=ROLLING, 6=STEEP SLOPE, 7=QUARRY, 8=METAL, 9=UNKNOWN),

SHOTN	DIST	LB/D	DEP	DIA	STEM	BUR	SPA	H1	H2	AB	V	SHTP
	FT	LBS	FT	IN	FT	FT	FT	IN/SEC	IN/SEC	PSI	IN/SEC	
154.4	575	125	26	7 3/8	19	15	15	NA	.34	.00498	.51	5
155	400	120	46	7 3/8	16	15	15	NA	NA	.0057	NA	5
155	80	120	46	7 3/8	16	15	15	NA	NA	.0096	NA	5
155	315	120	46	7 3/8	16	15	15	NA	NA	.0038	NA	5
155	285	120	46	7 3/8	16	15	15	NA	.429	NA	.546	5
156	390	80	46	7 3/8	15	15	15	NA	NA	.0061	NA	5
156	80	80	46	7 3/8	15	15	15	NA	NA	.0201	NA	5
156	260	80	46	7 3/8	15	15	15	NA	NA	.0055	NA	5
156	220	80	46	7 3/8	15	15	15	NA	.568	NA	.960	5
157.4	1100	75	46	7 7/8	19	15	15	NA	.137	.00165	NA	5
157	450	75	46	7 7/8	19	15	15	NA	NA	.0038	NA	5
158.4	360	41	35	7 7/8	18	15	15	.413	.315	.00380	.251	5
158.74	1150	41	35	7 7/8	18	15	15	NA	.100	.00170	NA	5
158.77	1150	41	35	7 7/8	18	15	15	NA	NA	.00422	NA	5
159.4	250	23	25-18	7 7/8	17	15	15	.327	.237	.00508	.327	5
159.74	1200	23	25-18	7 7/8	17	15	15	NA	.0394	.00047	NA	5
159.77	250	23	25-18	7 7/8	17	15	15	NA	NA	.00559	NA	5
160.7	450	78	30	7 7/8	16	12	12	.292	.229	.00282	.126	5
161.4	215	41	25	7 7/8	15	10	10	1.17	.64	.010	.64	5
161.5	215	41	25	7 7/8	15	10	10	NA	NA	.0082	NA	5
162.4	1500	602	65	7 7/8	12	18	15	.18	.19	.00257	.16	6
164.7	835	351	50	7 7/8	14	18	15	.19	.15	.00339	.10	6
165.6	815	351	50	7 7/8	14	18	15	.25	.36	.00138	.13	6
165.6	815	351	50	7 7/8	14	18	15	NA	NA	.00165	NA	6
167.5	350	35	25	7 7/8	16	18	15	NA	NA	.00260	NA	5
167.7	350	35	25	7 7/8	16	18	15	.33	.42	.00214	.50	5
168.5	275	86	30	7 7/8	15	18	15	.85	1.16	.00362	.72	5
168.7	275	86	30	7 7/8	15	18	15	NA	NA	.0069	NA	5
169.9	250	86	35	7 7/8	18	15	15	2.11	1.81	.0157	1.45	5
169.10	250	86	35	7 7/8	18	15	15	3.74	2.45	.0079	2.81	5
170.9	240	86	30	7 7/8	18	15	15	2.84	1.85	.0157	1.65	5
170.10	240	86	30	7 7/8	18	15	15	5.25	5.02	.00807	4.58	5
171.7	240	71	23	7 7/8	17	15	15	2.14	1.91	.00858	1.46	5
171	240	71	23	7 7/8	17	15	15	1.23	1.24	NA	.97	5
173	440	86	22	7 7/8	17	15	15	.59	.96	NA	1.01	5
173	440	86	22	7 7/8	17	15	15	.82	1.20	NA	.78	5
173	440	86	22	7 7/8	17	15	15	.52	.78	NA	.81	5
173	440	86	22	7 7/8	17	15	15	.63	NA	NA	NA	5
173.13	440	86	22	7 7/8	17	15	15	.97	NA	.00352	NA	5
174.13	310	86	30	7 7/8	15	15	15	1.38	1.86	.00760	.85	5

SHOTN	DIST FT	LB/D LBS	DEP FT	DIA IN	STEM FT	BUR FT	SPA FT	H1 IN/SEC	H2 IN/SEC	AB PSI	V IN/SEC	SHTP
174.14	310	86	30	7 7/8	15	15	15	1.23	1.08	.00772	1.79	5
175.13	260	212	35	7 7/8	15	15	15	10.21	6.92	.0157	5.65	5
175.14	260	212	35	7 7/8	15	15	15	NA	NA	.0151	NA	5
176	98	71	33	7 7/8	16	15	15	4.23	NA	NA	NA	5
176	98	71	33	7 7/8	16	15	15	4.31	NA	NA	NA	5
176	98	71	33	7 7/8	16	15	15	5.58	2.34	NA	2.61	5
176.13	98	71	33	7 7/8	16	15	15	3.93	2.95	.0125	4.88	5
176.14	98	71	33	7 7/8	16	15	15	4.24	2.54	.0136	2.88	5
177.13	98	36	38	7 7/8	19	15	15	3.90	2.44	.0061	1.65	5
177	98	36	38	7 7/8	19	15	15	3.44	2.99	NA	2.02	5
177	98	36	38	7 7/8	19	15	15	3.39	2.54	NA	1.78	5
177	98	36	38	7 7/8	19	15	15	3.27	NA	NA	NA	5
177	98	36	38	7 7/8	19	15	15	3.33	NA	NA	NA	5
178.7	242	33	20-24	7 7/8	18	15	15	1.04	.64	.00316	.83	5
179.7	167	33	25-30	7 7/8	17	15	15	1.84	2.08	.00728	1.47	5
180.7	57	18	NA	7 7/8	NA	NA	NA	10.58	2.02	.020	2.92	5
181.7	78	22	32	7 7/8	18	15	15	7.25	4.90	.020	4.76	5
182.7	54	18	NA	7 7/8	NA	NA	NA	6.37	3.46	.012	3.46	5
183.4	2300	125	22	7 7/8	13.5	12	12	.021	.021	.00055	.018	6
184.4	2600	2000	NA	NA	NA	NA	NA	.0461	.0689	.00321	NA	6
185.4	600	5	NA	NA	NA	NA	NA	.0277	.0286	.00087	.0366	6
186.4	750	35	NA	NA	NA	NA	NA	.0575	.0355	.00052	.0348	6
187.4	750	35	NA	NA	NA	NA	NA	.0413	.0401	.00075	.0362	6
188.4	1500	175	NA	NA	NA	NA	NA	.0283	.0165	.00209	.0191	6
189.4	750	40	NA	NA	NA	NA	NA	.05	.03	.00338	.07	6
190.4	750	40	NA	NA	NA	NA	NA	.06	.03	.00053	.03	6
191.4	750	40	NA	NA	NA	NA	NA	.04	.02	.00218	.06	6
192.4	750	40	NA	NA	NA	NA	NA	.06	.03	.000592	.05	6
193	280	60	NA	NA	NA	NA	NA	2.6	2.1	.0053	3.2	6
194.4	1100	40	NA	NA	NA	NA	NA	.02	.01	.0011	.02	6
195.4	1100	40	NA	NA	NA	NA	NA	.02	.01	.0006	.02	6
196.4	1100	40	NA	NA	NA	NA	NA	.03	.02	.00127	.03	6
197	345	80	NA	NA	NA	NA	NA	.80	.94	NA	.59	6
198.4	180	30	NA	NA	NA	NA	NA	1.02	.92	NA	.43	5
199	170	30	NA	NA	NA	NA	NA	1.08	.98	NA	NA	5
200	1100	276	NA	NA	NA	NA	NA	.25	.34	NA	.20	5
201.2	157	30	NA	NA	NA	NA	NA	1.19	1.13	.0243	.77	5
202.1	137	30	NA	NA	NA	NA	NA	2.06	1.13	.00376	1.29	5
203.8	247	100	NA	NA	NA	NA	NA	1.35	.77	.00663	NA	5
203	247	100	NA	NA	NA	NA	NA	.89	NA	NA	NA	5
204	242	100	NA	NA	NA	NA	NA	2.23	.68	NA	NA	5
204.8	242	100	NA	NA	NA	NA	NA	1.23	.54	.00725	.92	5
205.1	242	100	NA	NA	NA	NA	NA	1.05	.66	.0127	.39	5
205	242	100	NA	NA	NA	NA	NA	1.98	1.15	NA	.69	5
206.1	245	100	NA	NA	NA	NA	NA	.73	.75	.00771	.55	5
206	245	100	NA	NA	NA	NA	NA	1.21	1.12	NA	.30	5
207	245	100	NA	NA	NA	NA	NA	1.88	1.76	.0046	.49	5
208	170	80	NA	NA	NA	NA	NA	1.90	2.48	.0110	.65	5
211	1600	204	NA	NA	NA	NA	NA	NA	NA	.0025	.05	6.1
213	400	75	46	6 3/4	NA	15	15	.08	.16	.0022	.10	6.1
215	550	75	25	6 3/4	NA	15	15	.15	.13	.0046	.15	6.1
216	550	75	30	6 3/4	NA	12	12	.13	.10	.0036	.08	6.1
226	1730	550	NA	NA	NA	NA	NA	.17	.12	.0196	.08	6.1

SHOTN	DIST FT	LB/D LBS	DEP FT	DIA IN	STEM FT	BUR FT	SPA FT	H1 IN/SEC	H2 IN/SEC	AB PSI	V IN/SEC	SHTP
227	1900	205	NA	NA	NA	NA	NA	.18	.17	.0026	.20	6.1
228	570	500	NA	NA	NA	NA	NA	.10	.07	.0013	.06	6.1
229	580	300	NA	NA	NA	NA	NA	.19	.36	.0019	.25	6.1
230	1340	550	NA	NA	NA	NA	NA	.13	.14	.0016	.06	6.1
232	730	500	NA	NA	NA	NA	NA	.11	.14	.0011	.07	6.1
233	530	350	NA	NA	NA	NA	NA	.28	.26	.0028	.35	6.1
234	630	120	NA	NA	NA	NA	NA	.19	.22	.0023	.20	6.1
235	600	472	NA	NA	NA	NA	NA	.24	.37	.0012	.26	6.1
236	1530	160	NA	NA	NA	NA	NA	.17	.18	.0034	.16	6.1
237	1400	180	NA	NA	NA	NA	NA	.22	.24	.0012	.23	6.1
238	1380	296	NA	NA	NA	NA	NA	.14	.11	.0011	.10	6.1
239	1430	175	NA	NA	NA	NA	NA	.11	.09	.0012	.07	6.1
240	1480	175	NA	NA	NA	NA	NA	.10	.09	.0010	.09	6.1
241	1100	200	NA	NA	NA	NA	NA	.06	.05	.0015	.06	6.1
242	920	250	NA	NA	NA	NA	NA	.43	.41	.0082	.28	6.1
243	930	250	NA	NA	NA	NA	NA	.17	.20	.0021	.12	6.1
244	650	280	NA	NA	NA	NA	NA	.31	.52	.0080	.34	6.1
245	1850	300	NA	NA	NA	NA	NA	.19	.19	.0021	.13	6.1
246	1800	625	NA	NA	NA	NA	NA	.08	.08	.0010	.06	6.1
247	830	200	NA	NA	NA	NA	NA	.11	.14	.0024	.15	6.1
248	650	200	NA	NA	NA	NA	NA	.29	.22	.0039	.20	6.1
249.1	580	77	21	6	10	12	12	.439	.286	.0035	.139	6
250.1	705	363	45	6 1/4	12	14	14	.159	.326	.0076	.324	6
250.2	1125	363	45	6 1/4	12	14	14	.170	.106	NA	.157	6
250.3	3430	363	45	6 1/4	12	14	14	.019	.035	.0027	.009	6
251.2	680	140	22	5	12	10	12	.364	.223	.0540	.139	6
251.3	1190	140	22	5	12	10	12	.045	.062	NA	.044	6
251.5	3320	140	22	5	12	10	12	.008	.008	.0006	.008	6
252.1	820	266	31	5	12	12	12	.056	.071	.0101	.084	6
252.2	1110	266	31	5	12	12	12	.107	.129	.0314	.069	6
252.3	1710	266	31	5	12	12	12	.036	.039	NA	.022	6
252.4	2725	266	31	5	12	12	12	.020	.020	.0023	.010	6
252.5	4005	266	31	5	12	12	12	.006	.009	.0013	.009	6
253.1	450	726	45	6 1/4	12	16	16	.335	.424	.0122	.419	6
253.2	810	726	45	6 1/4	12	16	16	.206	.290	.0720	.111	6
253.3	1270	726	45	6 1/4	12	16	16	.078	.062	NA	.018	6
253.4	2235	726	45	6 1/4	12	16	16	.020	.020	.0025	.020	6
253.5	3490	726	45	6 1/4	12	16	16	.015	.015	.0013	.016	6
254.1	715	266	31	5	12	12	12	.437	.659	.0051	.391	6
254.2	970	266	31	5	12	12	12	.132	.116	.0061	.031	6
254.3	1380	266	31	5	12	12	12	.077	.058	.0012	.016	6
254.4	2330	266	31	5	12	12	12	.010	.02	.0007	.030	6
255.1	920	732	45	6 1/4	12	16	16	.101	.176	.0088	.093	6
255.2	1090	732	45	6 1/4	12	16	16	.080	.088	.0077	.018	6
255.3	1390	732	45	6 1/4	12	16	16	.042	.058	.0029	.046	6
255.4	2370	732	45	6 1/4	12	16	16	.010	.010	.0018	.010	6
256.1	1080	770	45	6 1/4	10	15	15	.353	.435	.0322	.293	6
256.2	1080	770	45	6 1/4	10	15	15	.170	.155	.0429	.186	6
256.3	1530	770	45	6 1/4	10	15	15	.140	.160	.0183	.130	6
256.4	1980	770	45	6 1/4	10	15	15	.033	.040	.0069	.032	6
256.5	2940	770	45	6 1/4	10	15	15	.065	.047	.0025	.092	6
257.1	450	133	31	5	12	12	12	.312	.353	.0063	.242	6
257.2	700	133	31	5	12	12	12	.134	.086	.0062	.097	6

SHOTN	DIST FT	LB/D LBS	DEP FT	DIA IN	STEM FT	BUR FT	SPA FT	H1 IN/SEC	H2 IN/SEC	AB PSI	V IN/SEC	SHTP
257.3	1100	133	31	5	12	12	12	.020	.040	.0023	.030	6
257.4	2050	133	31	5	12	12	12	.023	.022	.0013	.023	6
257.5	3320	133	31	5	12	12	12	.012	.012	.0006	.012	6
258.1	1070	132	15	6 1/4	9	12	14	.079	.106	.0061	.051	6
258.2	1250	132	15	6 1/4	9	12	14	.054	.069	NA	.044	6
258.3	1600	132	15	6 1/4	9	12	14	.040	.030	.0018	.030	6
258.4	2580	132	15	6 1/4	9	12	14	.019	.022	.0012	.018	6
260	1150	590	NA	NA	NA	NA	NA	.120	.130	.0011	.200	6.1
262	1060	770	NA	NA	NA	NA	NA	.190	.160	.0017	.190	6.1
263	1200	812	NA	NA	NA	NA	NA	.110	.100	.0016	.090	6.1
264	1170	234	NA	NA	NA	NA	NA	.060	.040	.0025	.010	6.1
265	980	882	NA	NA	NA	NA	NA	.280	.220	.0009	.180	6.1
266	980	403	NA	NA	NA	NA	NA	.190	.240	.0007	.120	6.1
267	860	635	NA	NA	NA	NA	NA	.280	.240	.0014	.270	6.1
268	860	905	NA	NA	NA	NA	NA	.440	.310	.0019	.240	6.1
269	750	765	NA	NA	NA	NA	NA	.250	.250	.0049	.210	6.1
270	600	695	NA	NA	NA	NA	NA	.240	.170	.0027	.170	6.1
271	600	838	NA	NA	NA	NA	NA	.230	.170	.0024	.210	6.1
272	500	307	NA	NA	NA	NA	NA	.180	.110	.0025	.130	6.1
273	500	250	NA	NA	NA	NA	NA	.300	.130	.0026	.170	6.1
274	450	250	NA	NA	NA	NA	NA	.290	.210	.0032	.190	6.1
275	475	350	NA	NA	NA	NA	NA	.140	.130	.0020	.120	6.1
276	500	350	NA	NA	NA	NA	NA	.160	.290	.0013	.180	6.1
277	600	400	NA	NA	NA	NA	NA	.160	.280	.0017	.120	6.1
279	1150	450	NA	NA	NA	NA	NA	.140	.270	.0043	.140	6.1
280	1175	400	NA	NA	NA	NA	NA	.180	.260	.0014	.090	6.1
281	1350	450	NA	NA	NA	NA	NA	.110	.250	.0036	.100	6.1
282	1375	400	NA	NA	NA	NA	NA	.120	.240	.0009	.080	6.1
283	1400	400	NA	NA	NA	NA	NA	.380	.340	.0057	.240	6.1
284	500	450	NA	NA	NA	NA	NA	.350	.360	.0044	.310	6.1
285	550	210	NA	NA	NA	NA	NA	.200	.210	.0038	.140	6.1
286	400	165	NA	NA	NA	NA	NA	.350	.230	.0057	.220	6.1
287	500	150	NA	NA	NA	NA	NA	.330	.280	.0045	.170	6.1
288	450	400	NA	NA	NA	NA	NA	.090	.160	.0023	.090	6.1
289	1309	400	NA	NA	NA	NA	NA	.070	.050	.0032	.040	6.1
290	1201	500	NA	NA	NA	NA	NA	.370	.380	.0075	.250	6.1
291	870	1000	NA	NA	NA	NA	NA	.090	.190	.0026	.090	6.1
292	1024	1000	NA	NA	NA	NA	NA	.100	.100	.0027	.070	6.1
293	1062	400	NA	NA	NA	NA	NA	.110	.130	.0020	.070	6.1
294	914	600	NA	NA	NA	NA	NA	.110	.150	.0010	.090	6.1
295	796	600	NA	NA	NA	NA	NA	.200	.330	.0037	.200	6.1
296	1208	400	NA	NA	NA	NA	NA	.190	.090	.0059	.130	6.1
297	669	400	NA	NA	NA	NA	NA	.170	.120	.0019	.130	6.1
299	554	400	NA	NA	NA	NA	NA	.080	.120	.0015	.090	6.1
300	1394	600	NA	NA	NA	NA	NA	.090	.180	.0032	.090	6.1
301	1572	400	NA	NA	NA	NA	NA	.130	.130	.0020	.100	6.1
328.2	725	1000	NA	NA	NA	NA	NA	.074	.071	.0037	.036	6
328.5	4380	1000	NA	NA	NA	NA	NA	.0115	.0125	.0006	.0105	6
329.1	1100	300	NA	NA	NA	NA	NA	.230	.200	.0043	.180	6
329.2	1350	300	NA	NA	NA	NA	NA	.028	NA	.0028	.073	6
329.3	1680	300	NA	NA	NA	NA	NA	.039	.039	.0036	.0026	6
329.4	2130	300	NA	NA	NA	NA	NA	.048	.035	.0025	.031	6
329.5	2220	300	NA	NA	NA	NA	NA	NA	.072	.0019	.083	6

APPENDIX D.--PROPAGATION EQUATIONS FROM CONTOUR MINE BLASTING

TABLE D-1. - Propagation equations from contour mine blasting

	Equations[1]	Correlation coefficient	Standard error	Observations
	ROLLING-TERRAIN CONTOUR MINES			
Maximum horizontal	$GV = 98.14 (D/W^{1/2})^{-1.248}$	0.699	1.91	44
Vertical	$GV = 37.16 (D/W^{1/2})^{-1.104}$	.630	2.02	44
0.1 Hz	$AB = 0.47 (D/W^{1/3})^{-1.013}$	.737	1.95	50
	STEEP-SLOPE CONTOUR MINES			
Maximum horizontal	$GV = 16.64 (D/W^{1/2})^{-1.194}$	0.759	2.00	122
Vertical	$GV = 7.83 (D/W^{1/2})^{-1.101}$	.703	2.13	122
0.1 Hz	$AB = 14.68 (D/W^{1/3})^{-1.589}$	.761	2.59	54
5 Hz	$AB = 0.086 (D/W^{1/3})^{-0.726}$	.389	2.41	67
	TEST HOLLOWS			
Hollow 1: All shots				
Maximum horizontal	$GV = 47.8 (D/W^{1/2})^{-1.498}$	0.846	1.91	38
Vertical	$GV = 15.59 (D/W^{1/2})^{-1.498}$	.775	2.11	38
0.1 Hz	$AB = 4.23 (D/W^{1/3})^{-1.315}$	.807	1.92	31
Hollow 3:				
Radial	$GV = 299.3 (D/W^{1/2})^{-1.907}$	.580	2.54	4
Transverse	$GV = 448.1 (D/W^{1/2})^{-1.917}$	.773	1.86	4
Vertical	$GV = 115.3 (D/W^{1/2})^{-1.758}$	.322	5.97	5
0.1 Hz	$AB = 0.406 (D/W^{1/3})^{-0.898}$	.829	1.23	5
	INDIVIDUAL SHOTS FROM TEST HOLLOW 1			
Shot 250:				
Maximum horizontal	$GV = 53.54 (D/W^{1/2})^{-1.412}$	0.999	1.01	3
Vertical	$GV = 1,631.2 (D/W^{1/2})^{-2.319}$	.995	1.30	3
0.1 Hz	NA	NA	NA	2
Shot 251:				
Maximum horizontal	$GV = 4,274.8 (D/W^{1/2})^{-2.357}$	.992	1.41	3
Vertical	$GV = 179.8 (D/W^{1/2})^{-1.783}$	.998	1.12	3
0.1 Hz	NA	NA	NA	2
Shot 252:				
Maximum horizontal	$GV = 42.17 (D/W^{1/2})^{-1.506}$	.930	1.56	5
Vertical	$GV = 42.41 (D/W^{1/2})^{-1.581}$	.973	1.32	5
0.1 Hz	$AB = 5.47 (D/W^{1/3})^{-1.296}$	.999	1.03	3
Shot 253:				
Maximum horizontal	$GV = 91.67 (D/W^{1/2})^{-1.827}$	.977	1.46	5
Vertical	$GV = 25.22 (D/W^{1/2})^{-1.616}$	.906	2.03	5
0.1 Hz	$AB = 0.84 (D/W^{1/3})^{-1.074}$	.996	1.06	3
Shot 254:				
Maximum horizontal	$GV = 17,580 (D/W^{1/2})^{-2.782}$	.975	1.48	4
Vertical	$GV = 167.4 (D/W^{1/2})^{-1.885}$	.674	3.60	4
0.1 Hz	$AB = 51.2 (D/W^{1/3})^{-1.888}$	.950	1.18	4
Shot 255:				
Maximum horizontal	$GV = 5,514 (D/W^{1/2})^{-2.947}$	.995	1.17	4
Vertical	$GV = 36.8 (D/W^{1/2})^{-1.823}$	.761	2.19	4
0.1 Hz	$AB = 28.4 (D/W^{1/3})^{-1.754}$	.947	1.14	4
Shot 256:				
Maximum horizontal	$GV = 143.4 (D/W^{1/2})^{-1.738}$	.799	1.90	5
Vertical	$GV = 25.97 (D/W^{1/2})^{-1.336}$	.679	2.03	5
0.1 Hz	$AB = 17,260 (D/W^{1/3})^{-2.726}$	.992	1.08	5
Shot 257:				
Maximum horizontal	$GV = 122.7 (D/W^{1/2})^{-1.662}$	.980	1.37	5
Vertical	$GV = 36.95 (D/W^{1/2})^{-1.446}$	.966	1.43	5
0.1 Hz	$AB = 1.98 (D/W^{1/3})^{-1.236}$	.977	1.11	5
Shot 258:				
Maximum horizontal	$GV = 253.1 (D/W^{1/2})^{-1.742}$	.983	1.16	4
Vertical	$GV = 12.09 (D/W^{1/2})^{-1.205}$	.997	1.05	4
0.1 Hz	$AB = 105.3 (D/W^{1/3})^{-1.854}$	.951	1.18	3

NA Not available.

[1] AB = airblast, pound per square inch; GV = ground vibration, inch per second; D = distance, ft; W = charge weight, lb.

NOTE.--Data not available for test hollow 2 (2 observations) and shot 249, test hollow 1 (1 observation).

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