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The Effects Of Structural Setting On The Azimuthal Velocities Of Blast Induced
Ground Motion in Perlite

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ABSTRACT

A series of small scale explosive tests were performed during the spring of 1994 at a perlite mine located near Socorro, NM. The tests were designed to investigate the azimuthal or directional relationship between small scale geologic structures such as joints and the propagation of explosively induced ground motion. Three shots were initiated within a single borehole located at ground zero (gz) at depths varying from the deepest at 83 m (272 ft) to the shallowest at 10 m (32 ft). The intermediate shot was initiated at a depth of 63 m (208 ft). An array of three component velocity and acceleration transducers were placed in two concentric rings entirely surrounding the single shot hole at 15° and 30° azimuths as measured from ground zero. Data from the transducers was then used to determine the average propagation velocity of the blast vibration through the rock mass at the various azimuths. The rock mass was mapped to determine the prominent joint orientations (strike and dip) and the average propagation velocities were correlated with this geologic information. The data from these experiments shows that there is a correlation between the orientation of prominent joints and the average velocity of ground motion. It is theorized that this relationship is due to the relative path the ground wave follows when encountering a joint or structure within the rock mass. The more prominent structures allow the wave to follow along their strike thereby forming a sort of channel or path of least resistance and in turn increasing the propagation velocity. Secondary joints or structures may act in concert with more prominent features to form a network of channels along which the wave moves more freely than it may travel against the structure. The amplitudes of the ground motion was also shown to vary azimuthally with the direction of the most prominent structures.

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TABLE OF CONTENTS

	page
ABSTRACT	i
ACKNOWLEDGMENTS	ii
LIST OF FIGURES	v
LIST OF TABLES	vii
CHAPTER 1.0 INTRODUCTION	1
1.1 Purpose	1
1.2 Site characterization	3
1.3 Scope of study	4
CHAPTER 2.0 BLAST INDUCED GROUND VIBRATIONS	6
2.1 Overview of Blast Design for the Control of Ground Vibrations	7
2.2 Geological Controls and Blasting Vibrations	11
2.3 Velocity Models	16
2.3.1 Depth model of the Dicaperl deposit	18
2.3.2 Azimuthal velocity models	19
CHAPTER 3.0 EXPERIMENTAL METHODS AND PROCEDURES	22
3.1 Instrumentation	22
3.2 Experimental Procedures	25
3.2.1 Shots	25
3.2.2 Data Reduction	27
3.3 Geologic Mapping	29
CHAPTER 4.0 RESULTS	34
4.1 Introduction	34
4.1.1 Shot 14 (83 m (272 ft) depth)	34
4.1.2 Shot 15 (63 m (208 ft) depth)	36
4.1.3 Shot 16 (10 m (32 ft) depth)	36
4.2 Velocity Plots	37
4.3 Structural Analysis	43
4.3.1 Rose Diagrams	43
4.3.2 Spherical projections of Joint Orientations	53
4.3.2.1 Overview of Spherical projections	53

TABLE OF CONTENTS (cont.)

	page
4.3.2.2 Results	56
CHAPTER 5.0 CONCLUSIONS AND RECOMMENDATIONS	69
5.1 Summary	69
5.2 Conclusions	70
5.2 Recommendations	71
REFERENCES	73
APPENDIX A	76
APPENDIX B	210
APPENDIX C	214

LIST OF FIGURES

	page
Figure 1. Project location.	2
Figure 2. Particle motions as a function of wave type.	12
Figure 3. Typical results from a seismic refraction survey.	18
Figure 4. Depth velocity model for Dicaperl Site.	20
Figure 5. Instrument Layout.	23
Figure 6. Explosive container.	26
Figure 7. Excavation of trench used for geologic analysis.	30
Figure 8. Configuration of cells used for taking structural data.	31
Figure 9. Rock mass showing paint markings for reference.	32
Figure 10. Prominent joint with manganese staining evident.	32
Figure 11. View of trench from above showing highly fractured nature of rock mass and undulating nature of manganese staining.	33
Figure 12. Average velocity versus azimuth for outer ring from all shots.	38
Figure 13. Average velocity versus azimuth for inner ring from all shots.	39
Figure 14. Polar plot of average velocity for outer ring from all shots.	40
Figure 15. Polar plot of average velocity for inner ring from all shots.	41
Figure 16. Rose Diagram of Test Cell 1.	44
Figure 17. Rose Diagram of Test Cell 2.	45
Figure 18. Rose Diagram of Test Cell 3.	46
Figure 19. Rose Diagram of Test Cell 4.	47
Figure 20. Rose Diagram of Test Cell 5.	48
Figure 21. Rose Diagram of Test Cell 6.	49
Figure 22. Rose Diagram of Test Cell 7.	50
Figure 23. Rose Diagram of Test Cell 8.	51
Figure 24. Rose Diagram of All Test Cells.	52
Figure 25. Sectional view of a sphere showing the relationship between meridional and polar nets.	54
Figure 26. Methods of stereographic projection.	54
Figure 27. Definition and orientation of an inclined plane using stereographic projection.	55
Figure 28. Illustration of terms used in stereographic projection.	56

LIST OF FIGURES (cont.)	page
Figure 29. Stereographic projection showing the poles of planes for all mapping cells.	57
Figure 30. Stereographic projection showing prominent joint orientations (strikes, dips) for all mapping cells.	58
Figure 31. Ground motion time histories for shot 14, outer ring layout showing relative arrival times and amplitudes of ground motion.	62
Figure 32. Ground motion time histories for shot 14, inner ring layout showing relative arrival times and amplitudes of ground motion.	63
Figure 33. Ground motion time histories for shot 15, outer ring layout showing relative arrival times and amplitudes of ground motion.	64
Figure 34. Ground motion time histories for shot 15, inner ring layout showing relative arrival times and amplitudes of ground motion.	65
Figure 35. Ground motion time histories for shot 16, outer ring layout showing relative arrival times and amplitudes of ground motion.	66
Figure 36. Ground motion time histories for shot 16, inner ring layout showing relative arrival times and amplitudes of ground motion.	67

LIST OF TABLES

	page
Table 1. Ground vibration variables.	9
Table 2. Summary of shot data.	25
Table 3. Technical data of explosive used for test blasts.	26
Table 4. Data acquisition for all shots.	35

CHAPTER 1.0

INTRODUCTION

Mine blast induced ground vibrations have long been of concern to both the mining and construction industries and the public who may be exposed to such vibrations. Since the advent of the Office of Surface Mining's final regulations in March 1983, mining companies and engineers have struggled to find ways in which to reduce the intensity of ground vibrations from their surface blasting operations in order to comply with federal regulations. Some methods of control and compliance include the reduction of borehole explosive charge weights initiated within 8 millisecond intervals, blasting at strictly scheduled times, and time delaying the explosive charges within the shot to increase the number of free faces and to decrease overall confinement. All of the above are effective to some degree. One important aspect of the blasting process that is largely ignored in vibration control, however, is the influence of the fabric and structure of the rock mass. The influence of the rock mass characteristics is well understood in the arena of fragmentation, but few investigations have been made concerning the role of geologic structure in ground vibration propagation.

1.1 Purpose

A series of small scale explosives tests were conducted during the spring of 1994 at a perlite mine located west of Socorro, NM as shown on Figure 1.

Figure 1. Project location.

This series of tests comprised the second phase of a joint project between New Mexico Tech (NMT), Los Alamos National Lab (LANL), the Defense Nuclear Agency (DNA) and Southern Methodist University (SMU). Both phases of testing to date have been designed to investigate the effects of geologic structure on ground motion produced by blasting. During Phase I, the effects of horizontal layering and rock density changes with depth were investigated (Edwards, et al, 1994). Phase II was designed specifically to investigate the azimuthal effects of geologic structure and to investigate the presumed correlation between prominent joint set orientation and seismic wave propagation.

1.2 Site characterization

The site chosen to conduct these experiments was the Dicaperl owned perlite deposit located approximately 4.8 km (3 mi) southwest of Socorro on the edge of the Socorro Mountains. Perlite, usually in an expanded or "popped" form, is used primarily in the construction industry as aggregate, in insulation board, plaster, and concrete. It is also used widely as a soil conditioner in commercial potting soils and as an aid in filtering water and other liquids, in food processing, and in pharmaceutical manufacture (Harben, et al, 1963). The Socorro deposit is composed of prominently flow-banded, pumiceous, pale gray to buffish-gray glass of rhyolitic composition (Weber, 1965). The ore body was deposited as a volcanic dome approximately 610 m (2000 ft) wide and 790 m

(2590 ft) long and has a 137 m (450 ft) vertical exposure. The dome was deposited as an extrusive, rhyolitic lava between 23.7 and 33.2 million years ago according to Weber and Basset (1963). After the dome was deposited, the perlite formed via hydration of the obsidian core. The vesicular nature of the deposit provided paths for travel of meteoric water, allowing for the hydration of the glass. The dome has a surface layer of crystalline rock on the northeast edge and is bounded on the east and west margins by high angle normal faults (Weber, 1965).

Mining the perlite at the Dicaperl site is accomplished by dozers equipped with ripper teeth and scrapers used to move the ore to the primary crushing site. Blasting is rarely utilized in the pit except in cases of hard, unrippable ore. Ore production at the Dicaperl site is 218,000 metric tons (240,000 short tons) per year and the deposit contains 10,900,000 metric tons of minable ore (12,000,000 short tons).

Blasting experiments were conducted in a currently dormant pit southwest of the active mining area. The pit used was approximately 200 m (655 ft) long and 75 m (245 ft) wide with the long axis oriented approximately north-south.

1.3 Scope of study

This phase of the study was implemented for the purpose of describing a correlation between the strike and dip of prominent joint sets within a rock mass and the velocity of blast induced ground motions passing through those

structures. Chapter 2 is a review of ground vibrations induced by traditional production blasting and an overview of blast design with respect to vibration control. This chapter also contains information regarding past findings on geologic controls with respect to ground vibrations and on the more traditional velocity models that have been produced to describe these controls. Chapter 3 describes the experimental methods and procedures used in conducting this investigation including descriptions of the type and numbers of recording equipment, the type of explosive used, and the depth of burial for each experimental shot. Information regarding geologic mapping is also contained in Chapter 3 along with the pertinent data reduction procedures. Chapter 4 describes the results of the data reduction and the process by which conclusions were made. Chapter 5 contains conclusions and recommendations for further study in this area.

CHAPTER 2

BLAST INDUCED GROUND VIBRATIONS

Ground vibrations are an integral part of rock blasting (Persson, 1993).

The shock forces generated during explosive detonation acting on the rock mass surrounding the blast induce dynamic stresses that in turn produce wave motions similar to those developed by throwing a rock into a still body of water. Surface wave motions may cause damage to structures close to the blast site as well as for some distance away. Damage sustained by structures may range from major damage such as foundation cracking to minor or cosmetic damage such as dry wall or plaster cracks. The level and amount of damage depends on the frequency and amplitude of surface ground motions and on the characteristic attenuation of the vibration in a particular geologic setting. The effects of blasting operations on nearby structures need to be predicted and controlled in order to prevent damage and costly repairs to neighboring structures. A variety of methods for controlling and predicting ground vibrations have been developed for use in general circumstances, but no reliable method has been developed to predict ground vibrations within a given set of geologic parameters. Site specific control is often achieved by the process of trial and error because no clear relationships between geologic setting and the ground motion have been developed.

2.1 Overview of Blast Design for the Control of Ground Vibrations

Although applicable only to surface coal mining, the United States Office of Surface Mining (OSM) regulation, CFR 30 parts 700-999, concerning the use of explosives for production blasting had a great impact on the entire blasting industry. For many years, the industry had been subjected to annoyance and damage claims from neighbors alarmed and troubled by nearby blasting. Many metal mines, quarries, and construction companies that blast regularly have followed the OSM regulations in the interests of reducing the risks of litigation and improving public relations. The regulations have not stopped the threat of litigation or the annoyance from blasting, but have given the blasting industry a basis on which to measure both blasting performance and the adverse environmental effects associated with blasting operations.

Because of the increased interest in vibration control from both industry and the public, and the threat of further, more restrictive regulations, a great deal of research has been done to find the major controls on blast induced ground vibration. Much of this work has been conducted in surface coal mining and quarrying operations. The earliest work in this area titled Vibrations caused by Quarry Blasting and Their Effect on Structures was written in 1927 by E.H. Rockwell. The United States Bureau of Mines (USBM) lead the research in the effects and control of ground vibrations in the 1950's and 60's which culminated with the publication of Bulletin 656 titled Blasting Vibrations and their Effects on Structures (Nicholls, et al, 1971). Following Nicholls, other pertinent research

was conducted by the Bureau of Mines in the 1970's resulting in the publication of studies such as OFR 103-78 titled Control of Vibration and Blast Noise From Surface Coal Mining (Wiss, et al, 1978) and RI-8507 titled Structure Response and Damage Produced by Ground Vibration From Surface Mine Blasting (Siskind, et al, 1980).

Nicholls report presented the results of ten years of research intended to study the problem of air blast and ground motions generated by blasting. The major goal of the research was to establish damage criteria for residential structures and to determine those blasting parameters that affect vibrations. Nicholls recommended a safe blasting limit of 50.8 mm/s (2 in/s) for ground vibration and noted that this level would statistically preclude damage to the structures but would not minimize complaints. He also concluded that millisecond delayed blasts induced smaller ground motion than instantaneous blasting and that initiating with electric delay caps also offered a slight reduction in ground motions over initiating with primacord.

Wiss (1978) found that the most important vibration reducing controls are the total explosive charge weight detonating per 8 millisecond delay, the length of the delay between charged boreholes, the accuracy of the detonators used to delay the shot, and the shot confinement. Less significant, but still important are the blast geometry, and the direction of initiation relative to the location of structures or ground motion measurement. All of the above are under the control of the operator while other, significant, controls such as the surface

terrain, and stratigraphy and depth of overburden in coal operations are not under the direct control of the operator. Table 1 shows the various variables controlling ground vibrations and their relative significance.

Table 1. Ground Vibration Variables (after Morhard, 1987).

Variables	Ground vibrations		
	Significant	Moderately significant	Insignificant
Within the control of mine operators			
Charge weight per delay	X		
Length of delay	X		
Detonator accuracy	X		
Burden and spacing		X	
Stemming (amount)			X
Stemming (type)			X
Charge length and diameter			X
Angle of borehole			X
Direction of initiation		X	
Charge weight per blast			X
Charge depth			X
Bare versus covered detonating cord		X	
Initiating system—electric versus nonelectric detonators			X
Not in control of mine operators			
General surface terrain		X	
Type and depth of overburden		X	
Wind			
Atmospheric conditions			X

Siskind's report (1980) focused on the damage and annoyance potential of blast produced ground motion and concluded that safe levels of ground vibration range from 12.7 to 50.8 mm/s (0.5 to 2.0 in/s) peak particle velocity for typical residential structures. The damage potential of the ground motion is strongly influenced by the frequencies of the vibration and the type of construction used for the structure. The report defined different levels of damage ranging from threshold or cosmetic damage to major structural damage. In addition, the research extended to human response to ground motion and found that vibrations as low as 0.254 mm/s (0.01 in/s) were perceptible to most humans.

There are a number of empirical formulas available for designing surface blasts, most of which are similar in form. Most formulas are ratios of the borehole geometries which produce optimum fragmentation or describe the maximum distance between boreholes and the free face (Dowding, 1985). Vibration control measures can be easily incorporated into standard blast design formulas by a variety of means. For example, reducing the weight of explosive detonating per 8 millisecond delay is perhaps the greatest factor affecting the amplitude of particle velocity (Morhard, 1987). Decking the holes to reduce the maximum charge weight per delay is one effective way to achieve this. Explosives confinement may be reduced while still adhering to fragmentation considerations by reducing the distance between holes, designing delays for maximum relief, and allowing adequate free faces.

2.2 Geological Controls and Blasting Vibrations

Explosively generated waves may be described as belonging to one of two different groups: body and surface waves. Body waves may in turn be divided into two categories, compression or P-waves and shear or S-waves. There are a variety of surface waves generated by the action of the explosive, the most important of which is the Rayleigh wave. At small distances from the blast, only body waves are evident, but once the waves intersect an interface such as the ground surface or a lithologic change where a difference in elastic parameters persists, both surface and body waves are generated. Each wave type produces a different motion in the material through which it travels as shown in Figure 2. Blast vibrations may be approximated by a simple sine wave varying with either distance or time and may be described by a variety of parameters such as propagation velocity, frequency, peak particle velocity, wavelength, and attenuation.

Each wave type exhibits a different propagation velocity within a given material, as measured by the P-wave arrival time divided by the travel distance. The propagation velocity of blast induced vibrations is important in the overall scheme of vibration monitoring and control because it is an indication of the rock mass properties that affect attenuation and wavelength. Jointing and weathering of rock masses greatly affect propagation velocities by changing the stiffness of the rock mass (Dowding, 1985) thereby decreasing the velocity. Propagation velocities within one rock type may vary more widely than within differing

lithologies due to the influence of weathering and jointing. Generally, with increasing depth, the propagation velocity increases and the intensity of jointing decreases because, with depth, the increasing overburden weight produces more tightly closed joints and weathering is decreased. The tighter joints along with increased moisture content acts to increase the bedrock mass density which in turn produces far higher P-wave velocities.

Figure 2. Particle motions as a function of wave type for (a) Compressive, (b) Shear, and (c) Rayleigh Waves (after Dowding, 1985).

The importance of propagation velocity has been recognized in Sweden, where the 1989 Swedish Standard, SS 460 48 66, includes a correction factor using the P-wave propagation velocity in addition to type of building and construction and type of blasting activity corrections (Persson, 1993). For the standard, a safe blasting guidance velocity, v , is given by :

$$v = v_o F_k F_d F_t \quad (1)$$

where v_o is the uncorrected vertical peak particle velocity, F_k is a construction quality factor, F_d is a distance factor which considers the distance from the blast to the measurement site, and F_t is a factor describing the project time. For example, F_t may describe long-term mining activities or short-term construction. All of these values are available from standard tables or from formulas. For example, v_o is 18 mm/s (0.71 in/s) for loose moraine, sand gravel and clay and 70 mm/s (2.76 in/s) for granite. The factors F_k , F_d , and F_t range from 0.5 to 1.7 depending on the specific situation. A more detailed value for the vertical peak particle velocity, v_o , can be found if the P-wave propagation velocity (C_p) is measured in the ground where the building is founded using the empirical expression:

$$v_o = C_p / 65 \quad (2)$$

where v_o is in mm/s and C_p is in m/s. The relationship between particle velocity and stress, in an idealized case, when a shock wave passes through an infinite elastic medium, is expressed from the well known expressions $E = \sigma / \epsilon$, $\epsilon = v_o / C_p$,

and $v_o = (\sigma C_p)/E$ where σ is the stress, ε is the dilation or strain, v_o is the peak particle velocity, E is the modulus of elasticity (Persson, 1994). These formulas indicate that the propagation velocity is related to the particle velocity which in turn affects the stress induced by the passage of the wave.

The dominant frequency of blast vibrations is tied to the transmission medium as well as to the type of blasting being performed. The dominant frequency is the most prevalent frequency within the entire waveform as shown by Fourier frequency spectra. Construction blasting tends to develop higher frequencies due to the typically small shot-to-building distances and the absence of thick layers of soil or till that tend to absorb high frequencies. Large production blasts tend to develop lower frequency vibrations due to the larger shot-to-building distances and the presence of soil or till layers between the shot and building. The higher frequencies associated with blast induced ground vibrations further tend to attenuate over shorter distances in soil leaving the potentially more damaging lower frequencies unattenuated for greater distances. The principal frequency of blasting vibrations has been used in conjunction with the peak particle velocity in the United States to estimate limiting ground motion levels.

The peak particle velocity (ppv) of a blast induced ground vibration is a measurement of the maximum excitation of a particle of the medium through which the wave travels. It is the speed at which a reference particle moves in any direction in response to the passage of a ground disturbance. The use of

ppv as a regulatory blasting criteria may not be adequate for certain blasting situations as it does not take into account the geologic setting of the structure or the blast. Blasting foremen and engineers know from experience that two blasts with the same geometry, explosive loading, and timing patterns initiated in different geologic domains may generate very different particle velocities as well as dominant frequencies at the measurement site. It is fairly well known that the blast wave behaves differently within different mediums. Geologic structure, including the strike and dip of the rock formation, jointing patterns and the engineering properties of the rock has been studied in depth in order to optimize fragmentation and slope stability but little information is available concerning the affect of structure on vibration.

Early data suggests that there is a correlation between structure and vibration levels. In Bulletin 656, Nicholls reported in 1971 on quarries in six different rock types and noted that there were directional effects on amplitudes of vibration within some of the rock masses. These effects were least pronounced in horizontally bedded limestone and dolomite due to the homogeneous nature of the material. The effects were most pronounced in a diabase type rock mass. Nicholls states that the clear-cut effects within this rock mass were probably due to anisotropy and jointing but no effort was made to investigate further and no data was provided to definitively quantify this effect.

In 1985, the Bureau of Mines initiated a research project to study the geologic factors that affect vibrations (Reil, J.W., et al, 1985). The report

focuses on the effects of soil or till overburden on ground motion level and frequencies as measured with distance from the blast site. The study reinforced the long known effect that unconsolidated materials overlying bedrock have on the frequencies of surface ground motion. No information is given on the effects of the actual rock mass characteristics on vibration propagation and attenuation, therefore, the Reil study falls short of providing a comprehensive understanding of the relationships between bedding, jointing, rock type and ground motions.

2.3 Velocity Models

Velocity models are used by geophysicists to interpret and explain geologic structure with depth using seismology. Seismic energy is used to generate body (P) waves whose waveform characteristics are measured by accelerometers or velocity transducers. Models are routinely developed for specific sites as a part of mining or construction site characterization. In a typical refraction survey, an energy source such as an explosive or impacting hammer is used to generate surface seismic waves that travel into the rock mass and refract at strata interfaces, faults and caverns representing a change in materials at an interface. Geophones are used at the surface to measure the time of arrival at different sites within a carefully placed array. The resulting waveforms are analyzed for the first arrival of the P and S waves. The P-wave first arrival is used to determine the depths to the various strata on the basis of their characteristic transmission velocities (Hunt, 1984). The S-wave arrival,

which occurs later in the wave train is used in conjunction with the P-wave to determine certain dynamic properties of the transmission medium such as the dynamic modulus and Poisson's ratio. A typical result from a refraction survey is shown in Figure 3 in which first arrivals are determined from the various waveforms and converted to the time-distance graph by simply dividing the distance from the impact to the recording station by the time of the first arrival. The refraction method is most commonly used as an exploration tool to determine strata thickness in the transmission media that have densities that increase distinctly with depth and have planar interface surfaces.

Traditional velocity models developed by geophysicists describe the velocity changes with depth and give an indication of the size, geometry and location of large scale structures, such as faults and folds, within the rock mass. This technique serves the geophysical community well as it is generally concerned with the exploration for large scale formations such as oil and gas traps. It has been shown, on lab scale, that the presence of numerous microfractures in a rock reduces the particle motion when subjected to a seismic disturbance (Cordier, 1985). According to Cordier, this leads to a reduction in the velocity of the seismic pulse through the rock. Little information is given in classical velocity modeling on the medium or mine scale, localized jointing and fracturing within the rock mass. In short, geophysicists are chiefly interested in gross-scale features and some research has been done on a very small or

laboratory scale. There is a void in modeling on a scale suited to the mining operation itself.

2.3.1 Depth model of the Dicaperl deposit

The structure of the Dicaperl perlite deposit at depth was modeled during Phase I of this project (Ness, 1994). A P-wave model was developed indicating

Figure 3. Typical results from a seismic refraction survey (After Hunt, 1984)

that there are three distinct layers at the experimental site. Figure 4 shows the depth model for this site. Layer 1 has a velocity of 280 m/s (919 ft/s), Layer 2 velocity is 665 m/s (2182 ft/s) and the deepest detected layer has a velocity of 1230 m/s (4035 ft/s). The depth to the first refractor is about 1.5 meters (5 ft), and the depth to the second refractor is about 6.5 m (21 ft). The first, slower, layer was interpreted as the weathered layer and the second layer was considered to be a change in the depositional flow banding.

2.3.2 Azimuthal velocity models

As previously discussed, most of the data developed by seismic refraction surveys have been used to develop depth models. These models do not show to directional, or azimuthal, dependence on ground motion characteristics. Dunkin and Levin (1971) developed a refraction model from a dipping interface, in which they develop expressions in terms of a three dimensional system when energy returning to the measurement site consists of reflections and refractions from planes. The model attempts to contour zones of constant velocities that are developed from the refraction from subsurface structures. The model indicates a distortion in the shape of polar plots of velocity around a source as a function of the dip of structures. The distortion is most evident for shallow structures with the velocity showing a marked reduction in this instance.

The use of an azimuthal model incorporating geologic structures on the mine operating scale is extremely important for the characterization of the site

for vibration control. Such a model would give insight into the control of potentially damaging surface waves from mine and construction blasting. Directional models can explain why ground motion levels and wave velocities will be higher in certain azimuthal directions than in others. Models using

Figure 4. Depth velocity model for Dicaperl Site (After Ness 1994).

azimuthal data may be incorporated into standard vibration control information for a blast site to further reduce the risks of damage to structures from ground motion.

CHAPTER 3

EXPERIMENTAL METHODS AND PROCEDURES

3.1 Instrumentation

The shots used in this experiment were monitored using acceleration and velocity geophones laid out in two concentric circles within the experimental pit as shown in Figure 5. Ground zero (GZ) is the location of the shot hole. A total of 200 channels of data were recorded for each experiment. The analysis shown in this report used 132 channels of this data. The inner ring consisted of 14 Terra Tek 5G three-component acceleration transducers, numbered 25-36, placed 20 m (65 ft) from the central shot point or ground zero at 30° intervals. The outer ring consisted of 24 Terra Tek 3G three-component acceleration transducers, numbered 1 through 24, placed 40 m (131 ft) from ground zero at 15 degree intervals. In addition, eight three-component velocity transducers, designated as D through K, were placed at intervals in the northern portion of the ring between the accelerometers. In order to ensure triggering of the velocity transducers, three additional transducers were placed closer to ground zero as follows: A at 6 m (20 ft), B at 14 m (46 ft) and C at 24 m (79 ft). Data from the velocity transducers were recorded on a Nomis seismograph with a sample rate of 1024 samples per second and 8-bit resolution. The Nomis instrument allows operation in a self-triggering mode. When set in scanning

Figure 5. Instrument Layout.

mode, the instrument continually senses one second of data. Once the predetermined triggering signal is sensed, the instrument begins to record the one second in memory (prior to the start of the ground motion equal to or greater than the trigger level) in addition to a selected waveform time interval. The instrument records for a time period of 5, 10, or 15 seconds. The self-trigger was set for this study to record at a ground motion at 0.1 inches per second or greater for all shots. The accelerometers were attached in pairs to separate 6 channel Reftek Data Acquisition units sampling at 500 samples per second. Each of these units was tied to the Global Positioning Satellite (GPS) timing system. This ensured that the time for each unit was synchronized.

Each transducer was placed on a grouted pad laid in a drilled hole approximately 0.15 m (0.5 ft) deep and secured with a sand covering to ensure proper coupling to the ground. In addition to the concentric rings, twenty 100 G accelerometers were placed at a depth of 10 m (30 ft) at ground zero. Data from the downhole accelerometers are not used in this analysis based on the limited applicability to azimuthal modeling.

3.2 Experimental Procedures

3.2.1 Shots

Three separate shots were initiated within a single borehole located at the center of the array. Pertinent data for the shots is summarized in Table 2. Each shot consisted of 56 kg (150 lbs) of Petrogel, a nitroglycerine based seismic explosive supplied by ICI explosives. Technical data for this product is shown in Table 3. The explosive was loaded into nalgene cylinders specially machined at Los Alamos National Labs (LANL) as shown in Figure 6. The explosives were hand-pressed into the cylinder to an average height of 0.47 m (1.55 ft) and approximately 0.30 m (1.0 ft) in diameter before being loaded into the borehole. The use of the loading containers ensured a uniform loading density for each shot.

Table 2. Summary of shot data

SHOT NUMBER	DEPTH	AVERAGE CHARGE HEIGHT
	m (ft)	m (ft)
14	83 (272)	0.46 (1.50)
15	63 (208)	0.47 (1.55)
16	10 (32)	0.47 (1.55)

Table 3. Technical data for explosive used for test blasts

Density	1.5 gm/cc
Velocity (open) 2 1/4"	6,096 m/s
Absolute Bulk Strength	1600 cal/cc
Relative Bulk Strength	217 (ANFO = 100)
Initiation Requirement	Electric Detonator

Figure 6. Explosive container.

After the explosive was loaded, a single #8 electric blasting cap was inserted and the container lid secured using machine screws. The cap's lead wires were attached to a spool of duplex blasting wire and the container was lowered to the appropriate depth using aircraft cable with a tensile strength of 222.4 KN (50,000 lb) . A winch attached to a 4-wheel drive vehicle was used to lower the assembly to the desired depth. Approximately 6.1 m (20.0 ft) of stemming consisting of drill cuttings was placed in the hole on top of the charge for each shot. The duplex wire was then hooked into a blaster's Macha box for initiation. The Macha box was used both as a cap initiating energy source and to produce a time zero initiation spike on the recording instrument. From this spike and the individual accelerometer tie-in via GPS, time zero for each recording system (other than the NOMIS) was then established.

3.2.2 Data Reduction

All data for the experiments was downloaded for use in the UNIX based version of the Seismic Analysis Code (SAC). SAC is a code developed by Lawrence Livermore Laboratories specifically for the detailed analysis of seismic data (Tapley, et al, 1991). The data was preprocessed in SAC at LANL. Preprocessing included corrections for timing, amplitude calibration, noise, and baseline offsets. All NOMIS velocity measurements were converted to acceleration by differentiating with respect to time and tied into accelerometer time zero.

The first arrival time of the P-wave for each transducer in all three shots was determined using a macro written by LANL personnel for SAC. Analysis was done at NMT on a SPARC 2 workstation. The macro was written to retrieve the vertical wave trace time history for each transducer and display it on the screen. The vertical trace was used for the analysis because the P-wave is contained in the vertical motion. The location of the waveform arrival was then chosen visually and marked using a cursor. The waveform could be magnified as needed to facilitate this process and to distinguish the true first arrival from noise. The marked times were copied to a file in SAC. Where the vertical component was unavailable because of recording problems, the radial or transverse component was used to evaluate arrival time. Each waveform was analyzed a number of times by three individuals to ensure accuracy and eliminate bias in a subjective process. Once consistent information was acquired, the times were converted to average velocities using the travel distance from each shot point center of gravity to each transducer. The travel distance, also referred to as slant distance, is the distance from the transducer on the surface to the shot location buried at some depth.

3.3 Geologic Mapping

Geologic information in the form of joint and fracture mapping was limited to surface evaluation prior to this project. After completion of all shots, a trench was excavated in an approximate North-South direction in order to retrieve the high G accelerometers that had been placed at depth in the same alignment near ground zero. The trench, shown in Figure 7, was prepared using a bulldozer with a ripper blade. This excavation proved to be a valuable resource for detailed mapping of the rock mass. After the trench was complete and the accelerometers retrieved, the east and west walls were sectioned into 10 m (30 ft) wide cells for mapping as shown in Figure 8. The cells were numbered 1 through 5 from south to north on the east wall and 6 through 8 from north to south on the west wall with cell 6 directly opposite cell 5. The area around ground zero on the west wall was avoided because of wall rock instability caused by explosive fracturing and undercutting of the wall by the excavating equipment. Strike and dip data for observed joints was taken randomly in each cell, with a minimum of 50 data points taken in each cell. Figures 9 through 11 show the method of data collection and the rock mass exposed in the excavation. Each plane was marked with spray paint as it was measured to ensure that there would be no duplication of data. Because of the geometry of the trench, the depth of the cells decreased away from ground zero yielding data from the rock mass close to the surface.

Figure 7. Excavation of trench used for geologic analysis.

Figure 8. Configuration of cells used for taking structural data.

Figure 9. Rock mass showing paint markings for reference.

Figure 10. Prominent joint with manganese staining evident.

Figure 11. View of trench from above showing highly fractured nature of rock mass and undulating nature of manganese staining

CHAPTER 4

RESULTS

4.1 Introduction

As noted in chapter 3, corrected data from all shots were analyzed for first arrivals using a macro written for the SAC code. In each case, the vertical component was used where possible as it is the most reliable trace for determination of time of arrival. Arrival times were chosen from the data available and are shown on Table 4. The table shows an "X" to indicate the component from which the arrival time was determined. Blank cells indicate unused or unavailable data. Complete time histories for each transducer are shown in Appendix A and the resulting data is shown in Appendix B. Data acquisition for each shot is summarized below.

4.1.1 Shot 14 (83 m (272 ft) depth)

Data acquisition for this shot was poor as several of the acceleration transducers failed to record data on any or all three components. Because of this, the data for this shot may be suspect. This is reflected in the summary shown in Table 4. The loss of data from this shot means that approximately 58% of the data is reliable while the remaining 42% is considered either unusable or

Table 4. Data Acquisition for all shots

STATION	SHOT								
	14			15			16		
	V	L	T	V	L	T	V	L	T
1	--	--	--	X	--	--	X	--	--
2	X	--	--	X	--	--	X	--	--
3	--	X	--	X	--	--	X	--	--
4	X	--	--	X	--	--	X	--	--
5	--	X	--	X	--	--	X	--	--
6	X	--	--	X	--	--	X	--	--
7	--	X	--	X	--	--	X	--	--
8	X	--	--	X	--	--	X	--	--
9	--	X	--	X	--	--	X	--	--
10	X	--	--	X	--	--	X	--	--
11	--	--	--	X	--	--	X	--	--
12	X	--	--	X	--	--	X	--	--
13	--	--	--	X	--	--	X	--	--
14	--	--	--	--	--	--	X	--	--
15	--	X	--	--	--	--	--	--	--
16	X	--	--	X	--	--	X	--	--
17	X	--	--	X	--	--	X	--	--
18	--	--	--	X	--	--	X	--	--
19	--	X	--	X	--	--	X	--	--
20	X	--	--	X	--	--	X	--	--
21	X	--	--	X	--	--	X	--	--
22	--	--	--	X	--	--	X	--	--
23	--	--	--	X	--	--	X	--	--
24	X	--	--	X	--	--	X	--	--
25	--	X	--	X	--	--	X	--	--
26	X	--	--	X	--	--	X	--	--
27	--	X	--	X	--	--	X	--	--
28	--	--	--	X	--	--	X	--	--
29	--	X	--	X	--	--	X	--	--
30	X	--	--	X	--	--	X	--	--
31	--	X	--	X	--	--	X	--	--
32	X	--	--	X	--	--	X	--	--
33	--	--	--	X	--	--	X	--	--
34	X	X	--	X	--	--	X	--	--
35	--	X	--	X	--	--	X	--	--
36	X	--	--	X	--	--	X	--	--
a	--	--	--	--	--	--	--	--	--
b	--	--	--	--	--	--	--	--	--
c	--	--	--	--	--	--	--	--	--
d	X	--	--	X	--	--	X	--	--
e	X	--	--	--	--	--	X	--	--
f	X	--	--	X	--	--	X	--	--
g	X	--	--	X	--	--	X	--	--
h	X	--	--	X	--	--	X	--	--
i	X	--	--	X	--	--	X	--	--
j	X	--	--	X	--	--	X	--	--
k	X	--	--	X	--	--	X	--	--

unreliable. In addition, station 24 had an odd trace that appears to be "truncated" and was unusable. There also was a timing error for stations 5 and 6 as the arrival times were far from realistic. These stations have been removed from the velocity model leaving only 53% of the stations giving reliable, vertical component information.

4.1.2 Shot 15 (63 m (208 ft) depth)

Shot 15 proved to be successful for data acquisition. All but three of the stations, E, 15 and 16, provided data for all three components of the ground motion. Unfortunately time zero for this shot was not available and could only be estimated. This affected the values computed for average velocity which, therefore, could not be taken as reliable. However, the data was useful when evaluating the overall trend in the average velocities with respect to azimuthal direction for this shot alone.

4.1.3 Shot 16 (10 m (32 ft) depth)

Data acquisition for this shot was excellent. Only two transducers were lost, A and 15. Station 24 provided unrealistic arrival times and appeared to have a timing error. This station was, therefore, not included in the velocity model.

4.2 Velocity Plots

The average velocity at each station was calculated by dividing the slant distance from the shot to the transducer by the first arrival times picked from each trace. These velocities were then plotted against the station's azimuth with respect to north (0° or 360°) as measured from ground zero. Plots showing all stations are given in Figures 12 and 13 for the outer and inner instrumented rings respectively. These plots indicate a variation in velocities dependent on the location of the station with respect to the shot. The variation is subtle for the deeper shots 14 and 15 but is more apparent for the shallow shot 16. The less regular variation exhibited by shots 14 and 15 are felt to be caused by both the lack of reliable data for these shots and by the travel path of the deeper shots. A deeper shot will have a travel path consisting of varying material with irregular thicknesses in different areas while the waves from the shallower shot travel through the more uniform surface material. For shot 16, the velocities are approximately 850 m/s (2789 ft/s) for the outer ring from 330° to 5° . They become markedly lower at 70° and 235° ranging from 590 to 610 m/s (1936 to 2001 ft/s) for the outer ring. The inner ring shows a similar pattern with a slight shift in the velocities for shot 15. The velocities dip at 190° and rise at 280° for this shot in the inner ring.

Figures 14 and 15 show the average velocities plotted in a polar form as laid out in the field. The variation in velocity is again most apparent for the shallowest shot 16 which shows higher velocity in the northwest-southeast

ALL SHOTS - OUTER RING

Figure 12. Average velocity versus azimuth for outer ring from all shots.

ALL SHOTS - INNER RING

Figure 13. Average velocity versus azimuth for inner ring from all shots.

Figure 14. Polar plot of average velocity for outer ring from all shots.

Figure 15. Polar plot of average velocity from for inner ring from all shots.

direction as indicated in the previous plots. The velocity is much slower to the northeast and to the southwest.

The variations in velocities indicate a definite influence related to the rock mass properties and/or anisotropy within the system. The lack of clear variation in the velocities for the deeper shots is likely due to the travel paths of the waves as discussed in section 4.2. Based on shot behavior shown in Figures 12 and 13, shot 15 indicates either the presence of a low velocity zone below the depth of the shot or a timing error generated from an estimated shot break. The shot break was estimated using the available data and it is possible that an error was incorporated into the estimate throwing the timing for the entire shot off. In the absence of a low velocity layer, the average velocity of this shot should be less than the average for shot 14 as shot 15 is shallower but the opposite is true here. The relative values of average velocities among the three shots, however, are not as important as the consistency noted in the azimuthal trends. Therefore, this abnormality has relatively little consequence. The average velocities for shot 15 should not be used for any analysis outside this report until the reason for the abnormality is clear.

4.3 Structural Analysis

4.3.1 Rose Diagrams

Information from geologic mapping was first compiled using rose diagrams presented in Figures 16 through 24 which show the strike of the joints mapped within the excavated trench with no dip indicated. Strike and dip data is presented in Appendix C. As noted previously in the description of geologic structure, the trench was mapped in eight 10 m (30 ft) cells. The data from each cell is represented by a separate rose diagram shown in Figures 16 through 23. Figure 24 is a rose diagram showing the combined data from all cells. All diagrams with the exception of cells 4 and 8 show a dominant joint strike to the northeast between 0° and 20° and southeast at approximately 140° . Cells 4 and 8 show a more random orientation of data which is an indication of the variability of the rock. A notable pattern can also be seen in the strikes from south to north within the trench. The diagrams show a change in the predominant strike moving north along the mapping area. Cell 1 shows a dominant strike from 20° to 30° which shifts to a more north-south orientation in cells 2-5.

The composite diagram shown in Figure 24 shows an overall dominant strike ranging from 0° to 10° and a secondary set at 140° . This dominant orientation roughly correlates with the velocity orientations discussed in section 4.2. A more precise correlation might be found using more detailed examination

GRECO TEST EXCAVATION CELL 1

Calculation Method Equal Area
 Class Interval 5 Degrees
 Filtering Deactivated
 Data Type Unidirectional
 Rotation Amount 0.0 Degrees
 Population 50
 Maximum Percentage 14.0 Percent
 Mean Percentage 4.0 Percent
 Standard Deviation 2.89 Percent
 Vector Mean 158.47 Degrees
 Confidence Interval 48.28 Degrees
 R-mean 0.23

Figure 16. Rose Diagram of Test Cell 1.

GREFCO TEST EXCAVATION CELL 2

Calculation Method . . . Equal Area
 Class Interval . . . 5 Degrees
 Filtering . . . Deactivated
 Data Type . . . Unidirectional
 Rotation Amount . . . 0.0 Degrees
 Population . . . 54
 Maximum Percentage . . 9.3 Percent
 Mean Percentage . . . 3.3 Percent
 Standard Deviation . . 2.14 Percent
 Vector Mean . . . 129.75 Degrees
 Confidence Interval . . 59.09 Degrees
 R-mag . . . 0.18

Figure 17. Rose Diagram of Test Cell 2.

GREFCO TEST EXCAVATION CELL 3

Calculation Method . . . Equal Area
 Class Interval . . . 5 Degrees
 Filtering . . . Deactivated
 Data Type . . . Unidirectional
 Rotation Amount . . . 0.0 Degrees
 Population . . . 46
 Maximum Percentage . . . 17.4 Percent
 Mean Percentage . . . 5.0 Percent
 Standard Deviation . . . 4.63 Percent
 Vector Mean . . . 52.22 Degrees
 Confidence Interval . . . 39.57 Degrees
 R-mag . . . 0.29

Figure 18. Rose Diagram of Test Cell 3.

GREFCO TEST EXCAVATION CELL 4

Calculation Method	Equal Area
Class Interval	5 Degrees
Filtering	Deactivated
Data Type	Unidirectional
Rotation Amount	0.0 Degrees
Population	25
Maximum Percentage	12.0 Percent
Mean Percentage	5.0 Percent
Standard Deviation	2.20 Percent
Vector Mean	118.71 Degrees
Confidence Interval	141.50 Degrees
R-mag	0.11

Figure 19. Rose Diagram of Test Cell 4.

GRECO TEST EXCAVATION CELL 5

Calculation Method . . . Equal Area
 Class Interval 5 Degrees
 Filtering Deactivated
 Data Type Unidirectional
 Rotation Amount 0.0 Degrees
 Population 57
 Maximum Percentage . . . 14.9 Percent
 Mean Percentage 2.7 Percent
 Standard Deviation . . . 2.43 Percent
 Vector Mean 141.46 Degrees
 Confidence Interval . . . 50.18 Degrees
 R-meag 0.19

Figure 20. Rose Diagram of Test Cell 5.

GREFCO TEST EXCAVATION CELL 6

Calculation Method ... Equal Area
 Class Interval ... 5 Degrees
 Filtering ... Deactivated
 Data Type ... Unidirectional
 Rotation Amount ... 0.0 Degrees
 Population ... 52
 Maximum Percentage ... 15.4 Percent
 Mean Percentage ... 3.4 Percent
 Standard Deviation ... 2.79 Percent
 Vector Mean ... 67.61 Degrees
 Confidence Interval ... 52.25 Degrees
 R-sq ... 0.21

Figure 21. Rose Diagram of Test Cell 6.

GREFCO TEST EXCAVATION CELL 7

Calculation Method : Equal Area
 Class Interval : 5 Degrees
 Filtering : Deactivated
 Data Type : Unidirectional
 Rotation Amount : 0.0 Degrees
 Population : 48
 Maximum Percentage : 16.7 Percent
 Mean Percentage : 4.0 Percent
 Standard Deviation : 3.12 Percent
 Vector Mean : 100.31 Degrees
 Confidence Interval : 75.35 Degrees
 R-sag : 0.15

Figure 22. Rose Diagram of Test Cell 7.

GREFCO TEST EXCAVATION CELL 8

Calculation Method Equal Area
 Class Interval 5 Degrees
 Filtering Deactivated
 Data Type Unidirectional
 Rotation Amount 0.0 Degrees
 Population 41
 Maximum Percentage .. 9.9 Percent
 Mean Percentage 3.3 Percent
 Standard Deviation ... 1.75 Percent
 Vector Mean 97.18 Degrees
 Confidence Interval .. 43.20 Degrees
 R-mag 0.28

Figure 23. Rose Diagram of Test Cell 8.

GREFCO TEST EXCAVATION CELLS 1-8

Calculation Method	Equal Area
Class Interval	5 Degrees
Filtering	Deactivated
Data Type	Unidirectional
Rotation Amount	0.0 Degrees
Population	383
Maximum Percentage	7.6 Percent
Mean Percentage	1.5 Percent
Standard Deviation	1.49 Percent
Vector Mean	106.43 Degrees
Confidence Interval	23.78 Degrees
R-mag	0.17

Figure 24. Rose Diagram of All Test Cells.

of the structure orientation that includes the dip and the dip direction in addition to the strike of the structure. For this reason, spherical projection was used to further refine the analysis.

4.3.2 Spherical projections of Joint Orientations

4.3.2.1 Overview of Spherical projections

Spherical projection using stereonets is a method used frequently by geologists and engineers to project three dimensional rock mass information into one dimension for interpretation. Figure 25 shows a sphere with one quarter removed showing the relationship between meridional and polar nets.

Meridional nets are used for the analysis which follows this discussion. The two types of projection used to generate the nets: equal area and equal angle are illustrated in Figure 26. Both types of projection are used for the analysis of structural data but the Schmitt or equal area net is preferred for analyzing statistical relationships between data points.

Spherical or stereographic projections are used to illustrate planes such as joints or faults within a rock mass. The inclination and orientation of an inclined plane are defined by the great circles on the projection. The great circles run from the north pole of the net to the south pole and occur in 2° intervals. The projection of the plane onto the spherical projection is illustrated in Figure 27 and can be explained by imagining a sphere which is centered on an inclined plane. The intersection of the plane and the surface of the sphere

Figure 25. Sectional view of a sphere showing the relationship between meridional and polar nets (After Hoek and Brown, 1982).

Figure 26. Methods of stereographic projection (After Hoek and Brown, 1982).

Figure 27. Definition and orientation of an inclined plane using stereographic projection (After Hoek and Brown, 1982).

forms a great circle. A line passing through the center of the sphere perpendicular to the plane touches the sphere at opposite points which are called the poles of the great circle representing the plane. Since the same information appears on both halves of the sphere, only one is used for the projection. The lower projection is the more commonly used and is used for this analysis. The terms used for analysis of structural data as they appear on projections are illustrated in Figure 28. When plotting large numbers of data, it

Figure 28. Illustration of terms used in stereographic projection (After Hoek and Brown, 1982).

is more convenient to plot the poles of planes as the relative concentrations of data may be more readily determined from these poles.

4.3.2.2 Results

The results of the stereographic analysis of the structural data are shown on Figures 29 and 30. Poles of the planes mapped in the field were plotted on a standard equal area or Schmitt net and their densities were calculated using a step function gridding algorithm provided by Rockware's Stereo software. The grid is developed by calculating the numerical densities of the poles after they have been projected onto the stereonet. An imaginary grid of 67 X 67 cells is placed over the stereonet and each node of the grid acts as a counting station

GREFCO TEST EXCAVATION CELLS 1-8

Projection	Schmidt
Number of Sample Points	383

- Cell *1
- △ Cell *2
- + Cell *3
- Cell *4
- × Cell *5
- ⊕ Cell *6
- ◇ Cell *7
- ◆ Cell *8

Figure 29. Stereographic projection showing the poles of planes for all mapping cells

GREFCO TEST EXCAVATION CELLS 1-8

Figure 30. Stereographic projection showing prominent joint orientations (strikes, dips) for all mapping cells

which is incremented by a whole integer if a point lies within a chosen circular area around it. The size of the circle chosen for these stereonet was 1% of the total area of the stereonet. The number of points affecting each grid node are counted and converted to a percentage of the total number of points resulting in the density plot.

The most prominent joint set within the system occurs at approximately 8° strike and 60° dip as indicated by the darkest shading on the density map (Figure 30). A secondary set occurs at 150° strike and 62° dip. The planes representing these joint orientations are depicted on the density plot shown on Figure 30 and are taken from the center point of the density area. The standard error on field measurements such as these is approximately $\pm 10^\circ$ for strike and $\pm 5^\circ$ for dip.

The orientation of both the primary and the secondary joint sets corresponds well with the direction of increased velocity shown on Figures 12 through 15. These plots indicate that the velocity reaches a peak between 130° and 190° and 330° and 5° for shot 16 particularly in the case of the outer ring of instruments. This increased velocity correlates well with the line of strike for either joint set (150° and 5° respectively) given the $\pm 10^\circ$ margin for error.

The reason for the increased velocity in the direction of the most prominent joint set may be tied directly to the motion of the P-wave itself. Since the motion of the wave is compressional, as it moves against the joint, the gap formed by the joint planes is forced to open and close in response to the particle

Figure 31. Ground motion time histories for shot 14, outer ring layout showing relative arrival times and amplitudes of ground motion.

Figure 32. Ground motion time histories for shot 14, inner ring layout showing relative arrival times and amplitudes of ground motion.

Figure 33. Ground motion time histories for shot 15, outer ring layout showing relative arrival times and amplitudes of ground motion.

Figure 34. Ground motion time histories for shot 15, inner ring layout showing relative arrival times and amplitudes of ground motion.

Figure 35. Ground motion time histories for shot 16, outer ring layout showing relative arrival times and amplitudes of ground motion.

Figure 36. Ground motion time histories for shot 16, inner ring layout showing relative arrival times and amplitudes of ground motion.

times and peak particle motions. Blast waves traveling in the direction of predominant joint strikes and nearly parallel to dip show the greatest arrival time and relative amplitudes. The slowest waves tend to produce the lowest amplitudes in azimuthal directions away from predominant joints and in travel directions nearly perpendicular to joint dips. It is anticipated that these differences may extend to farther distances away from the blast than those analyzed for this study. This site-specific relationship may be significant for large scale blasting in other geologies when structures exist nearby and may help to explain why mine and construction operators frequently receive more complaints from neighbors in one direction than in another.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Summary

A series of three small scale test blasts were initiated in a test pit located at the Dicaperl perlite mine west of Socorro, NM. The tests were instrumented using three component velocity and acceleration transducers arranged in two concentric rings in order to investigate the effect that geologic features and rock mass properties have on the propagation velocities of blast induced ground vibrations. The influence of the fabric and structure of the rock mass on the propagation and intensity of ground motion from blasting operations has not been widely investigated for the purposes of vibration control and compliance with Federal regulations. A clear understanding of the process of ground motion propagation and the factors which influence this process is vital to the blasting engineer and vibration control specialist. Knowledge of the site specific controls influencing ground vibration may aid the engineer in reducing the intensity of ground motion thereby reducing the risks of litigation and complaints and improving public relations efforts.

5.2 Conclusions

The influence of geologic structure on the propagation velocity of ground motion in perlite has been clearly shown throughout this study. Prominent joint sets tend to increase the propagation velocity of blast induced ground motion in perlite. In this case, the rock mass was highly fractured as shown by the scatter of data when presented in stereographic projection. This study found that, despite the large range of joint and fracture orientations, the direction of increased propagation velocity clearly occurred between the two most prominent joint sets. This is a site specific phenomenon and the results of this investigation may not be applied globally to all blasting situations. The structural effects should be similar everywhere, however, and should be used on a site specific basis to model areas where blasting is to occur on a regular basis and the chance for complaints or structural damage exists. It is vital to understand this phenomenon when blasting in the vicinity of structures or neighbors so that ground vibration may be more accurately predicted and preventative measures taken to avoid damage to structures and complaints resulting from annoyance. It appears, from the results of this study, that damage and complaints may be more probable along the line of strike of prominent structures and less likely, but certainly not impossible, away from prominent structures. This is a preliminary conclusion, and more information is necessary to confirm or disprove it. Certainly, the data presented in this report applies to close in blasting such as used in construction and does nothing to describe the effects of surface waves

which develop at a distance equal to about three times the depth of burial of the explosive charge.

One vital conclusion that may be drawn from this analysis is that the amplitudes of ground motion may also vary with direction. This is an extremely important step in the understanding of the variability in blast induced ground motion.

5.3 Recommendations

A great deal of further study is required to fully understand the effects of geologic structures on ground motion. The peak particle velocities of the motion in an azimuthal array similar to that studied here should be analyzed in order to tie the data into current federal regulations. This investigation indicates that the peak particle velocities may be correlated to the propagation velocities as the two are related as discussed in chapter 2 and shown on figures 35 and 36. Most importantly, the attenuation properties of ground vibration should be studied to determine if there is a predictable distance from the blast at which ground motion stops varying azimuthally. The surface waves which develop are the most damaging at large distances and should be studied to determine if the same effect is apparent in the far field. Frequency changes and the dispersion characteristics of the wave train should also be analyzed and compared with the azimuth. Finally, additional testing should be done using full scale mine or

construction blasts to determine the effects of delay timing and large quantities of explosives on the ground motion.

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APPENDIX A

TIME HISTORIES FOR SHOTS 14, 15, AND 16, ALL STATIONS

DicaPerl Phase 2 - Shot 14 - Station e

DicaPerl Phase 2 - Shot 14 - Station k

DicaPerl Phase 2 - Shot 14 - Station 2

DicaPerl Phase 2 - Shot 14 - Station 8

DicaPerl Phase 2 - Shot 14 - Station 9

DicaPerl Phase 2 - Shot 14 - Station 10

DicaPerl Phase 2 - Shot 14 - Station 12

DicaPerl Phase 2 - Shot 14 - Station 16

DicaPerl Phase 2 - Shot 14 - Station 25

DicaPerl Phase 2 - Shot 14 - Station 32

DicaPerl Phase 2 - Shot 14 - Station 33

DicaPerl Phase 2 - Shot 14 - Station 34

DicaPerl Phase 2 - Shot 14 - Station 36

DicaPerl Phase 2 - Shot 15 - Station a

DicaPerl Phase 2 - Shot 15 - Station c

DicaPerl Phase 2 - Shot 15 - Station i

DicaPerl Phase 2 - Shot 15 - Station 1

DicaPerl Phase 2 - Shot 15 - Station 2

DicaPerl Phase 2 - Shot 15 - Station 3

DicaPerl Phase 2 - Shot 15 - Station 7

DicaPerl Phase 2 - Shot 15 - Station 8

DicaPerl Phase 2 - Shot 15 - Station 9

DicaPerl Phase 2 - Shot 15 - Station 12

DicaPerl Phase 2 - Shot 15 - Station 13

DicaPerl Phase 2 - Shot 15 - Station 17

DicaPerl Phase 2 - Shot 15 - Station 18

DicaPerl Phase 2 - Shot 15 - Station 19

DicaPerl Phase 2 - Shot 15 - Station 21

DicaPerl Phase 2 - Shot 15 - Station 22

DicaPerl Phase 2 - Shot 15 - Station 24

DicaPerl Phase 2 - Shot 15 - Station 25

DicaPerl Phase 2 - Shot 15 - Station 26

DicaPerl Phase 2 - Shot 15 - Station 27

DicaPerl Phase 2 - Shot 15 - Station 28

DicaPerl Phase 2 - Shot 15 - Station 29

DicaPerl Phase 2 - Shot 15 - Station 30

DicaPerl Phase 2 - Shot 15 - Station 31

DicaPerl Phase 2 - Shot 15 - Station 32

DicaPerl Phase 2 - Shot 15 - Station 33

DicaPerl Phase 2 - Shot 15 - Station 34

DicaPerl Phase 2 - Shot 15 - Station 35

DicaPerl Phase 2 - Shot 15 - Station 36

DicaPerl Phase 2 - Shot 16 - Station b

DicaPerl Phase 2 - Shot 16 - Station e

DicaPerl Phase 2 - Shot 16 - Station f

DicaPerl Phase 2 - Shot 16 - Station g

DicaPerl Phase 2 - Shot 16 - Station h

DicaPerl Phase 2 - Shot 16 - Station k

DicaPerl Phase 2 - Shot 16 - Station 2

DicaPerl Phase 2 - Shot 16 - Station 3

DicaPerl Phase 2 - Shot 16 - Station 8

DicaPerl Phase 2 - Shot 16 - Station 9

DicaPerl Phase 2 - Shot 16 - Station 10

DicaPerl Phase 2 - Shot 16 - Station 11

DicaPerl Phase 2 - Shot 16 - Station 12

DicaPerl Phase 2 - Shot 16 - Station 13

DicaPerl Phase 2 - Shot 16 - Station 14

DicaPerl Phase 2 - Shot 16 - Station 15

DicaPerl Phase 2 - Shot 16 - Station 16

DicaPerl Phase 2 - Shot 16 - Station 17

DicaPerl Phase 2 - Shot 16 - Station 18

DicaPerl Phase 2 - Shot 16 - Station 20

DicaPerl Phase 2 - Shot 16 - Station 22

DicaPerl Phase 2 - Shot 16 - Station 23

DicaPerl Phase 2 - Shot 16 - Station 24.

DicaPerl Phase 2 - Shot 16 - Station 25

DicaPerl Phase 2 - Shot 16 - Station 26

DicaPerl Phase 2 - Shot 16 - Station 27

DicaPerl Phase 2 - Shot 16 - Station 28

DicaPerl Phase 2 - Shot 16 - Station 29

DicaPerl Phase 2 - Shot 16 - Station 31

DicaPerl Phase 2 - Shot 16 - Station 33

DicaPerl Phase 2 - Shot 16 - Station 34

DicaPerl Phase 2 - Shot 16 - Station 35

DicaPerl Phase 2 - Shot 16 - Station 36

APPENDIX B

FIRST ARRIVAL TIMES FOR ALL SHOTS

SHOT 14 - ALL PICKS

SHOT #	STATION	AZIMUTH	SLANT RANGE (m)	1ST PICK TOA (s)	2ND PICK TOA (s)	3RD PICK TOA (s)	AMPLITUDE MAX 1 (cm/s^2)	AMPLITUDE MIN 1 (cm/s^2)	1ST PICK VELOCITY (m/s)	2ND PICK VELOCITY (m/s)	3RD PICK VELOCITY (m/s)	DEPTH OF SHOT (m)	HORIZONTAL DISTANCE (m)
14	A	302	82.89	0.064676			1237.50	-1081.50	1267.57	N/A	N/A	82.67	6
	B	302	83.85	0.063880			998.32	-873.53	1372.56	N/A	N/A		
	C	302	86.08	0.064795			759.14	-1080.70	1328.54	N/A	N/A		
	D	287	89.77	0.063661	0.063727		395.17	-467.96	1410.18	1408.72	N/A		
	E	302	89.77	N/A			N/A	N/A	N/A	N/A	N/A		
	F	317	89.77	0.068148			935.93	-935.93	1317.33	N/A	N/A		
	G	332	89.77	0.070631			1216.70	-998.32	1271.02	N/A	N/A		
	H	347	89.77	0.068639			1050.30	-998.32	1307.90	N/A	N/A		
	I	2	89.77	0.067538			925.53	-790.34	1329.22	N/A	N/A		
	J	17	89.77	0.066723			987.92	-935.93	1345.46	N/A	N/A		
	K	32	89.77	0.068560			769.54	-852.73	1309.41	N/A	N/A		
	L	9.5	89.77	N/A			N/A	N/A	N/A	N/A	N/A		
	M	24.5	89.77	0.059349	0.060208	0.059504	1086.50	-1181.70	1512.63	1491.05	1508.69		
	N	39.5	89.77	0.067455			257.79	-246.23	1330.86	N/A	N/A		
	O	54.5	89.77	0.070476	0.070136		388.01	-518.42	1273.81	1279.99	N/A		
	P	69.5	89.77	0.100460	0.098424	0.099163	64.41	-296.75	893.62	912.11	905.31		
	Q	84.5	89.77	0.096377	0.098096	0.097980	506.34	-549.65	931.48	915.16	916.24		
	R	99.5	89.77	0.068554			128.30	-61.33	1348.88	N/A	N/A		
	S	114.5	89.77	0.065481			400.84	-281.81	1370.98	N/A	N/A		
	T	129.5	89.77	0.068474			143.92	-132.84	1311.06	N/A	N/A		
	U	144.5	89.77	0.068548			744.46	-986.21	1309.64	N/A	N/A		
	V	159.5	89.77	N/A			N/A	N/A	N/A	N/A	N/A		
	W	174.5	89.77	0.072452	0.072124		1040.50	-1584.60	1239.07	1244.71	N/A		
	X	189.5	89.77	N/A			N/A	N/A	N/A	N/A	N/A		
	Y	204.5	89.77	N/A			N/A	N/A	N/A	N/A	N/A		
	Z	219.5	89.77	0.067268			75.59	-132.94	1334.56	N/A	N/A		
	AA	234.5	89.77	0.066439			1117.00	-1241.00	1351.21	N/A	N/A		
	AB	249.5	89.77	0.066285			505.34	-657.58	1354.35	N/A	N/A		
	AC	264.5	89.77	N/A			N/A	N/A	N/A	N/A	N/A		
	AD	279.5	89.77	0.063409	0.063506		102.66	-185.79	1415.78	1413.62	N/A		
	AE	294.5	89.77	0.066576			737.78	-1222.10	1348.43	N/A	N/A		
	AF	309.5	89.77	0.070418			1682.70	-2191.10	1274.86	N/A	N/A		
	AG	324.5	89.77	N/A			N/A	N/A	N/A	N/A	N/A		
	AH	339.5	89.77	N/A			N/A	N/A	N/A	N/A	N/A		
	AI	354.5	89.77	0.079892	0.081119	0.081116	2592.80	-125.46	1123.68	1106.69	1106.73		
	25	9.5	85.05	0.063373			173.49	-36.61	1342.12	N/A	N/A	82.67	20
	26	39.5	85.05	0.062387			654.48	-958.47	1363.33	N/A	N/A		
	27	69.5	85.05	0.064403			102.22	-189.94	1320.66	N/A	N/A		
	28	99.5	85.05	0.062374			635.54	-814.96	1363.62	N/A	N/A		
	29	129.5	85.05	0.064041			101.35	49.78	1328.12	N/A	N/A		
	30	159.5	85.05	0.062454			488.40	-650.99	1361.87	N/A	N/A		
	31	189.5	85.05	0.065184			11.54	-14.81	1304.83	N/A	N/A		
	32	219.5	85.05	0.060512			577.60	-897.24	1405.58	N/A	N/A		
	33	249.5	85.05	0.061359			0.67	-42.38	1386.17	N/A	N/A		
	34	279.5	85.05	0.062354			528.78	-615.66	1364.05	N/A	N/A		
	35	309.5	85.05	0.061486			230.40	-378.48	1383.31	N/A	N/A		
	36	339.5	85.05	0.063715			998.98	-1404.40	1334.92	N/A	N/A		

SHOT 15 - ALL PICKS

SHOT #	STATION	AZIMUTH	SLANT RANGE (m)	1ST PICK TOA (s)	2ND PICK TOA (s)	3RD PICK TOA (s)	4TH PICK TOA (s)	AMPLITUDE MAX 1 (cm/s ²)	AMPLITUDE MIN 1 (cm/s ²)	1ST PICK VELOCITY (m/s)	2ND PICK VELOCITY (m/s)	3RD PICK VELOCITY (m/s)	4TH PICK VELOCITY (m/s)	DEPTH OF SHOT (m)	HORIZONTAL DISTANCE (m)	
15	A	302	63.45	0.045364	0.043597			790.34	-831.93	1398.61	1455.30	N/A	N/A	63.16	6	
	B	302	63.16	0.042771	0.044436			644.75	-634.35	1476.75	1421.42	N/A	N/A		14	
	C	302	64.70	0.044567	0.046528			447.16	-603.15	1451.64	1390.46	N/A	N/A		24	
	D	287	72.21	0.044551	0.044534	0.044496		176.79	-187.19	1620.87	1621.49	1622.87	N/A		35	
	E	302	72.21	N/A				N/A	N/A	N/A	N/A	N/A	N/A			
	F	317	72.21	0.047405	0.048409			384.77	-447.16	1523.28	1481.50	N/A	N/A			
	G	332	72.21	0.047355	0.048469			571.95	-613.55	1524.89	1459.73	N/A	N/A			
	H	347	72.21	0.047458	0.048437			436.77	-467.96	1521.65	1480.67	N/A	N/A			
	I	2	72.21	0.048404	0.048493			447.16	-426.37	1556.14	1489.11	N/A	N/A			
	J	17	72.21	0.047483	0.048266			447.16	-530.36	1520.78	1465.74	N/A	N/A			
	K	32	72.21	0.050404	0.052392	0.050367		426.37	-686.35	1432.65	1378.29	1433.70	N/A			
	L	9.5	72.21	0.044442	0.044943			377.80	-576.76	1624.84	1606.73	N/A	N/A			
	M	2	72.21	0.049989	0.050125			425.34	-801.84	1444.54	1440.62	N/A	N/A			
	N	39.5	72.21	0.049164	0.050141			390.92	-796.02	1468.78	1440.18	N/A	N/A			
	O	4	72.21	0.052756	0.053026	0.053988		330.92	-497.48	1368.78	1361.81	1338.04	N/A			
	P	5	69.5	72.21	0.053418	0.054724	0.053731	0.053529	300.10	-407.33	1351.81	1319.55	1343.94	1349.01		
	Q	6	84.5	72.21	0.053390	0.052978	0.050874	0.050515	385.69	-569.17	1352.52	1363.04	1425.02	1429.50		
	R	7	99.5	72.21	0.049872	0.050985			291.58	-319.43	1447.93	1418.32	N/A	N/A		
	S	8	114.5	72.21	0.051197	0.051017			386.98	-513.50	1410.46	1415.43	N/A	N/A		
	T	9	129.5	72.21	0.048462	0.048319			412.38	-561.40	1554.20	1494.47	N/A	N/A		
	U	10	144.5	72.21	0.048828	0.048991			639.48	-865.74	1478.89	1473.97	N/A	N/A		
	V	11	159.5	72.21	0.047033	0.044926		0.047973	427.95	-627.18	1535.33	1607.34	N/A	1605.25		
	W	12	174.5	72.21	0.052934	0.054333	0.054368		749.91	-1292.80	1384.17	1329.05	1328.19	N/A		
	X	13	189.5	72.21	0.050067	0.050508	0.051823	0.050941	246.20	-377.46	1442.29	1429.70	1393.42	1417.55		
	Y	14	204.5	72.21	0.051067	0.052549	0.052958	0.052426	476.01	-927.07	1414.05	1374.17	1363.56	1377.39		
	Z	15	219.5	72.21	N/A				N/A	N/A	N/A	N/A	N/A	N/A		
	AA	16	234.5	72.21	N/A				N/A	N/A	N/A	N/A	N/A	N/A		
	AB	17	249.5	72.21	0.041137	0.042803	0.043212	0.042610	194.83	-175.46	1755.38	1687.06	1671.09	1694.70		
	AC	18	264.5	72.21	0.042861	0.042490	0.043055	0.043344	366.43	-652.90	1684.78	1699.49	1677.19	1688.00		
	AD	19	279.5	72.21	0.043447	0.044109	0.044358	0.044223	197.30	-221.84	1662.05	1637.11	1627.99	1632.89		
	AE	20	294.5	72.21	0.046881	0.045008	0.048294	0.046968	317.59	-474.59	1540.31	1604.41	1495.24	1537.46		
	AF	21	309.5	72.21	0.048432	0.048483			471.13	-687.77	1490.98	1489.41	N/A	N/A		
	AG	22	324.5	72.21	0.048856	0.049516			676.38	-1088.60	1478.04	1458.34	N/A	N/A		
	AH	23	339.5	72.21	0.046204	0.046777			509.77	-543.64	1562.88	1543.73	N/A	N/A		
	AI	24	354.5	72.21	0.048034	0.048219			370.64	-388.58	1503.34	1497.57	N/A	N/A		
	AJ	25	9.5	66.25	0.044134	0.042958			647.05	-501.87	1501.18	1542.27	N/A	N/A	63.16	20
	AK	26	39.5	66.25	0.042133	0.042996			456.40	-652.83	1572.47	1540.91	N/A	N/A		
	AL	27	69.5	66.25	0.042359	0.044443			358.60	-660.83	1564.08	1490.74	N/A	N/A		
	AM	28	99.5	66.25	0.041634	0.044138			589.23	-775.29	1591.32	1501.04	N/A	N/A		
	AN	29	129.5	66.25	0.040410	0.041039	0.041040		522.14	-709.19	1639.52	1614.39	1614.35	N/A		
	AO	30	159.5	66.25	0.040350	0.042436	0.042786		366.81	-474.59	1641.96	1561.25	1548.47	N/A		
	AP	31	189.5	66.25	0.046151	0.046355	0.046376		403.85	-843.17	1435.57	1429.25	1428.61	N/A		
	AQ	32	219.5	66.25	0.042057	0.042900			330.22	-583.72	1575.31	1544.38	N/A	N/A		
	AR	33	249.5	66.25	0.040123	0.041116	0.040321		298.35	-416.70	1651.25	1611.37	1643.14	N/A		
	AS	34	279.5	66.25	0.040281	0.042224	0.041504		335.50	-457.58	1645.59	1569.08	1596.30	N/A		
	AT	35	309.5	66.25	0.042697	0.043789			463.08	-567.79	1551.70	1513.01	N/A	N/A		
	AV	36	339.5	66.25	0.045450	0.047800	0.047314		585.61	-999.99	1457.71	1386.05	1400.28	N/A		

SHOT 16 - ALL PICKS

SHOT #	STATION	AZIMUTH	SLANT RANGE (m)	1ST PICK TOA (s)	2ND PICK TOA (s)	AMPLITUDE MAX 1 (cm/s^2)	AMPLITUDE MIN 1 (cm/s^2)	1ST PICK VELOCITY (m/s)	2ND PICK VELOCITY (m/s)	DEPTH OF SHOT (m)	HORIZONTAL DISTANCE (m)
16	A	302	11.25	N/A		N/A	N/A	N/A	N/A	9.52	6
	B	302	16.93	0.031262	0.029841	7497.80	-10129.00	541.51	567.30		
	C	302	25.82	0.037498		727.94	-925.53	688.52	N/A		
	D	287	36.27	0.056033		103.99	-311.98	647.31	N/A		
	E	302	36.27	0.051210		291.18	-343.17	708.28	N/A		
	F	317	36.27	0.045360		447.16	-426.37	799.62	N/A		
	G	332	36.27	0.042420		1403.90	-852.73	855.04	N/A		
	H	347	36.27	0.042373		3816.50	-1143.90	855.99	N/A		
	I	2	36.27	0.042430		1071.10	-852.73	854.84	N/A		
	J	17	36.27	0.048302		488.76	-592.75	750.92	N/A		
	K	32	36.27	0.052146		197.58	-405.57	695.56	N/A		
	1	9.5	36.27	0.048049	0.045175	459.95	-797.62	754.87	802.90		
	2	24.5	36.27	0.052057		310.46	-655.39	696.75	N/A		
	3	39.5	36.27	0.053766		158.21	-498.45	674.61	N/A		
	4	54.5	36.27	0.056069		97.39	-367.32	646.90	N/A		
	5	69.5	36.27	0.062024	0.060420	94.16	-291.03	584.79	600.31		
	6	84.5	36.27	0.059690		141.99	-337.40	607.66	N/A		
	7	99.5	36.27	0.054492		174.52	-375.95	665.62	N/A		
	8	114.5	36.27	0.054408		368.31	-531.84	666.65	N/A		
	9	129.5	36.27	0.051945		298.04	-516.05	698.26	N/A		
	10	144.5	36.27	0.052035		635.02	-920.87	697.05	N/A		
	11	159.5	36.27	0.048261	0.046409	343.45	-693.27	751.56	781.55		
	12	174.5	36.27	0.050821		907.25	-1141.50	713.70	N/A		
	13	189.5	36.27	0.048574		504.07	-469.38	746.71	N/A		
	14	204.5	36.27	0.056313		672.17	-919.37	644.10	N/A		
	15	219.5	36.27	N/A		N/A	N/A	N/A	N/A		
	16	234.5	36.27	0.059024		163.55	-528.74	614.51	N/A		
	17	249.5	36.27	0.054261		79.24	-207.13	668.45	N/A		
	18	264.5	36.27	0.055768		96.80	-318.03	650.39	N/A		
	19	279.5	36.27	0.054282		65.81	-203.26	668.19	N/A		
	20	294.5	36.27	0.054750		367.67	-643.92	662.48	N/A		
	21	309.5	36.27	0.049929		430.44	-623.75	726.45	N/A		
	22	324.5	36.27	0.046148		856.28	-1002.10	785.97	N/A		
	23	339.5	36.27	0.043898		137.79	-1516.90	826.25	N/A		
	24	354.5	36.27	0.031799	0.032079	953.46	-1587.20	1140.63	1130.68		
	25	9.5	22.15	0.035986		2082.30	-2127.00	615.52	N/A	9.52	20
	26	39.5	22.15	0.038377		346.23	-948.22	577.17	N/A		
	27	69.5	22.15	0.043837	0.041238	572.77	-467.85	505.28	537.13		
	28	99.5	22.15	0.035947		1207.50	-585.54	616.19	N/A		
	29	129.5	22.15	0.027924	0.036020	927.80	-846.49	793.23	614.94		
	30	159.5	22.15	0.028674	0.029901	789.64	-746.52	772.48	740.78		
	31	189.5	22.15	0.027786	0.031882	2262.90	-1554.30	797.17	694.75		
	32	219.5	22.15	0.022851	0.035978	1719.20	-1144.40	969.33	615.66		
	33	249.5	22.15	0.035358	0.035986	175.54	-424.37	626.45	615.52		
	34	279.5	22.15	0.034066	0.033915	399.72	-540.45	650.21	653.11		
	35	309.5	22.15	0.029795	0.029967	917.29	-1214.60	743.42	739.15		
	36	339.5	22.15	0.018023	0.025995	1881.50	-1720.90	1229.00	852.09		

APPENDIX C

STRIKE AND DIP DATA FOR TEST EXCAVATION MAPPING

TEST EXCAVATION CELL 1

TITLE: PERLITE TEST EXCAVATION CELLS 1 - 8

:dip direction = strike + 90

PLANES: 1 Cell #1

:STRIKE	DIP DIR.	DIP
55	145	72
145	235	60
150	240	68
185	275	60
180	270	65
210	300	63
72	162	78
140	230	62
168	258	25
212	302	55
150	240	65
22	112	36
195	285	87
175	265	78
177	267	72
188	278	70
153	243	90
17	107	80
5	95	52
23	113	80
25	115	65
24	114	67
21	111	68
166	256	75
28	118	56
259	349	81
180	270	61
265	355	81
20	110	52
221	311	61
17	107	63
13	103	80
286	16	68
189	279	52
19	109	74
192	282	28
170	260	43
220	310	24
230	320	24
175	265	48
12	102	60
22	112	57
65	155	78
177	267	72
165	255	76
255	345	57
156	246	56
166	256	67
22	112	75
183	273	67

END-DATA:

TEST EXCAVATION CELL 2

TITLE: PERLITE TEST EXCAVATION CELLS 1 - 8

:dip direction = strike + 90

PLANES: 1 Cell #1

:STRIKE DIP DIR. DIP

PLANES: 2 Cell #2

170	260	69
13	103	60
201	291	45
142	232	65
239	329	82
186	276	64
204	294	30
110	200	68
216	306	69
37	127	44
20	110	46
242	332	64
6	96	57
140	230	74
185	275	54
144	234	73
161	251	58
167	257	68
12	102	41
9	99	56
45	135	78
200	290	43
295	25	81
349	79	30
176	266	38
185	275	71
179	269	52
28	118	84
69	159	32
62	152	78
14	104	80
184	274	58
350	80	84
30	120	51
52	142	83
96	186	77
145	235	57
25	115	83
18	108	46
212	302	37
145	235	59
3	93	60
4	94	55
146	236	84
221	311	39
149	239	62
28	118	57
145	235	74
6	96	57
215	305	30
175	265	67
174	264	63
14	104	65
5	95	57

END-DATA:

TEST EXCAVATION CELL 3

TITLE: PERLITE TEST EXCAVATION CELLS 1 - 8

:dip direction = strike + 90

PLANES: 1 Cell #1

:STRIKE DIP DIR. DIP

PLANES: 3 Cell #3

135	225	64
197	287	69
15	105	40
11	101	64
152	242	72
354	84	83
6	96	56
9	99	51
172	262	58
137	227	70
154	244	56
9	99	72
166	256	69
7	97	77
19	109	53
217	307	76
19	109	63
135	225	70
28	118	72
17	107	64
21	111	56
172	262	59
11	101	60
15	105	44
13	103	57
343	73	32
14	104	63
120	210	61
165	255	54
356	86	77
9	99	60
192	282	26
161	251	64
52	142	75
172	262	70
6	96	66
236	326	72
167	257	85
140	230	40
9	99	59
140	230	73
136	226	55
11	101	52
11	101	60
12	102	65
6	96	61

END-DATA:

TEST EXCAVATION CELL 4

TITLE: PERLITE TEST EXCAVATION CELLS 1 - 8

:dip direction = strike + 90

PLANES: 1 Cell #1

:STRIKE DIP DIR. DIP

PLANES: 4 Cell #4

6	96	58
105	195	76
130	220	68
238	328	68
12	102	56
20	110	51
8	98	60
159	249	81
0	90	46
324	54	88
208	298	48
266	356	72
160	250	49
268	358	90
88	178	62
100	190	69
124	214	75
9	99	73
115	205	76
11	101	67
140	230	51
148	238	49
225	315	51
207	297	31
245	335	62

END-DATA:

TEST EXCAVATION CELL 5

TITLE: PERLITE TEST EXCAVATION CELLS 1 - 8

:dip direction = strike + 90

PLANES: 1 Cell #1

:STRIKE DIP DIR. DIP

PLANES: 5 Cell #5

200	290	35
120	210	80
5	95	33
0	90	68
102	192	35
185	275	45
120	210	65
235	325	88
135	225	25
25	115	50
285	15	80
197	287	48
2	92	50
18	108	30
150	240	45
127	217	52
156	246	50
165	255	46
145	235	70
175	265	52
15	105	50
138	228	73
120	210	78
140	230	60
215	305	74
0	90	58
190	280	88
152	242	60
183	273	52
246	336	75
160	250	84
310	40	88
250	340	29
134	224	73
3	93	48
348	78	54
352	82	55
327	57	63
105	195	63
4	94	84
0	90	65
196	286	57
0	90	64
116	206	73
4	94	58
28	118	61
184	274	40
186	276	63
138	228	54
184	274	20
5	95	72
123	213	53
210	300	64
155	245	71
264	354	70
183	273	55
7	97	3
275	5	78
340	70	50
4	94	70
140	230	65
140	230	80
130	220	65
3	93	56
105	195	74
224	314	58
162	252	37

END-DATA:

TEST EXCAVATION CELL 6

TITLE: PERLITE TEST EXCAVATION CELLS 1 - 8

:dip direction = strike + 90

PLANES: 1 Cell #1

:STRIKE DIP DIR. DIP

PLANES: 6 Cell #6

350	80	80
3	93	38
204	294	88
168	258	49
18	108	54
142	232	56
245	335	40
220	310	46
66	156	67
5	95	42
2	92	46
4	94	74
11	101	75
7	97	73
140	230	54
0	90	34
345	75	57
100	190	68
0	90	56
180	270	54
108	198	80
4	94	58
353	83	58
340	70	79
140	230	54
345	75	62
4	94	58
90	180	85
197	287	49
154	244	58
11	101	54
131	221	61
87	177	84
8	98	28
188	278	47
110	200	60
356	86	69
90	180	53
180	270	42
210	300	83
7	97	80
345	75	75
105	195	61
115	205	73
100	190	63
195	285	50
200	290	90
190	280	70
0	90	67
200	290	82
177	267	50
77	167	88

END-DATA:

TEST EXCAVATION CELL 7

TITLE: PERLITE TEST EXCAVATION CELLS 1 - 8

:dip direction = strike + 90

PLANES: 1 Cell #1

:STRIKE DIP DIR. DIP

PLANES: 7 Cell #7

5	95	61
0	90	60
132	222	73
4	94	82
55	145	77
173	263	61
195	285	35
27	117	88
4	94	60
4	94	65
141	231	68
156	246	76
245	335	74
2	92	66
115	205	89
135	225	62
157	247	60
356	86	76
162	252	70
205	295	45
220	310	55
0	90	63
210	300	80
356	86	86
209	299	17
85	175	79
355	85	55
0	90	67
283	13	79
7	97	66
197	287	81
280	10	74
151	241	30
130	220	62
230	320	58
105	195	80
25	115	77
187	277	64
115	205	75
173	263	59
134	224	67
23	113	62
115	205	70
5	95	56
3	93	43
160	250	62
165	255	39
25	115	37

END-DATA:

TEST EXCAVATION CELL 8

TITLE: PERLITE TEST EXCAVATION CELLS 1 - 8

:dip direction = strike + 90

PLANES: 1 Cell #1

:STRIKE DIP DIR. DIP

PLANES: 8 Cell #8

348	78	63
26	116	38
154	244	78
135	225	72
165	255	66
113	203	80
120	210	76
145	235	80
17	107	43
17	107	55
160	250	79
100	190	61
159	249	69
143	233	63
33	123	38
218	308	86
300	30	88
160	250	71
290	20	88
170	260	65
20	110	44
125	215	74
28	118	39
155	245	81
355	85	53
335	65	82
5	95	50
160	250	64
298	28	78
17	107	77
90	180	65
30	120	29
116	206	70
130	220	84
132	222	72
125	215	75
164	254	81
335	65	40
340	70	87
200	290	85
45	135	30

END-DATA: