Mines Branch Technical Bulletin TB 75

A SONIC SYSTEM FOR THE DETERMINATION OF 'IN SITU' DYNAMIC PROPERTIES AND FOR THE OUTLINING OF FRACTURE ZONES

by

G.E. Larocque*

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ABSTRACT

A sonic system is described which has been developed for probing the rock around mining openings. With this system, transit time measurements of a few hundred microseconds to many milliseconds can be made with an accuracy of 5%. The sonic apparatus is relatively portable and entirely independent of external power requirements, allowing its use in remote mining locations. A hammer blow is used as a source of signal. For transit time measurements between boreholes, hydraulically wedged transmitting and receiving units have been developed; receiving units for application on rock faces have also been developed and used.

The basic assumption on which sonic transit velocity is related to fracture zone is stated and some of the possible applications of such measurements are outlined. Field measurements to substantiate some of the statements made are also included.

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This report was presented as a paper at the Sixth Symposium on Rock Mechanics, held at the University of Missouri, Rolla, Mo., October 1964. It is based on work contained in earlier reports DR FMP 63/121-MIN and FMP 64/8-MRL.

Direction des mines

Bulletin technique TB 75

APPAREIL SONIQUE POUR DÉTERMINER 'IN SITU' LES PROPRIÉTÉS DYNAMIQUES ET POUR DÉLIMITER LES ZONES DE FRACTURE

par

G. E. Larocque*

RÉSUMÉ

L'auteur décrit ici un appareil sonique qui a été mis au point pour sonder la roche autour des puits de mine. Avec cet appareil on peut mesurer le temps de la propagation du son depuis quelques centaines de microsecondes jusqu'à plusieurs millisecondes, avec une précision de 5 pour cent près. L'appareil sonique est plus ou moins portatif et entièrement indépendant de sources d'énergie extérieures, ce qui permet de l'employer dans des régions minières éloignees. Un coup de marteau sert de source de signalisation. Pour mesurer la vitesse de propagation du son entre des trous de sonde, on a mis au point un émetteur et un récepteur coincés hydrauliquement; on a aussi mis au point et utilisé des récepteurs que l'on applique à la paroi rocheuse.

L'hypothèse fondamentale, d'après laquelle la vitesse de transmission du son est liée aux zones de fracture, est formulée ici et quelques-unes des applications possibles des mesures sont brièvement décrites. On a aussi inclus les résultats de mesures effectuées sur le terrain pour confirmer certaines affirmations.

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Ce rapport a été présenté au Sixième Symposium sur la mécanique des roches, tenu à l'Université de Missouri, à Rolla, Mo., U. S. A., en octobre 1964. Il est fondé sur des travaux décrits dans les rapports précédents DR FMP 63/121-MIN et DR FMP 64/8-MRL.

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A SONIC SYSTEM FOR THE DETERMINATION OF 'IN SITU' DYNAMIC PROPERTIES AND FOR THE OUTLINING OF FRACTURE ZONES

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INTRODUCTION

In field investigations in rock mechanics, considerable emphasis is currently being placed on discrete, quantitative determinations of stress, using the many devices that have been developed for this purpose (e.g., deformation meters, stress meters, flat jacks). When such measurements are applied to structural design, there usually are basic assumptions concerning the mechanical state and the constancy of the elastic properties of the material involved. Such assumptions can only be confirmed by subsidiary measurements. Auxiliary methods for assessing a rock mass as to its mechanical state and the uniformity of its elastic properties, independently of stress measurements, would be advantageous to the mining engineer. Sonic probing is proposed as an inexpensive means of making such assessments. This paper describes a sonic apparatus that has been developed for the purpose and presents the results of the first field trials.

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BASIS OF SONIC MEASUREMENTS IN THE FIELD

When sonic probing is contemplated for field use, only two types of measurement are available: a) energy absorption, b) transit time.

The energy absorption type of measurement requires both a constant source of sonic energy and repeatable conditions of coupling to the host material, if measurements at different locations, or successive measurements at the same location, are to be comparable. Essentially, a constant amount of energy must be transferred to the host material each time. With this technique a study is made of the attenuation of sonic waves in the rock mass as a function of position and time; increases in attentuation are associated with deterioration in the competency of the rock mass.

The prime assumption underlying this first type of sonic field measurements is that one of the processes accompanying rock deterioration is the development of discontinuities, such as fractures, which act as a myriad of rock-to-air and air-to-rock interfaces; one should expect such discontinuities to reflect a portion of the previously transmitted sonic wave energy. For the particular case of a narrow crack and normal incidence, Rayleigh (1)* has determined the intensity reflection factor as:

$$R = \left(\frac{V\rho}{V_1\rho_1} - \frac{V_1\rho_1}{V\rho}\right) \div \left[4\cot^2\frac{2\Pi\ell}{V_1\tau} + \left(\frac{V\rho}{V_1\rho_1} + \frac{V_1\rho_1}{V\rho}\right)^2\right]^{\frac{1}{2}},$$

where $V\rho$ = specific acoustic impedance of the rock,

$V_1\rho_1$ = specific acoustic impedance of the crack,

ℓ = width of the crack, and

τ = period of incident sonic disturbance.

Where discontinuities develop that are completely opaque to elastic wave propagation, and the path lies essentially in the remaining solid material, Huygens' principle would suggest attenuation of the transmitted wave with crack extension.

The development of cracks or discontinuities also affects the velocity of propagation of sonic waves, i.e., transit time. A reduction in average velocity results from the lower velocity across air gaps, or, if the cracks are completely opaque, from the more circuitous transmission path, or from a combination of the

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* Figures in brackets indicate references listed at the end of the report.

two effects. This increased transit time is associated with strata deterioration.

The sonic apparatus to be described, while capable of making attenuation measurements, has been designed primarily to make transit-time measurements. Although good coupling is needed to ensure an adequate transfer of sonic energy to the host material, for transit time measurements the demand on repeatability of coupling conditions are not so severe as for attenuation measurements.

APPLICATIONS OF SONIC MEASUREMENTS

It is assumed that an increase in strata deterioration is accompanied by a decrease in sonic velocity. It should thus be possible to delineate fracture zones by transit time measurements. It should also be possible to follow, by means of periodic sets of measurements, the growth of such fracture zones with lapse of time or progress of mining. The transit time of the first compressional wave is therefore all that is measured in this instance. If sonic transit measurements are made in areas where there is some assurance of competency, then, by a study of the wave form and a determination of the time of arrival of the compressional and shear waves, the elastic dynamic properties of the medium can be completely defined, using the equations:

$$V_s^2 = \frac{E}{2\rho(1+\sigma)} \qquad V_c^2 = \frac{E(1-\sigma)}{\rho(1+\sigma)(1-2\sigma)}$$

where V_s = shear wave velocity,

V_c = dilatational wave velocity,

E = Young's modulus,

σ = Poisson's ratio, and

ρ = density.

Where a site has been selected for stress or deformation meters, an initial sonic probing of the strata would be advantageous. A knowledge of the suitability of the sites, prior to any initial expenditure in the installation of these instruments, would be desirable because of the costs involved. The ability to delineate fracture zones in rock by means of sonic measurements has an application in the evaluation of the effectiveness of de-stressing techniques with time and mining. Initially, one could determine by sonic velocity methods the extent of the de-stressed zone. Any subsequent changes in sonic velocity, indicating a change in the fracture zone, could be interpreted as a closing of fractures because of reapplication of load and/or further fracturing of adjacent solid rock. Sonic contouring measurements made periodically, could be used as an indication of structural stability. Depending on the mining situation, various interpretations could be placed on the growth, or lack of growth, of existing fracture zones. In the case of pre-existing fractures in the medium, it is possible that the application of loads would be detected as increases in sonic velocities. Thus an approximate relation could be established between stress conditions and sonic transit velocity for the strata under investigation.

REQUIREMENTS TO BE FULFILLED BY MEASUREMENT SYSTEM

On the basis of past experience, a sonic system capable of measuring transit time through geologic media, with transmitter to receiver transducer spacings of between five and fifty feet, was required. It was considered that the characteristic velocities of the media encountered would possibly range from 2,000 f/s (a soil) to 24,000 f/s (a competent quartz rock). Thus the system should be able to measure, with equal accuracy, transit times from a few hundred microseconds to many milliseconds. Extreme accuracy was not a paramount requirement for this system: 5% accuracy was considered to be sufficient. Past experience had indicated the inadequacy of piezo-electric devices as sources of sonic energy, even under the most ideal conditions, namely, close transmitter-to-receiver spacing (less than 10 ft) and good elastic rock. A method of producing a larger, more accurately timed sonic disturbance was required. It was also considered to be necessary to improve the acoustical coupling of the receiver to the host material so as to obtain greater sensitivity; this would be particularly important where measurements involved large spacings in low-velocity, high-absorption media.

Portability and independence from a large external power supply or a.c. power source was another requirement; a sonic equipment capable of being moved between sub-levels via manways was necessary. The sonic system developed to meet the above requirements has been built around a small transistorized oscilloscope which has proved its ruggedness in repeated field use. An extension of the sledge-hammer technique used in seismological work on the surface has been developed to supply an adequate source of accurately timed sonic energy in transit time measurement between two boreholes.

DESCRIPTION OF THE SONIC APPARATUS

Figures 1, 2 and 3 are photographs of the complete sonic apparatus. In Figure 1 the console unit is shown. The upper portion of the wooden carrying case of this unit contains a Tektronix 321 portable transistorized oscilloscope; the bakelite-faced chassis in the lower section contains most of the auxiliary transistor circuitry required to make sonic measurements. Figure 2 is a photograph of the transmitting and receiving units; the

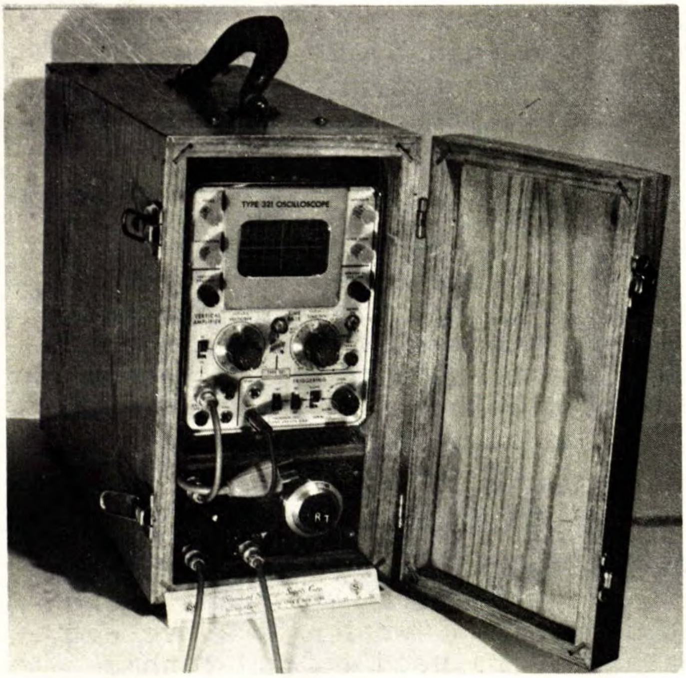


FIGURE 1 - Photograph of Sonic Console Unit.

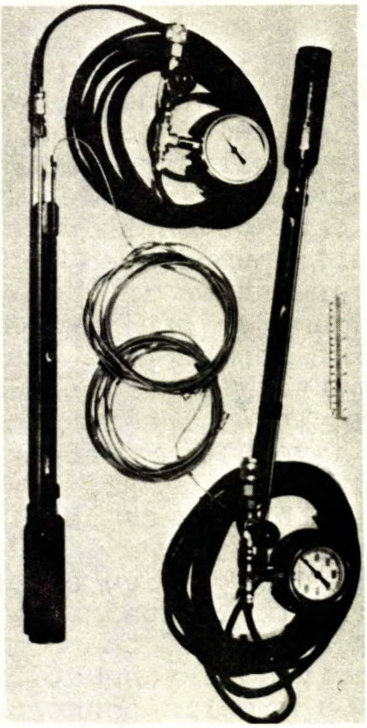


FIGURE 2 - Photograph of Sonic Transmitting and Receiving Units.

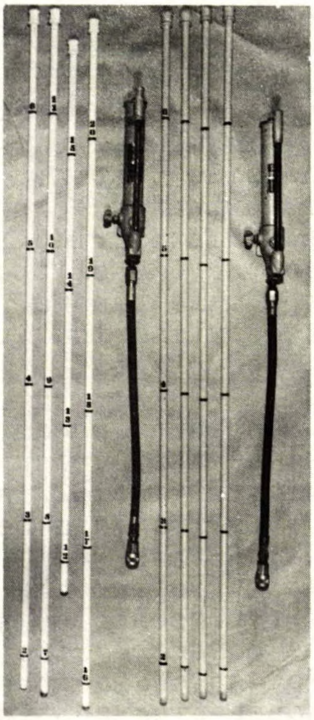


FIGURE 3 - Photograph of Connecting Rods and Hydraulic Pumps.

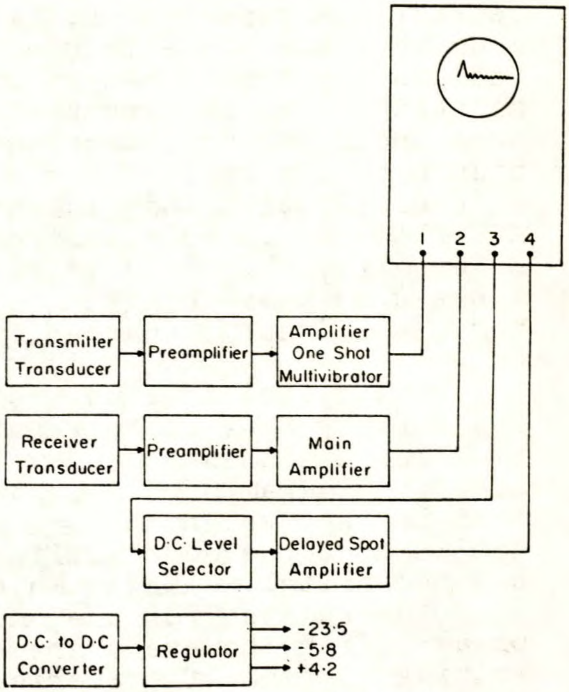


FIGURE 4 - Functional Block Diagram of Sonic System.

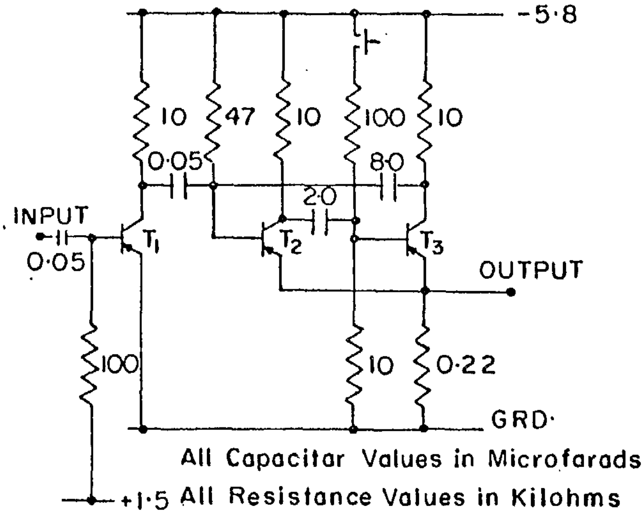
retracted side piston of each unit is clearly visible. Hydraulic pressure to extend these pistons is provided by Blackhawk D-14 pumps. Speed-D-Coupler fittings allow the hydraulic connection to be made easily and rapidly. A hydraulic pressure gauge and shut-off valve are included in each line. A single coaxial cable connects each of these units to the console. The connecting rods and hydraulic pumps used to position the transmitting and receiving units are shown in Figure 3. The rods are 5-foot lengths of 3/4-inch-diameter steel water pipe which are connected together by means of normal pipe couplers. Female couplers on the back of the transmitting and receiving units allow connection of the rods to these units. The sets of rods for the transmitting and receiving units have been painted in distinctive colours, yellow and white respectively. Marks have been painted at 1-foot intervals along the length of each set.

Figure 4 is an electrical block diagram of the sonic system. The circuits contained within the dotted line are mounted on the lower chassis of the console unit: Figures 5, 6, 7, 8 and 9 show the individual schematic circuit diagrams. Two No. 409 Eveready 6-volt dry cells connected in parallel are used to power this auxiliary circuitry; these batteries are normally changed after one hundred hours of use.

Figure 10 is a mechanical assembly drawing of the receiver unit. The single barium-titanate transducer used in this unit is pressed against the back of the face plate of the spring-loaded, retractable side piston. The end of the transducer in contact with the face plate is used as ground, and the casing of the unit becomes the ground return path. A central, spring-loaded plunger maintains contact with the electrically insulated back of the transducer during lateral motion of the side piston. This connection with the back of the transducer is extended through the base of the hydraulic body in which the piston is carried, by means of a Teflon-insulated axial feedthrough on the end of the chamber. Externally, this stud is equipped with a male banana plug which mates with a matching connector when the cylindrical unit following the hydraulic chamber is threaded into place.

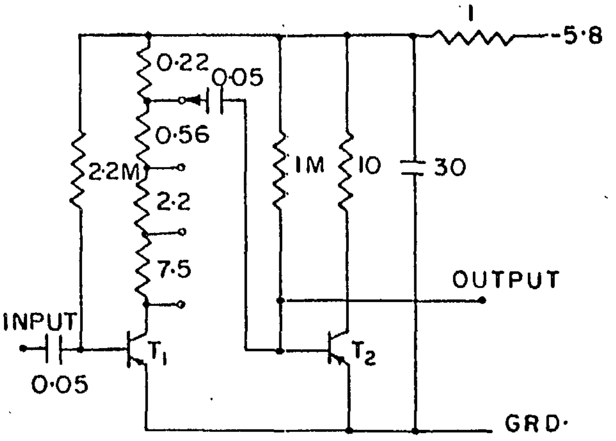
The cylindrical unit contains a transistor preamplifier and two Mallory RM-2 mercury batteries used as a power supply. Figure 11 shows a disassembled cylindrical unit; Figure 12 is a schematic circuit diagram of the preamplifier. No switch has been incorporated in the design to turn off the preamplifier when the unit is not in use; the added difficulty of waterproofing the unit, and the mechanical weakness which a switch represents to such a unit, were the reasons for the omission. The power requirements of the preamplifier, however, are extremely modest and at the time of writing one set of batteries had been operating continuously for three months with no deterioration in the performance of the unit.

The transmitting unit differs from the receiving unit in one essential detail: a central hole drilled in the single barium-



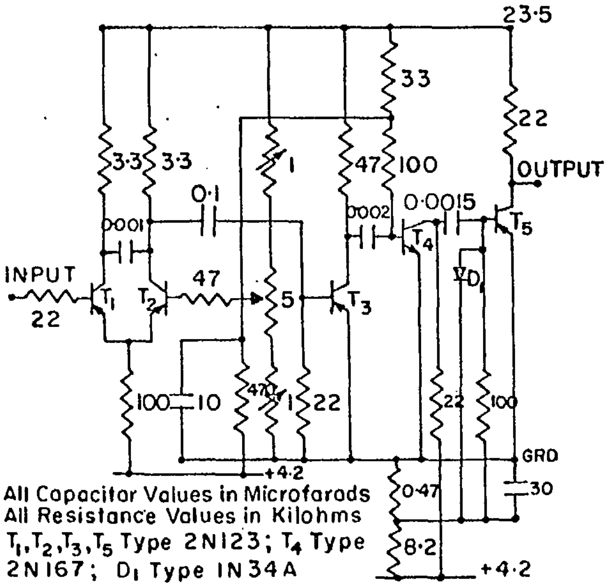
All Capacitor Values in Microfarads
All Resistance Values in Kilohms
T_1, T_2, and T_3 Type 2 N 123

FIGURE 5 - Schematic of Amplifier and One Shot Multivibrator.



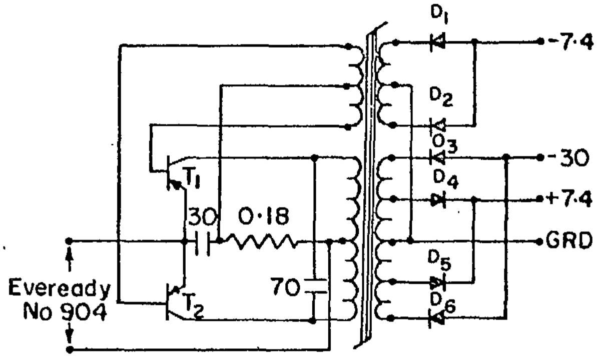
All Capacitor Values in Microfarads
All Resistance Values Unless Otherwise Stated in Kilohms·
T_1, T_2 Type 2 N 123

FIGURE 6 - Schematic of Main Amplifier.



All Capacitor Values in Microfarads
All Resistance Values in Kilohms
T_1,T_2,T_3,T_5 Type 2N123; T_4 Type 2N167; D_1 Type IN34A

FIGURE 7 - Schematic of d. c. Level Selector and Delayed Spot Amplifier.

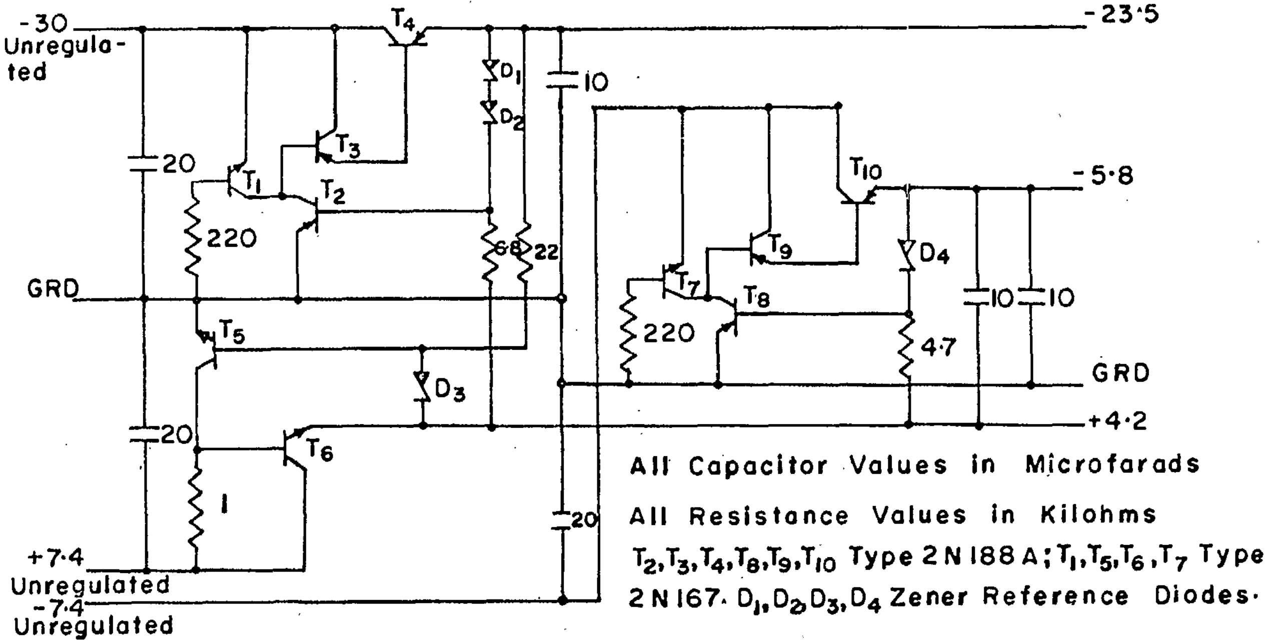


All Capacitor Values in Microfarads

All Resistance Values in Kilohms

T_1, T_2 Type 2 N 265; D_1,D_2,D_4,D_5 Type IN 100
D_3, D_6 Type IN2071

FIGURE 8 - Schematic of d. c. to d. c. Converter.

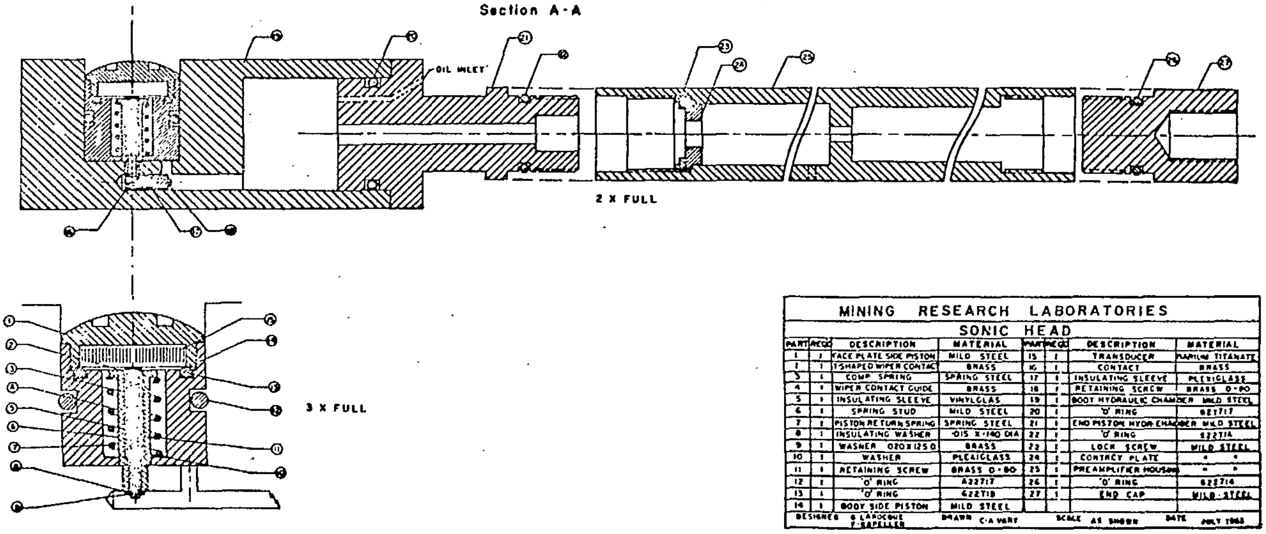


All Capacitor Values in Microfarads

All Resistance Values in Kilohms

$T_2, T_3, T_4, T_8, T_9, T_{10}$ Type 2N188A; T_1, T_5, T_6, T_7 Type 2N167. D_1, D_2, D_3, D_4 Zener Reference Diodes.

FIGURE 9 - Schematic of Voltage Regulator.



MINING RESEARCH LABORATORIES							
SONIC HEAD							
PART	REQD	DESCRIPTION	MATERIAL	PART	REQD	DESCRIPTION	MATERIAL
1	1	FACE PLATE SIDE PISTON	MILD STEEL	15	1	TRANSDUCER	BARIUM TITANATE
2	1	T-SHAPED WIPER CONTACT	BRASS	16	1	CONTACT	BRASS
3	1	COMP SPRING	SPRING STEEL	17	1	INSULATING SLEEVE	PLEXIGLASS
4	1	WIPER CONTACT GUIDE	BRASS	18	1	RETAINING SCREW	BRASS 0-80
5	1	INSULATING SLEEVE	VINYLGLAS	19	1	BODY HYDRAULIC CHAMBER	MILD STEEL
6	1	SPRING STUD	MILD STEEL	20	1	'O' RING	622717
7	1	PISTON RETURN SPRING	SPRING STEEL	21	1	END PISTON HYDR CHAMBER	MILD STEEL
8	1	INSULATING WASHER	·015 X ·140 DIA	22	1	'O' RING	622714
9	1	WASHER ·020 X ·125 O	BRASS	23	1	LOCK SCREW	MILD STEEL
10	1	WASHER	PLEXIGLASS	24	1	CONTACT PLATE	" "
11	1	RETAINING SCREW	BRASS 0-80	25	1	PREAMPLIFIER HOUSING	" "
12	1	'O' RING	A22717	26	1	'O' RING	622714
13	1	'O' RING	622718	27	1	END CAP	MILD STEEL
14	1	BODY SIDE PISTON	MILD STEEL				
DESIGNED	B. LAROCQUE F. SAPELLER	DRAWN	C.A. VERT	SCALE	AS SHOWN	DATE	JULY 1963

FIGURE 10 - Mechanical Assembly Drawing of Receiving Unit.

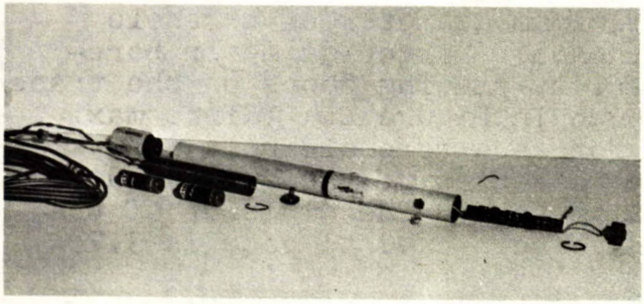
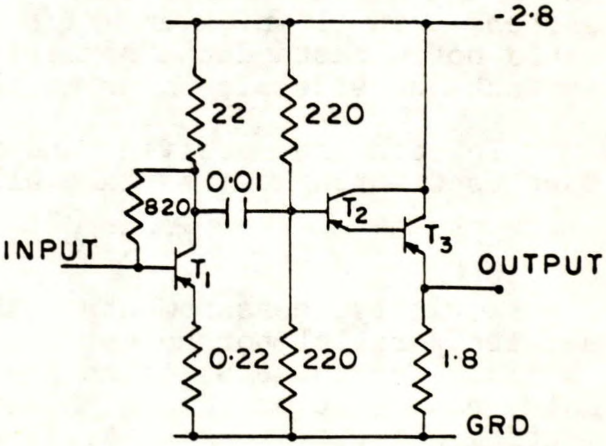


FIGURE 11 - Disassembled Cylindrical Unit



All Capacitor Values in Microfarads

All Resistance Values in Kilohms

T_1 Type 2N123; T_2, T_3 Type SB101

FIGURE 12 - Schematic of Preamplifier.

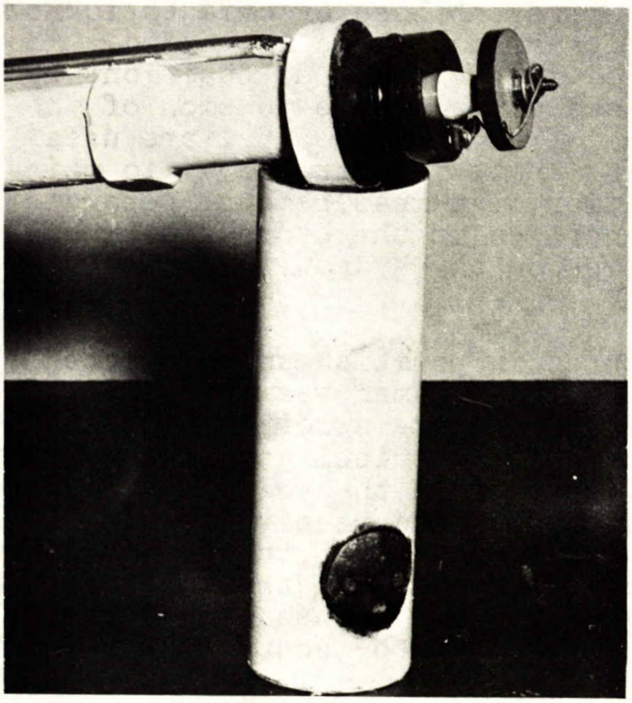


FIGURE 13 - Barium Titanate Transducer Mounting in Transmitting Unit.

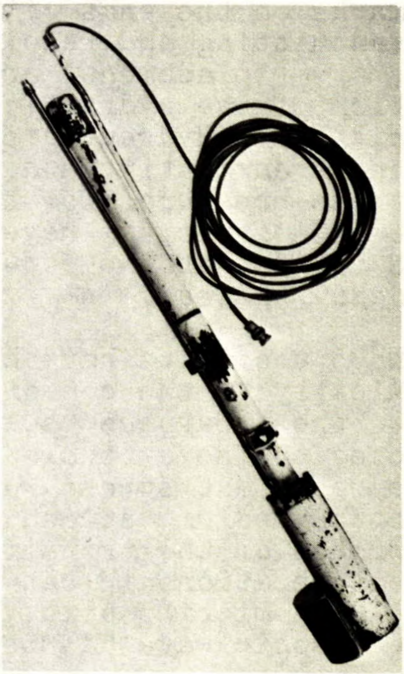


FIGURE 14 - Transmitting Unit with Shoe Attached.

titanate transducer has been used to mount it on a steel rod supported axially in an insulating sleeve in the back of the hydraulic chamber as shown in Figure 13. The reason for this difference in design is that while barium-titanate transducers of the dimensions used (1 in. diam x 1/8 in. thick) are not fragile, they would not withstand the hammering undamaged if mounted directly against the side piston as in the receiving unit.

In both the receiving and transmitting units, O rings have been used throughout to make all joints watertight.

OPERATION OF THE SONIC SYSTEM

Normally, measurements with the sonic system are conducted between parallel boreholes; the minimum diameter of borehole suitable for these units is 1.9 inches. Larger-diameter boreholes can be accommodated, however, by placing shoes on the transmitting and receiving units as shown in Figure 14. Since maximum extension of the side piston for each borehole unit is limited to one quarter of an inch, a series of shoes is required to accommodate holes of various diameters. The diameter of the largest hole in which the units have been used to date is 3.75 inches.

In using the sonic apparatus, the initial step is to insert the transmitting and receiving units into the boreholes to a selected depth by means of extension rods (see Figure 15). Alignment marks on the ends of the rods prevent loss of orientation of the transmitting and receiving units as more rods are added. The units, after placement, are secured in the required positions by operation of the hydraulic pumps and consequent extension of the side pistons. Hydraulic pressures of 1200 and 300 psi are used with the transmitting and receiving units respectively. To maintain these pressures for the duration of a measurement, separate needle cut-off valves have been included in the hydraulic lines; it was found that the cut-off valves on the hydraulic pumps had a tendency to leak.

When the units have been secured in position and connected electrically to the console, one of the two-man team required to operate the apparatus uses a hammer to strike a solid steel stud connected to the extension rods of the transmitting unit. Part of the resultant stress wave travelling down the rods is transferred to the medium between the transmitter and receiver via the side piston of the transmitting unit. Because of the fixed geometrical relationship between the side piston and the transducer in the transmitting unit, the transducer can be used to determine when the sonic wave has been transferred to the host medium.

The output from the barium-titanate transducer in the transmitter is used at the console to trigger the oscilloscope (see Figure 4). Prior to its application as an external trigger, however, the output is passed through a clipping amplifier and a one-shot multivibrator. The purpose of the clipping amplifier is

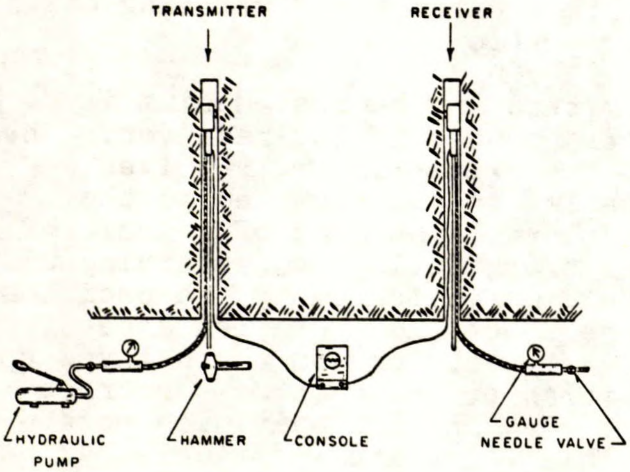


FIGURE 15 - Arrangement of Sonic System for Field Measurements

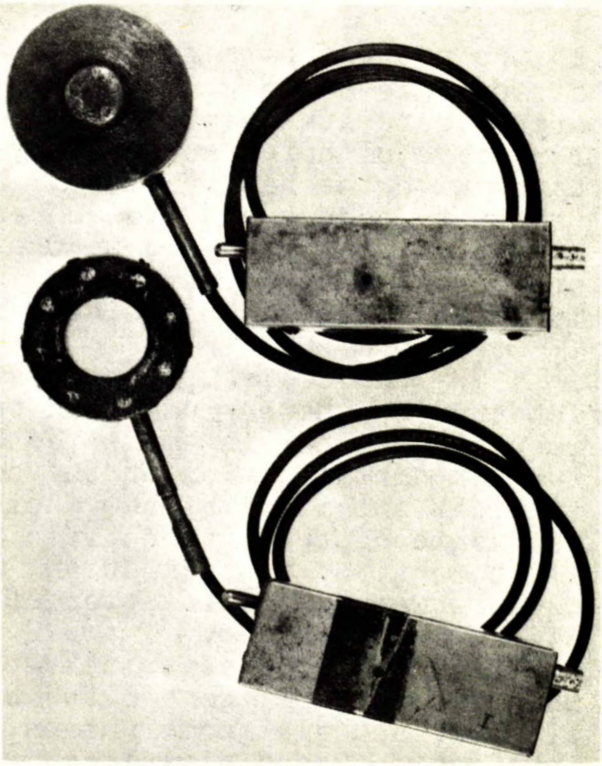


FIGURE 16 - Transmitting and Receiving Units for Surface Measurements.

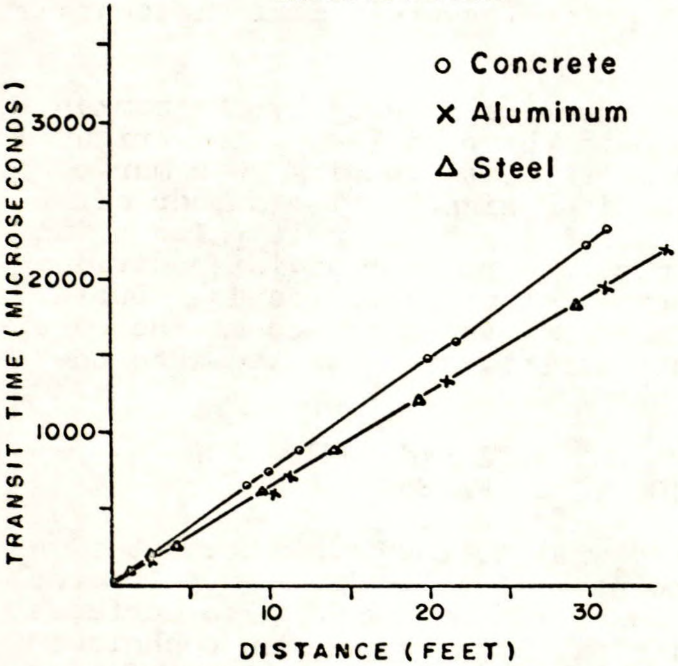


FIGURE 17 - Transit Time Versus Distance for the Sonic System with Concrete, Aluminum and Steel as Media.

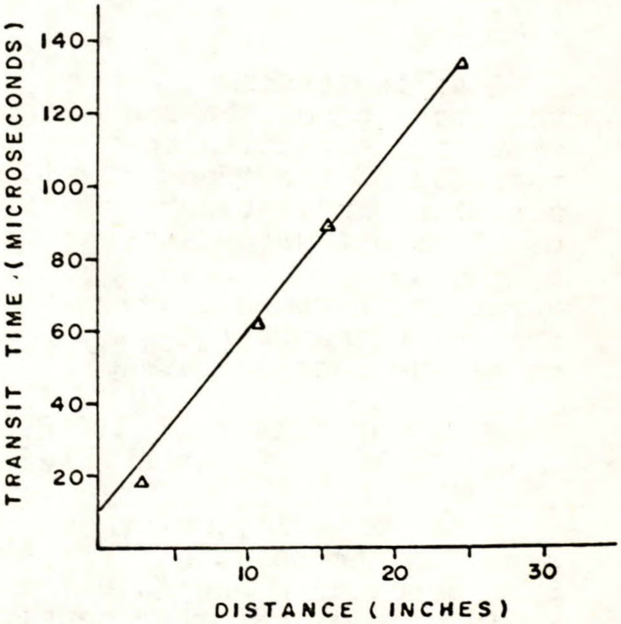


FIGURE 18 - Transit Time Versus Distance for Short Lengths of Steel.

to prevent the passage of extraneous noise and to require the disturbance to be a selected minimal size. This feature allows approximate attenuation measurements to be made, since results for pairs of holes are roughly comparative provided that care is taken with the hammer blows. For this purpose the operator attempts to adjust the blow in each case in order to produce the minimal signal required by the clipping amplifier. The function of the one-shot multivibrator is to prevent the developing of multiple sweeps from a single hammer blow.

The sonic disturbance transmitted by the host medium is detected by the barium-titanate transducer in the receiver. The resulting signal is amplified by the preamplifier, receives further amplification at the console, and is then fed to the vertical amplifier of the oscilloscope. The time of transit of the sonic disturbance between the transmitting and receiving units is, to a first approximation, the time indicated by the oscilloscope between the initiation of the sweep and the appearance of the signal on the trace. The D.C. level selector and the delayed spot amplifier provide a variable-position bright spot on the trace which is linearly controlled by a 10-turn, 1000-division potentiometer and dial combination. This effectively divides the sweep into one thousand divisions, replacing the graticule as a means of making time measurements and allowing the oscilloscope to be used in the 5X magnified sweep position. In this position the normal 2-1/2-inch display becomes 12-1/2 inches, allowing transit time measurements to be made with the oscilloscope's maximum accuracy (5%).

As the transmitter rod is struck repeatedly by the hammer, the operator of the console adjusts the position of the bright spot on the oscilloscope trace so that its leading edge marks the position of the front of the received signal. The number of divisions indicated by the potentiometer dial, multiplied by the oscilloscope sweep setting in microseconds per division divided by one hundred, gives the transit time in microseconds. During a run, measurements are made twice at each position of the receiving and transmitting units, once as they are advanced into the holes and once on retreat.

AUXILIARY TRANSMITTING AND RECEIVING UNITS FOR APPLICATION TO SURFACES

Occasionally, mine geometry will be such that transit time measurements between surface points are desirable. Development of transmitting and receiving units for application to surfaces would also allow experimentation with the reflection technique that has been so successfully applied in determinations of overburden depth and of ground water level. Figure 16 is a photograph of the units that have been developed for this purpose. Both surface units have a single barium-titanate crystal mounted on a stud in an oil bath. A transistor preamplifier and a battery supply identical to those used with the borehole units are mounted in each of the rectangular boxes shown in the photograph.

The transmitting unit has a steel face plate fitted over a rubber diaphragm window. This unit is the upper one in Figure 16. The receiving unit has a simple rubber diaphram which, in operation, is pressed directly against the rock while the surface transmitter in contact with the rock is struck with a hammer.

CALIBRATION OF THE SYSTEM

Determination of the zero correction for transit-time determinations made with the sonic system was considered to be necessary because of the indirect method of triggering the oscilloscope sweep. Figure 17 is a plot of transit time versus transmitter-receiver spacing, using steel and aluminium rods and a concrete slab as transmission paths. On the time scale of this graph, extrapolation to zero spacing would indicate zero delay in the unit for all three materials. Subsequently an investigation was conducted using shorter steel rods, and the results are plotted in Figure 18. On the much finer time scale of this second graph, extrapolation indicates that the true zero time occurs at a reading of 10 microseconds. Thus, 10 microseconds must be subtracted from the measured transit times when an error of this magnitude is significant.

A time marker generator is taken into the field with the sonic unit. Used on the surface, this unit allows periodic checks to be made of the correctness of the time base of the oscilloscope. To date, no adjustment of the oscilloscope has been required. An apparatus consisting of two short lengths of 2-inch internal diameter steel pipe, connected at the center between external diameters by a 2-foot steel rod, is taken underground with this sonic apparatus. Prior to the start of a series of measurements, a check measurement is made; the procedure is to install the receiving and transmitting units in the end pipes of the auxiliary apparatus and compare the measured transit time with the established value.

FIRST FIELD USES OF THE SONIC SYSTEM

The first field applications of the sonic system have been concerned with field evaluation. Accordingly, while some use has been made of mine sites where active field programs are under way, the measurements made with the unit have been primarily concerned with demonstrating its capabilities.

MEASUREMENTS AT NEW CALUMET MINES, BRYSON, QUEBEC

Some of the first sonic measurements with the new apparatus were made at New Calumet Mines. The test site chosen in this mine was along the north wall of the main drift of the 1050 Level. Figure 19 shows the location of the five 10-foot holes (A, B, C, D, E) that were drilled to accommodate the borehole units, and

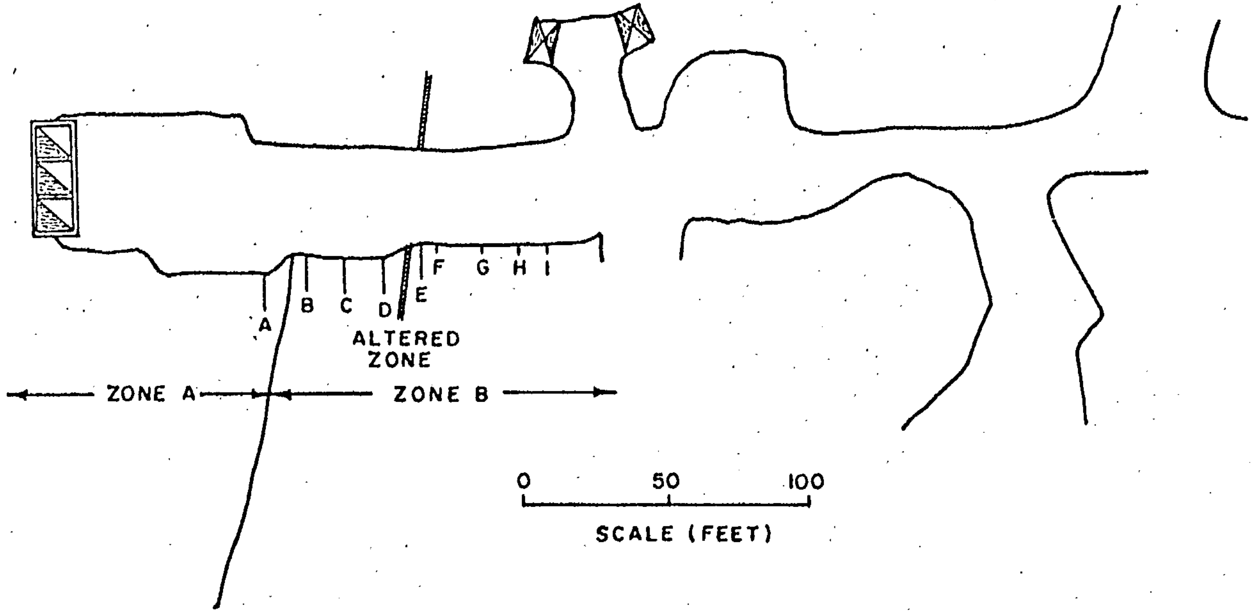


FIGURE 19 - New Calumet Mines, 1050 Level Experimental Site.

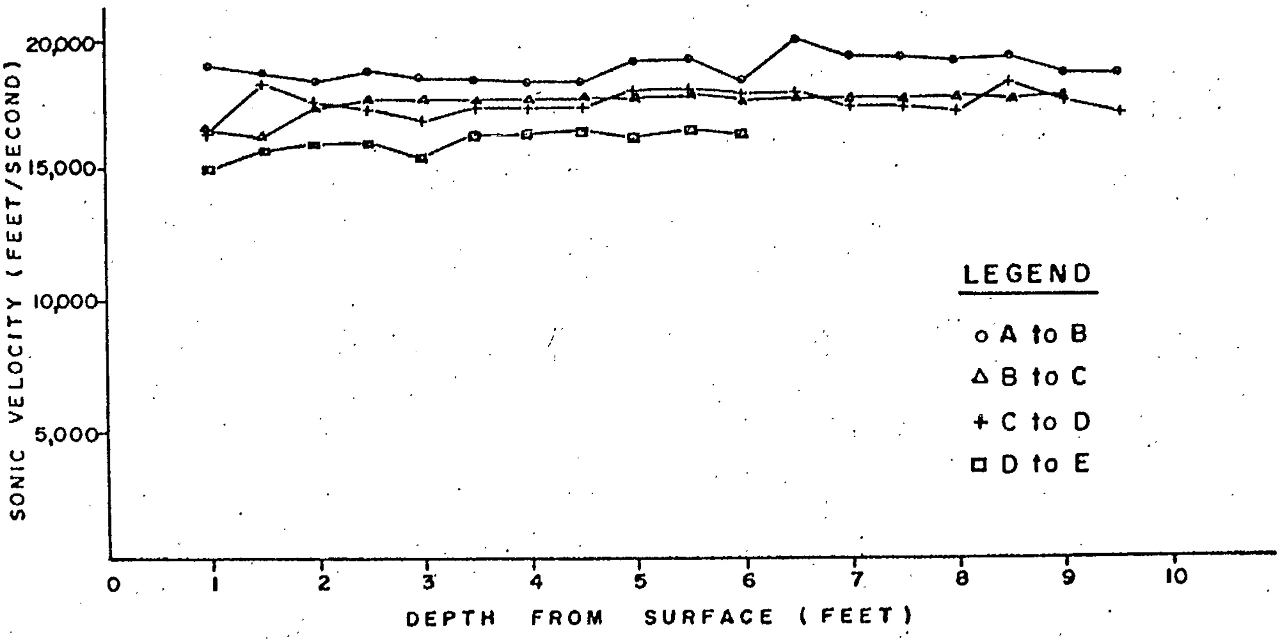


FIGURE 20 - Sonic Velocity Measurements, New Calumet Mines, 1050 Level Experimental Site.

the four places (F, G, H, I) where the surface transmitter was used. Three rock types are encompassed by these locations, and are noted on Figure 19 as Zone A, Zone B, and Altered Zone; they consist respectively of rhyolite, granite biotite schist, and altered granite biotite schist.

The results of the sonic velocity measurements are given in Figure 20 and it can be seen that they reflect the variations in rock composition. The highest velocities (average 18,500 f/s) were realized with measurements made between holes A and B, where the path is primarily through rhyolite. Slightly reduced velocities (average 17,500 f/s) were realized for measurements made between holes B and C, and C and D, where the rock between the holes is in both cases a granite biotite schist. Velocities are lowest for measurements between D and E (average 16,000 f/s), where the granite biotite schist between the holes is intersected by a sheared altered zone approximately 1 foot wide. In this study all sonic velocity measurements were made normal to the plane of schistosity. Because of the uniformity of the results obtained within the granite biotite schist as to both velocity and strength of signal, a study of the attenuation produced by the presence of the altered zone was undertaken. This consisted of a comparison of the maximum amplitudes of the signals received during repeated transmissions between holes A and B, B and C, and D and E, for which the transmitter was tapped just hard enough to initiate the oscilloscope sweep as explained above. A five times greater attenuation of the signal was noted in the case of measurements between D and E.

In spite of the considerable attenuation of transmitted sonic energy in the altered zone, transit time measurements were made, with no difficulty, between the receiver placed at the bottom of hole A and the surface transmitter placed at F, G, H and I. From the bottom of hole A to I, the path length is approximately eighty feet; a compressional-wave velocity of 17,500 feet per second was realized. This result is little affected by the small part of the path in Zone A and the Altered Zone; it confirms the uniformity of sonic velocity in the region of Zone B.

MEASUREMENTS AT McINTYRE MINE, SCHUMACHER, ONTARIO

Figure 21 is a partial sketch of the 5375 Level of the McIntyre Mine, locating the sonic test holes. An active research program was being conducted in this area of the mine, and was concerned with determining rock bursts in stope remnants. As part of this program, instruments for measuring stress and deformation had been installed in the remnant adjacent to the drift from which holes A, B, C and D were drilled, and on inter-connecting raises from the lower level (bounding the pillar below the sonic holes) A, B, C and D. The results of this program have already been reported (2). When holes A, B, C and D were drilled, this program had just begun and the ore zone immediately below them was unmined. The holes A, B, C and D were drilled in the quartz porphyry forming the hanging wall of the drift, as shown on the

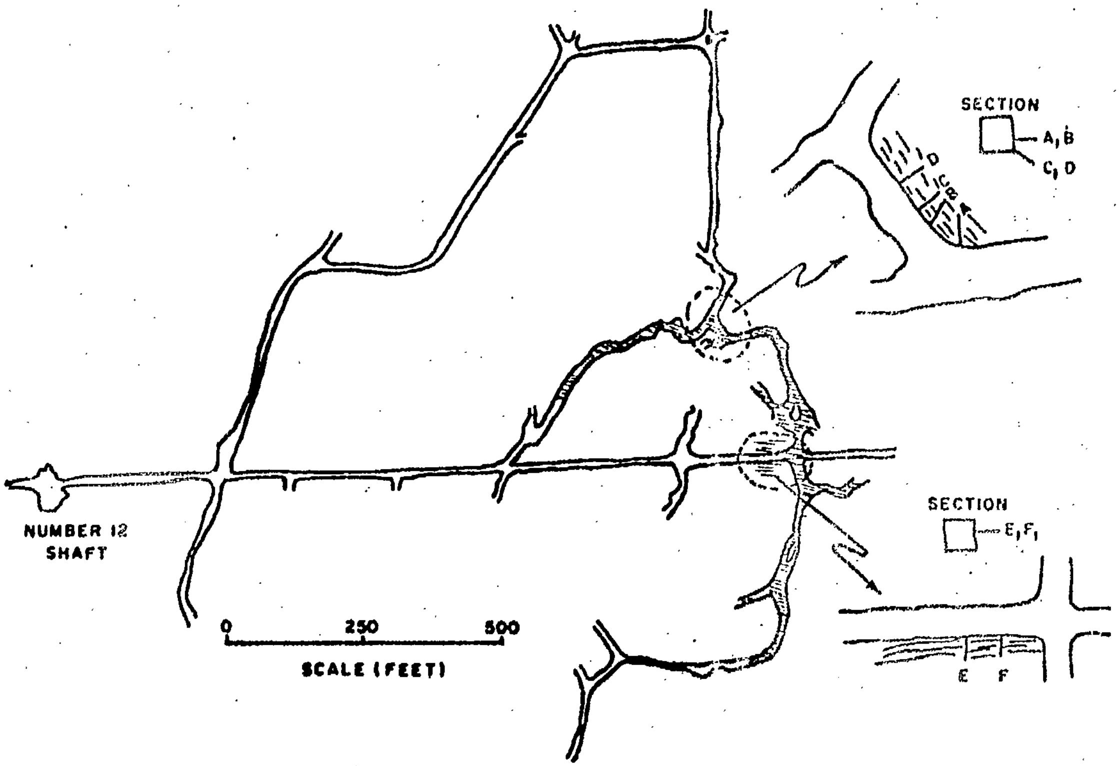


FIGURE 21 - McIntyre Mine, 5375 Level Experimental Site.

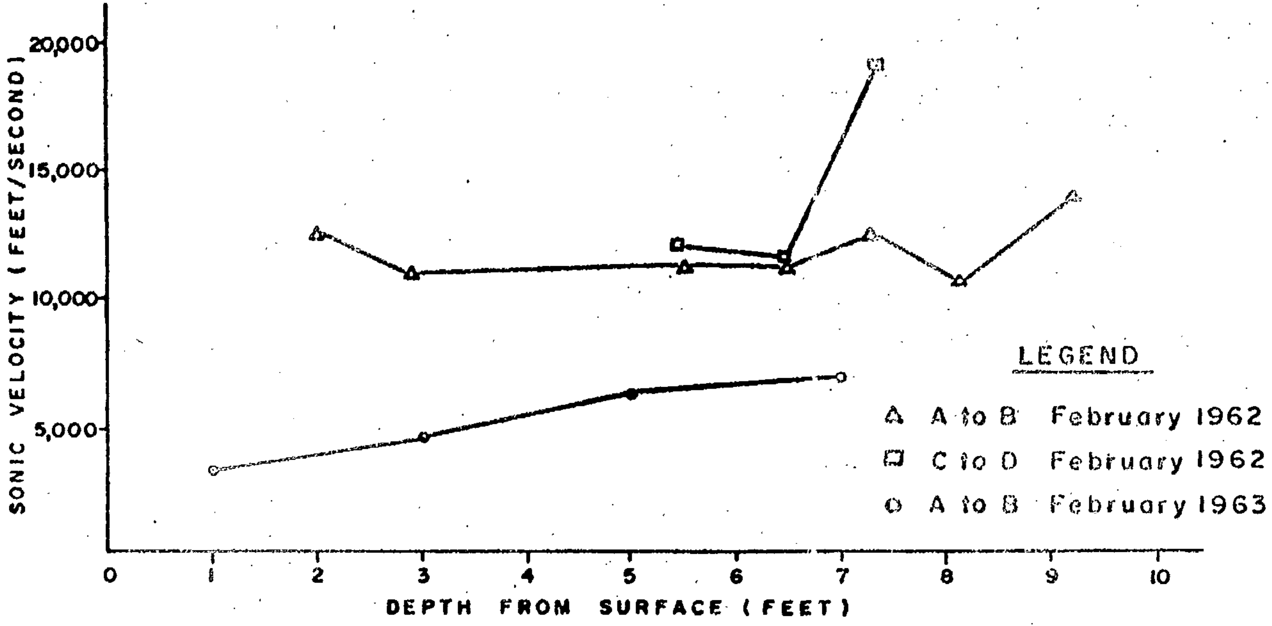


FIGURE 22 - Sonic Velocity Measurements, McIntyre Mine, 5375 Level Experimental Site.

section diagram. The holes E and F were drilled into a similar quartz porphyry from the main drift, a short distance from its intersection with the drift from which A, B, C and D were drilled. Prior to the start of the sonic program, all ore to the rise of the 5375 level in the test area had been removed and the void filled with waste rock. A further pair of holes, G and H (not shown in Figure 21), were located in quartz porphyry in a main drift at a considerable distance from the active mining area.

Figure 22 is a plot of sonic velocity measurements made between holes A and B, and C and D. The measurements between A and B were taken initially when the stope was entirely intact, and later when only a 40-foot remnant remained. During the intervening period a considerable reduction occurred in the velocity of sound in the 7 feet of rock next to the surface of the drift; the average velocity decreased from greater than 11,000 feet per second to less than 8,000 feet per second.

Figure 23 is a plot of sonic measurements between E and F in the main drift; measurements were not made at this location until February 1963. It is not considered likely that mining concerned with the removal of the remote stope remnant below sonic holes A, B, C and D would effect sonic velocities in this area. If deterioration in sonic velocity had occurred at this site it would probably have been related to removal of the ore to the rise. In this regard, it is interesting to note that the velocities realized at this location are comparable to those measured initially between A and B before reduction of the crown pillar.

The significance of this observation will be more apparent on referring to Figure 24, which shows a plot of sonic velocities measured between G and H. Here, at very little depth from the opening, velocities of the order of 15,000 to 16,000 feet per second were realized. It is obvious that in the vicinity of A, B, C and D and of E and F a significant reduction in velocity occurred prior to the initiation of the present study and of the concurrent mining; this may be attributed to fracturing of the rock in these locations, brought about by transferred load during removal of the ore immediately above the test site. The velocities realized between holes E and F would appear to be typical of the velocities generally realized with undisturbed quartz porphyry in this mine. Figures 25 and 26 are plots of sonic velocities measured at other levels and locations, showing the same characteristic velocity of 15,000 to 16,000 feet per second for the quartz porphyry host rock.

The original purpose in making sonic measurements, using hydraulic fill holes on various levels, was to investigate the effect of overburden on the sonic velocity patterns. All test sites involving hydraulic fill holes were in drifts of approximately the same dimension (8 feet by 8 feet), cut in similar rock. Thus, the conditions of all sites are comparable so far as dimensions and material are concerned. The results to date indicate no significant fracture zone at any of the levels; however, at all

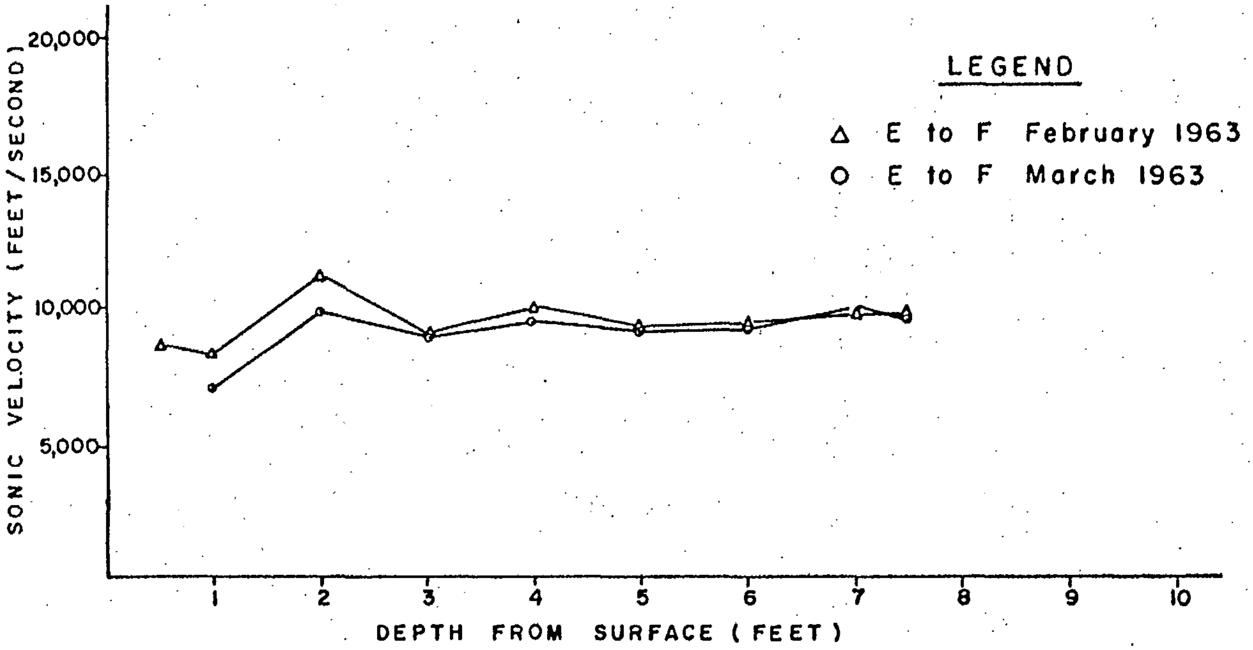


FIGURE 23 - Sonic Velocity Measurements, McIntyre Mine, 5375 Level Experimental Site.

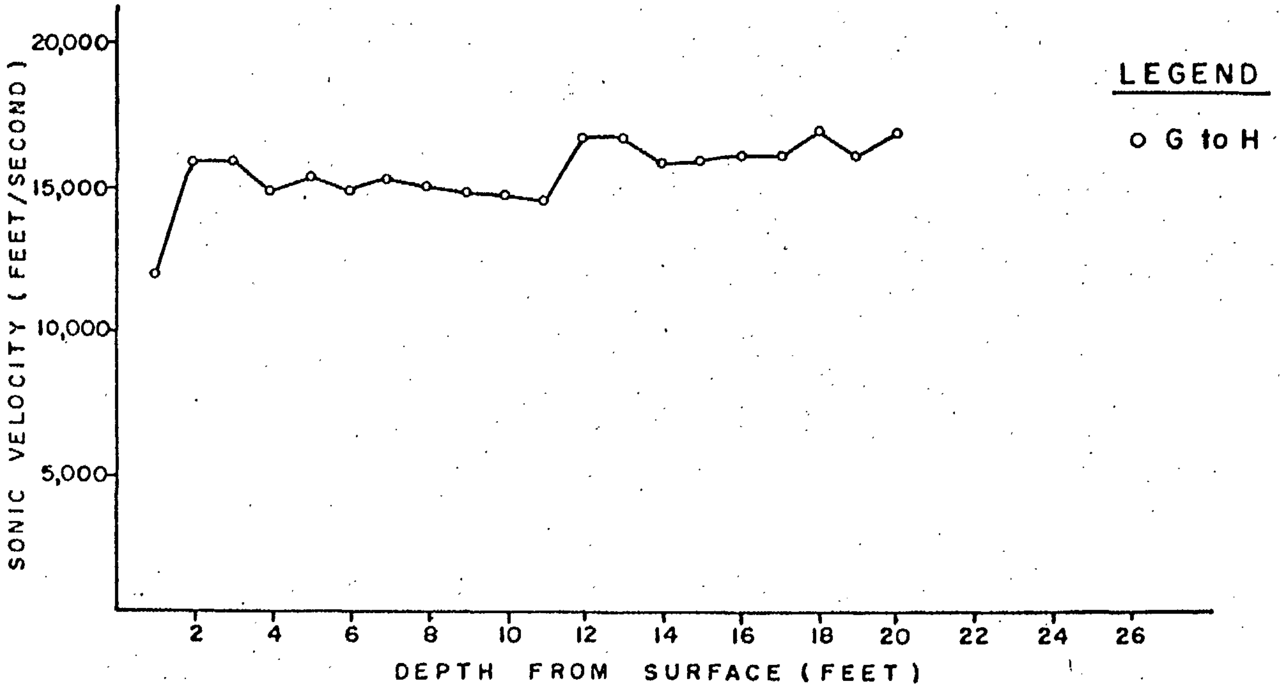


FIGURE 24 - Sonic Velocity Measurements, McIntyre Mine, 5375 Level Experimental Site.

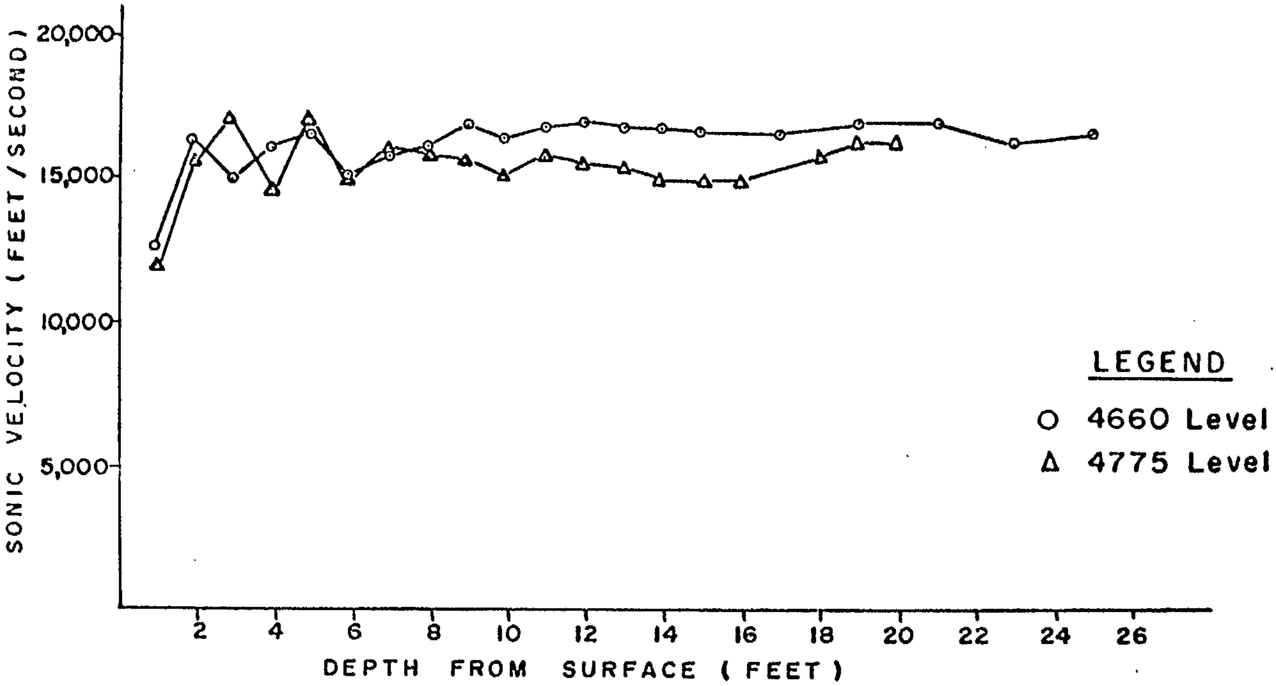


FIGURE 25 - Sonic Velocity Measurements, McIntyre Mine,Hydraulic Fill Holes Main Drift, 4660 and 4775 Levels.

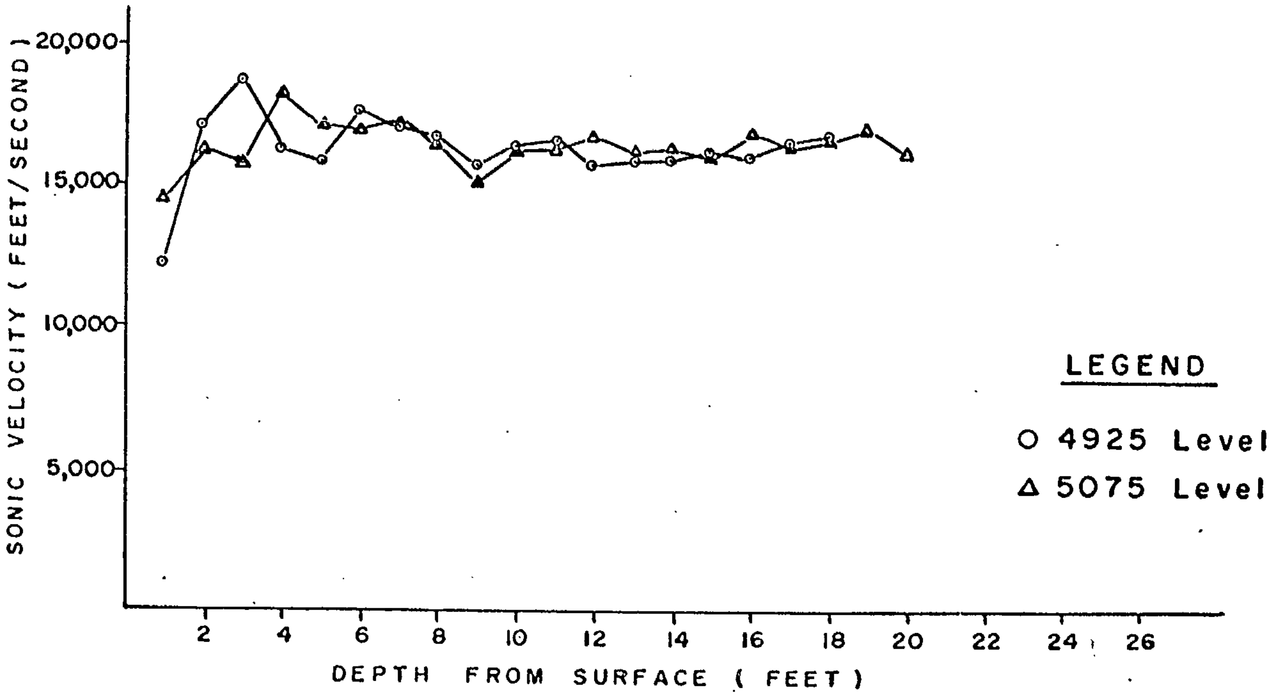


FIGURE 26 - Sonic Velocity Measurements, McIntyre Mine,Hydraulic Fill Holes Main Drift, 4925 and 5075 Levels.

levels, sonic velocity within the first six to eight feet from the collar of the holes is characterized by widely varying readings. This zone has contained some of the highest velocities obtained with the hydraulic fill holes. A possible explanation of this scatter of results is that the higher tangential stresses in the immediate wall, due to the presence of the opening and coupled with the removal of constraint, caused expansion of the rock into the openings. This expansion would produce a random opening and closing of naturally occurring discontinuities in the rock, producing the erratic sonic patterns that have been realized for the first six to eight feet of each pair of hydraulic holes probed. Since the hydraulic fill holes at McIntyre are ultimately to extend to the 6800 foot level, the opportunity exists to study the effect on sonic velocity of an extra 2140 feet of cover on a base overburden of 4600 feet.

The drill holes and surface stations used to make sonic velocity measurements around the 494910 blasthole stope are shown in Figure 27. As shown, measurements in the roof above the extracted portion of the stope were made from an upper roadway immediately above the stope by means of two parallel down holes. Sonic velocity measurements were made to within 25 feet of the stope's roof line before breakage of the holes terminated the probing. The distance of 43 feet from the collar of the drill holes to the transmitting and receiving units constitutes, however, the deepest probing that has been made with the sonic velocity apparatus to date. Ground conditions within the rim drifts limited the probing to within a mean distance of 27 feet of the open free face of the stope.

The results of these sonic velocity measurements are given in Figure 28. Sonic velocity measurements made from the upper roadway indicate no physical change in the roof rock at least within 25 feet of the opening. On the other hand, measurements made between surface stations in the rim drifts across the ore body show some sonic velocity deterioration as far as 45 feet ahead of the open face of the stope.

MEASUREMENTS AT HELEN MINE, WAWA, ONTARIO

Figure 29 indicates the location of the holes used for sonic velocity measurements at the Helen Mine. Subsidiary to the active field program under way at that time, plans had been made for the extensive probing of stope pillars composed of the siderite ore being mined. The background noise level in the mine prevented this, however, and measurements were limited to those made during one weekend in the five holes indicated. The results of these measurements are presented in Figure 30. The dotted lines on this graph define the limits on sonic velocity realized with various block and drill core samples of siderite tested in the laboratory. From these preliminary measurements there is an indication of sonic deterioration at this site for the first ten feet of the pillar from the open stope. To derive more specific conclusions concern-

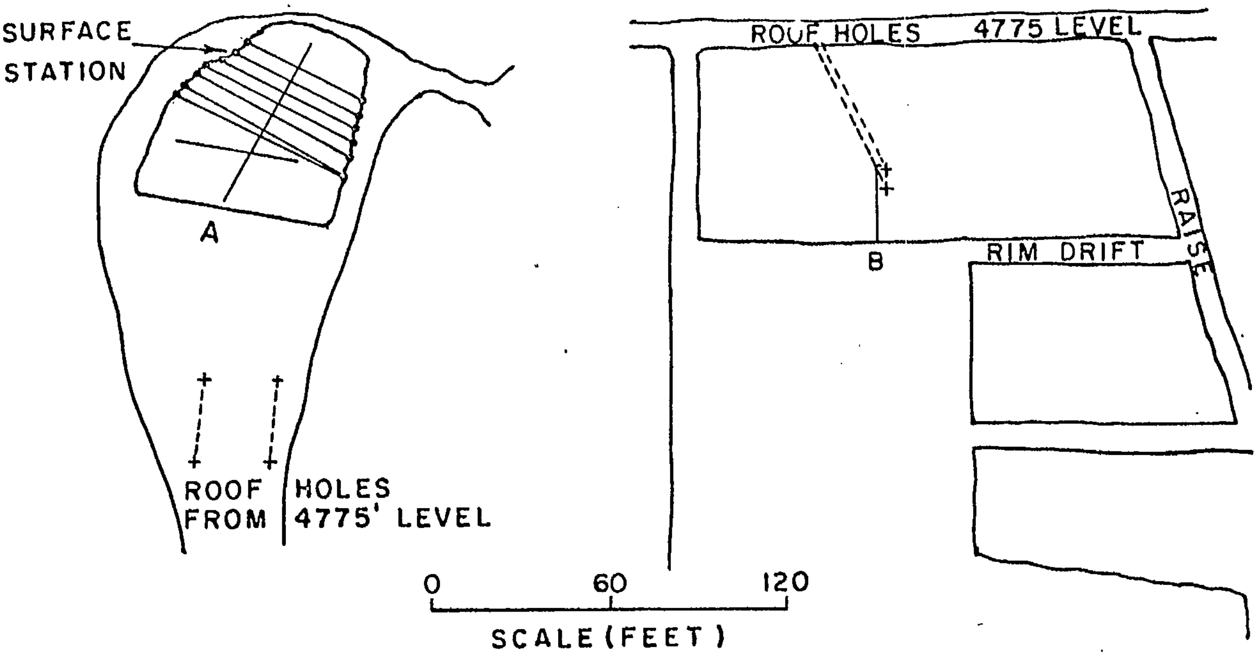


FIGURE 27 - McIntyre Mine, Plan of Rim Drift Horizon and Idealized Section of 494910 Stope.

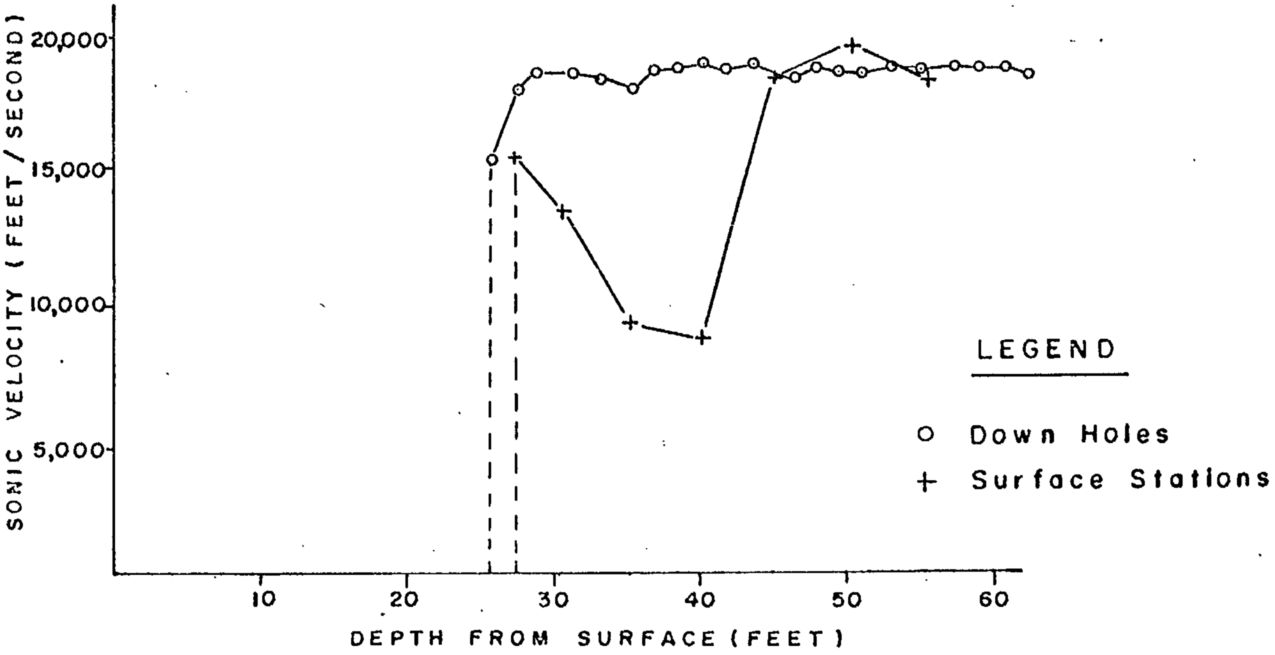


FIGURE 28 - Sonic Velocity Measurements, McIntyre Mine, 494910 Stope.

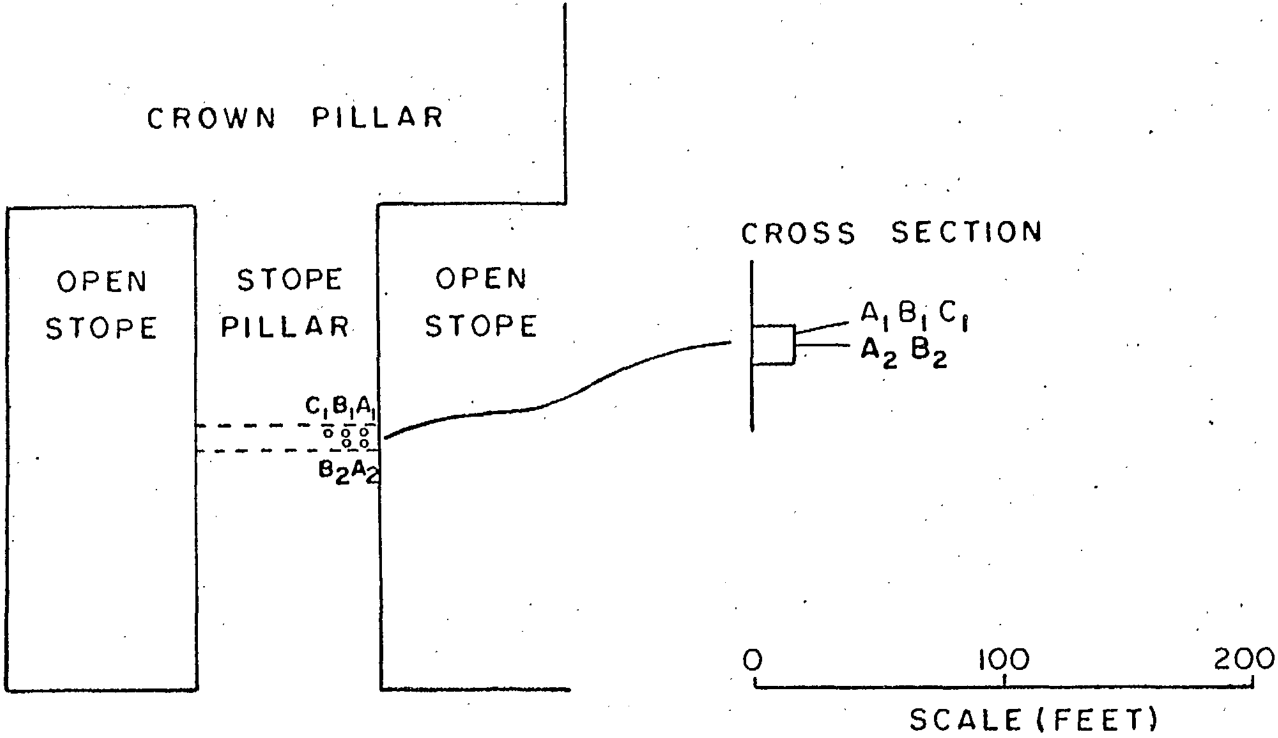


FIGURE 29 - Helen Mine, Stope 49 Experimental Site.

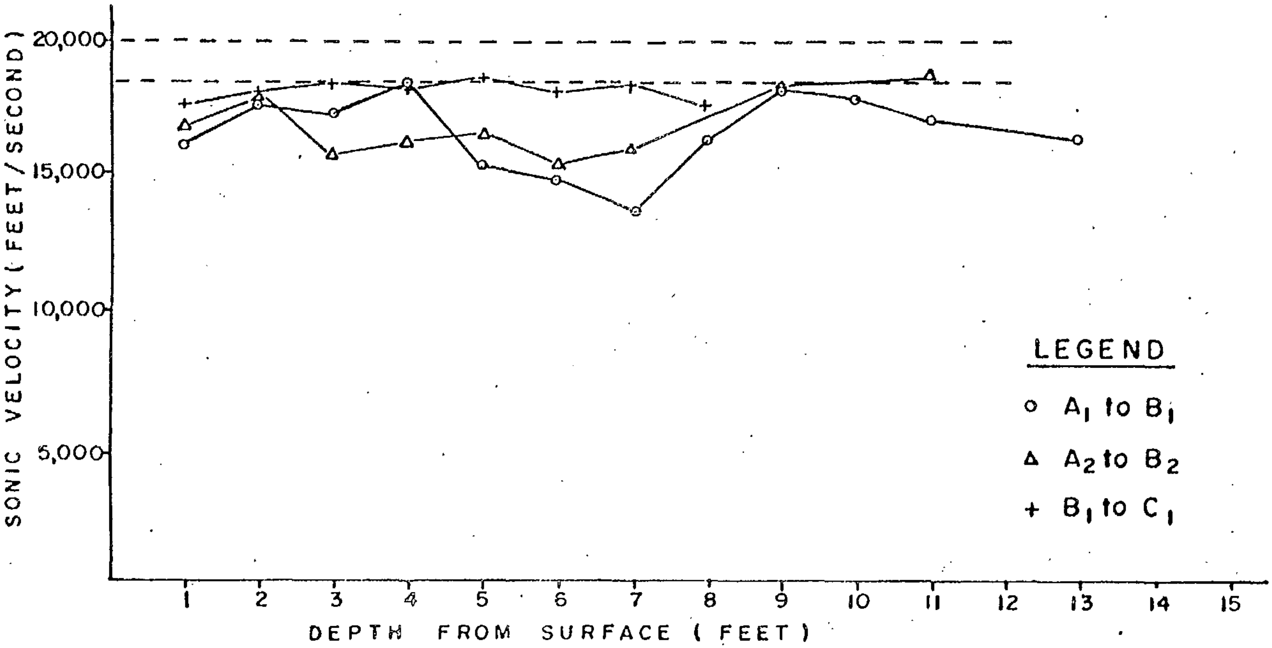


FIGURE 30 - Sonic Velocity Measurements, Helen Mine, Stope 49 Experimental Site.

ing sonic velocity patterns in stope pillars in this mine would require a considerable amount of further probing.

CONCLUSIONS

Preliminary field trials with the sonic apparatus have confirmed its fieldworthiness.

Measurements conducted at New Calumet Mines demonstrated the system's good sensitivity and its general ability to contour large masses. It was also shown that the apparatus is capable of making useful absorption measurements if the attenuation is great enough, as in the Altered Zone.

Measurements conducted at the McIntyre Mine illustrated the considerable changes that can occur in sonic velocity with lapse of time and progress of mining, substantiating the earlier suggestions regarding the use of such measurements. The increases in sonic velocities measured between some of the hydraulic fill holes near openings support the contention that approximate relationships may exist between sonic velocity and stress in some discontinuous rock masses.

The noise difficulty experienced at the Helen Mine showed the need for studies of vibration levels, preliminary to the use of the sonic apparatus.

ACKNOWLEDGMENTS

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