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REPORT OF INVESTIGATIONS

UNITED STATES DEPARTMENT OF THE INTERIOR - BUREAU OF MINES

USE OF SUBAUDIBLE NOISES FOR THE PREDICTION OF ROCK BURSTS, PART II

By Leonard Obert and Wilbur Duvall

INTRODUCTION

The investigation reported herein is part of a comprehensive research program being conducted by the Metal Mining Research Section, Mining Division, Bureau of Mines, on pressure problems in underground mines. This program was initiated in 1937 and for the first 3 years was concerned primarily with measurement of the pressure on mine pillars and supports and their strength. During this period, investigations were conducted in both the laboratory and the field in the comparatively shallow lead and zinc mines of Missouri and Oklahoma. As a result, a seismic method of determining the pressure on mine pillars was developed.

Before this research program was initiated, Chas. F. Jackson, chief of the Mining Division, suggested that rock under pressure might give rise to noises inaudible to the unaided ear - that is, subaudible noises. As a result of this suggestion, listening tests were made concurrently with the routine pressure measurements to see if any rock noises were present; with one exception, it was found there were no rock noises in any of these shallow mines. At the same time, pressure measurements disclosed that, with one exception,

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pills were not under pressure amounting to more than 10 percent of the crushing strength of the rock. The one exception was a pillar in the Big John mine of the Eagle Picher Mining & Smelting Co. in the Tri-State district, which showed some physical evidence of failure, such as small cracks and spalling; it was reported that the pillar had been heard to crack or snap at intervals. Listening tests in this pillar disclosed that subaudible noises of comparatively small intensity were present and occurred at 1- to 2-minute intervals, on the average. Unfortunately, owing to the shortness of this pillar it was impossible to make any pressure measurements.

In 1940 it was decided to attempt pressure measurements in deep mining. The Ahmeek mine of the Calumet & Hecla Consolidated Mining Co., Ahmeek, Mich., was selected, and tests were made in small rib pillars in the stopes at a vertical depth of approximately 3,800 feet below the surface. During these tests the pillars showed repeated evidences of pressure, such as cracking, spalling and hourglassing, and the back became displaced with respect to the footwall. Moreover, several small rock bursts occurred in the stope adjacent to these pillars. It was not surprising that the pressure measurements showed these pillars to be under a pressure approximately equal to that of the crushing strength of the rock. Throughout these experiments, a number of listening tests were made, and it was found that subaudible noises were continuously present, at times occurring with such frequency that they could not be counted. Listening tests at another section in the mine disclosed that this area, which normally was comparatively quiet (that is, with few subaudible noises present), became noisy just before a rock burst. On the strength of these observations, a series of tests of a preliminary nature was conducted over a period of approximately 1 month to determine something about the nature of these subaudible noises and whether they could be used for predicting rock bursts.6/ The tests disclosed that several types of rock noises could be classified, in addition to the noises due to rock drilling and machinery. The latter were found to be so intense that they obscured the rock noises, making it impossible to make observations except when the mine was inoperative. It was concluded that the occurrence of subaudible rock noises could be correlated with the occurrence of rock bursts; but, owing to the statistical nature of these tests, observations over an extended period with the proper apparatus would be required before it could be determined whether these correlations were accurate enough to permit prediction of rock bursts.

This report describes a series of tests over a 2-month period at the Ahmeek mine with a new apparatus designed particularly for this purpose. The

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6/ Obert, Leonard, Use of Subaudible Noises for the Prediction of Rock Bursts, Bureau of Mines Rept. of Investigations 3555, 1941, 4 pp. This report will hereafter be referred to as part I.
results of these tests are discussed both in respect to the nature of the
subaudible noises and to the ability to predict rock bursts. The report also
describes preliminary investigations at the Sunshine mine of the Sunshine
Mining Co., Kellogg, Idaho; the Frood mine of the International Nickel Co.,
Ltd., Copper Cliff, Ontario; and the Lake Shore mine of the Lake Shore Mines,
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TERMINOLOGY

Any sudden displacement or disturbance in the rock creates an impulse
which travels away from the source with a velocity equal to the velocity of
sound of that particular rock. When this impulse is picked up by the geophone
an electrical counterpart or pulse is generated. This pulse, when sufficiently
amplified, can be heard with the aid of ear phones. This acoustical equivalent
is referred to as a rock noise. When the amplified electrical pulse is recorded
by the graphic recorder it is referred to as a recorded noise. The term noise
will be used synonymously with disturbance, impulse, rock noise or recorded
noise whenever no ambiguity will result.

PHYSICAL PROPERTIES OF NOISE

To facilitate proper interpretation of the results of this investigation as
well as to clarify the reasons for the selected design of the apparatus used
in these tests, a brief discussion of the physical properties of impulse noises is included. Rock noises are a type of impulse noise, that is, a noise of short duration made up of a large number of frequency components of different amplitude. The tonal character of such a noise depends on the relative intensity of the various frequency components. For example, high frequencies—that is, high-frequency components with relatively large amplitudes—predominate in the sharp metallic noise made by dropping a small ball bearing on a steel plate, whereas low frequencies predominate in the drummy noise produced by striking a thin wood panel. The tonal character of such a noise often changes as the distance from the source to the point of detection is increased, owing to the fact that some frequencies are more strongly absorbed by the transmitting medium than others. Thunder is a good example of this phenomenon. The sharp report heard near the source becomes a low rumble at a distance owing to absorption of the higher frequencies by the atmosphere. The duration of a noise can also be increased by reflecting boundaries, a phenomenon also evidenced by thunder. Near the source the report lasts a comparatively short time, whereas at a distance from the source the sound persists much longer. This increase in duration time is due to the sound waves reflecting from one or more boundaries before reaching the observer and usually is referred to as reverberation.

Rock noises also exhibit all of these properties. Although no exact measurement has been made of the spectrum (that is, the frequency components) of rock noises or the effect of the medium on the transmission of such noises, these characteristics may be estimated qualitatively by listening to the amplified noises with earphones. After a period of practice it is not only possible to identify numerous types of disturbance but also to estimate the distance of the source from the point of detection. Although subjective observation of this type is very useful in the preliminary stages of an investigation, it is obviously not suitable for making a more exacting study. For such an investigation it is desirable to use some type of equipment that not only will record the rock noises but will make it possible to determine something about the intensity of the disturbance as well as the distance from the source of the disturbance to the point of detection.

**APPARATUS**

This discussion of the apparatus will cover only the essential functions of the various components. The apparatus will be described in detail in a later report, now in preparation. The apparatus will be considered in four parts (see fig. 1): (A) The geophone or sound detector and the transmission cable; (B) the high-gain amplifier and filters; (C) the logarithmic amplifier, time-discriminating circuits, power amplifier, and power pack; (D) the graphic recorder.
Figure 1.— Schematic diagram of apparatus used for recording rock noises: A, Geophone and transmission cable; B, high-gain amplifier and filters; C, logarithmic amplifier, discriminating circuits, power amplifier, and power supply; D, graphic recorder.
The geophone is essentially the same as that previously described. A bimorphic piezoelectric crystal 2-1/2 inches long, 3/4 inch wide, and 1/4 inch thick was mounted as a cantilever in a steel tube 1-1/4 inches in diameter and approximately 8 inches in length. It is thus about the size of a stick of powder and was designed so that it could be inserted in a rock-drill hole. This type of geophone is essentially an accelerometer; that is, the output voltage is proportional to the square of the frequency of vibration. This characteristic is desirable for a detector used in observing rock noises, because it places an emphasis on the higher-frequency components of these disturbances, which are usually of low intensity. The output of the geophone was connected to a transformer that reduced the line impedance to 30 ohms, permitting the use of as much as 1,000 feet of cable without serious attenuation or frequency discrimination, which is desirable because the geophone often was placed in a relatively dangerous region and this length of cable permitted the apparatus and observers to be stationed at a safe point.

The high-gain amplifier was a conventional three-stage resistance couple unit having a voltage gain of approximately 100,000 and a flat frequency response from 150 to 10,000 cycles. The amplifier was equipped with a calibrated attenuator having a range of 45 db. in 2-1/2-db. steps. This unit also contained a series of high-pass and low-pass filters having cut-off frequencies at 500, 1,000, 2,500, 5,000, and 7,500 cycles. These filters could be switched into the circuit so that any high-pass or low-pass section could be used alone or so that both a high-pass and a low-pass could be used simultaneously to form a band pass.

The next unit contained the logarithmic and peak limiting amplifier, the time discriminating circuits, the power amplifier, and the power supply. The logarithmic amplifier (that is, an amplifier whose output is proportional to the logarithm of the input) was used to compress the recording scale so that anything from the most minute disturbance to the most severe rock burst could be included on the same record. The limiting action of this amplifier prevented damaging the recorder if overvoltage was applied to the input.

The output of the logarithmic amplifier was divided and supplied to two circuits. One circuit effectively rectified and filtered the electrical impulse supplied to it in such a way that the output voltage varied as the peak voltage of the input pulse. The other circuit effectively rectified and filtered the electrical impulse supplied to it in such a way that the output voltage varied as both the peak voltage and the duration of the input pulse. These circuits will be referred to hereafter as the “fast” and the “slow” discriminating circuits according to the respective short- and long-time constants of the

circuit. These circuits make it possible to record the relative amplitude of the disturbances, as well as to discriminate between local and distant noises. The output of each discriminating circuit was supplied to a power amplifier having an output sufficient to drive the recording units (about 6 watts).

The power pack furnished both the plate and filament voltage for all of the apparatus, hence no batteries were required. It was designed to operate from a 25- to 60-cycle, 95- to 120-volt alternating-current supply. Operation from the alternating-current power source is necessary economically due to both the power consumption of this equipment and to the protracted periods of operation.

The last unit contained the graphic recorder. The recording paper used in this unit is manufactured by the Western Union Telegraph Co. and sold under the trade name of Teledeltos Dry Recording Paper. The trace on this paper is made by moving a stylus over the surface, through which a small current passes to a metal platen. This paper is much more desirable for such recording than photographic paper because no development is required; more important is the fact that the trace is immediately visible. This is particularly helpful, because the observer can listen with the earphones and see the record simultaneously, making it possible to correlate the pulses on the record with their counterpart as heard.

The recording paper was driven by a synchronous clock motor at a speed of 1-1/2, 3, or 6 inches per minute, depending on the gear ratio. The synchronous drive permitted simultaneous comparison of records made by the different recorders, which proved to be very useful in localizing the source of disturbances.

Two writing units were incorporated in each recorder; one operated from the amplified output of the "fast" discriminating circuit and the other from the amplified output of the "slow" discriminating circuit. They will be referred to respectively as the "fast" and "slow" recorders, and their corresponding records will similarly be referred to as "fast" and "slow". Sample records are shown in figure 2.

INVESTIGATIONS AT AHMEEK MINE

Geology and Mining Method

The Ahmeek mine of the Calumet & Hecla Consolidated Copper Co., Ahmeek, Mich., is in the Kearsage Amygdaloid lode of the Keweenawan copper-bearing series. The lode dips approximately 35° at the surface and decreases slightly with depth. The workable thickness at the present operating depth
Figure 2.—Representative records of drilling, blasting, and rock noises: A, Record of drilling noise; B, record of distant sounds; C, record of rock noises (comparatively quiet); D, record of rock noises, showing a series of remote disturbances of large magnitude; E, record of rock noises (comparatively noisy), showing a predominance of small noises. The upper trace in each record is made by the fast recorder and the lower trace by the slow recorder. All are for an 8-minute interval.
is 6 to 10 feet, and some sections of poorer ground are left unmined. The only rock in the mine is an amygdaloid, which varies widely in strength and hardness. The gray rock in some sections of the mine is comparatively hard and friable, whereas the brown to red amygdaloids are usually softer and have lower crushing strength. The present operating depth of the mine is 3,500 to 5,000 feet vertically from the surface. At this depth there is considerable evidence of pressure, such as movement of the hanging wall, crushing of pillars, and rock bursts. The mining method is a retreating system of open stoping with regularly spaced pillars. When this investigation was being made the mine operated two shifts a day, with a 4-hour supply period between each shift 6 days a week. Sunday was used for supplies and maintenance. All blasting was done in a 15-minute interval at the end of each shift.

Rock Bursts

The rock bursts in this mine vary widely in magnitude. The smallest amount to no more than a small bump, throw little or no rock, and often are so local that the jar cannot be felt 25 feet from the center of the disturbance. The largest bursts usually occur in the drifts and adjacent stope remnants in mined-out areas and may close as much as 100 to 200 feet of drift; however, no bursts affect more than one level. Between these limits there is a virtually continuous gradation of magnitudes. A small part of the bursts can be felt on the surface, although often the same bursts cannot be felt in other parts of the mine. The type occurring most frequently is a small burst, usually in the stope face, which displaces 1 to 5 tons of rock. Bursts often occur during or shortly after the blasting interval; otherwise, there is no period of the day more likely than another. Bursts are also more likely to occur in the hard-rock section of the mine than the soft.

Although the records taken are not adequate to permit studying the distribution of bursts, the data do indicate that bursts occur in cycles of 6 to 10 days. This cyclic effect may be correlated with the state of the stope development. It is reported also that bursts tend to occur in cycles lasting several months.

Normally, records of the number of bursts are not kept; in fact, it would be difficult to do so because some of them occur in remote parts of the mine or in supply periods and are not observed. During the 40-day interval in which these experiments were conducted, 45 bursts were reported by the miners (in the vicinity of the No. 3 and No. 4 shafts), a figure that probably is low by 10 to 20 percent.
Spectrum of Machinery and Rock Noises

The first test was conducted to determine the spectrum of the different mine noises to ascertain whether it would be possible to eliminate the noises made by machinery by using the filters in the recording apparatus. The equipment used in these tests was similar to the set-up shown in figure 1, except that a General Radio Sound Analyzer Type 60-A, was substituted for the power amplifier (unit C) and the graphic recorder (unit D) was not employed. Geophone A was always placed in a rock drill hole several feet deep to insure contact with solid rock. The output of the geophone was amplified by high-gain amplifier B, the output of which was supplied to the sound analyzer. With this arrangement, it is possible to study the frequency distribution of any continuous noise such as that due to rock drilling. Figure 3 shows the spectrum of the noise produced by a rock drill. In this record the geophone was placed about 100 feet from the drill. Several interesting points are indicated. First, the peaks at approximately 25, 50, 75, and 100 cycles are due to the fundamental and first three harmonics of the rock drill, corresponding to a drilling speed of approximately 1,500 impacts a minute. The large increase in the response at 700, 900, 1,100, and 1,400 cycles is due to the resonance of the geophone. If the increased output due to the resonances of the geophone is disregarded (that is, the region shown on the curve between 500 and 1,500 cycles), the results indicate that the output of the rock noises as shown in figure 3, was comparatively constant from 25 to 7,500 cycles a second. Assuming that it is constant and recognizing that the output of the geophone is proportional to the square of the frequency, this implies that the rock noises decrease in amplitude as the square of the frequency.

Such an analysis of the rock noises could not be made because they test too short a time for a reading to be obtained on the analyzer. However, an approximate analysis can be made by listening to the output of the analyzer with ear phones.8/ Using this method during an interval when more than 100 rock noises were occurring per minute, it was found that they had a spectrum quite similar to that of the rock drill over the same frequency range. Tests were also made with impact blows on the face of the drill by a very light hammer. The intensity of these blows was checked with the recorders, and it was found that a blow could be reproduced with fair accuracy. When the hammer blows were made near the geophone it was again found that the spectrum was similar to that of the rock drill, whereas, when they were made several hundred feet from the geophone (the gain of the amplifier was increased to compensate for the corresponding loss of intensity), the low-frequency end of the spectrum was found to be similar but the high-frequency end showed

8/ This approximation is not too bad because the output in the General Radio Sound Analyzer for any frequency varies approximately logarithmically with the input, that is, roughly in proportion to loudness units.
Figure 3.—Spectrum of drilling noise.
Figure 4.—Plan of 41st, 43d, and 44th levels, Ahmeek mine, showing stope development and position of test holes (indicated by numbers in circles).
that the output dropped off above 2,000 cycles, due to absorption of the higher frequencies in the rock.

In another test, the recorder was substituted for the noise analyzer. When the geophone was planted near the rock drill, it was found impossible to discriminate between the drilling noise and the rock noise, regardless of the filter combination. This is what would be expected from the analysis made with the sound analyzer. The apparatus was then moved to one of the upper levels, so that the geophone was over 300 feet from the rock drill. It was now found that noises, presumably originating in the vicinity of the geophone, could be distinguished from the drilling noise when a high-pass filter was used, because the high-frequency components of the drilling noise had been sufficiently absorbed in traversing this distance to make it possible (with the aid of the high-pass filters) to discriminate between the rock and the drilling noises. A series of tests using the hammer blow near the geophone also gave similar results.

The conclusion gained from these tests was that the rock noises arising in the vicinity of the active stopes could not be recorded while the drills were running. A record could be made some distance from the stopes; but it would include noises originating in that vicinity and not those originating in the stope. Observations possible in the vicinity of the stope are thus limited to periods when the stope is idle.

Origin of Rock Noises

A series of tests was conducted for a 9-day period to determine how and where the rock noises originate and the distance they are propagated. For these tests, 14 test holes were drilled in the hanging-wall side of the drift on the 43d level (approximately 4,000 feet vertically below the surface) directly above the operating stopes of the 44th level. Figure 4 is a map of this area, showing the location of the holes.

Two complete recording systems (such as in fig. 1) were used in these tests. Each day the geophone of one of the recorders was placed in one of the test holes (usually the hole found to be noisiest) and allowed to remain there throughout the test. The second geophone was used as a probe and placed successively in the remaining test holes. A 10-minute recording of the noises was thus made for each pair of holes. As the recorders are driven synchronously, the two records may be compared and the corresponding record of each noise identified. These are referred to hereafter as coincidences. By comparing the corresponding amplitudes of the coincidences it is possible to determine which geophone is closer to the source of the disturbance (the amplitude diminishes as the distance from the sources increases).
comparing the results for the different pairs of test holes further, the general area in which the maximum number of noises originate can be localized. These tests gave the following results:

(1) The type of disturbance recorded by the slow recorders usually came from a distance exceeding 200 feet, as was inferred from the fact that simultaneous amplitudes on the two records for such a disturbance had very nearly the same amplitude. This would necessitate that the distance from the source to the geophones was large compared with the separation of the geophones. No further information could be obtained from the slow recording, and for this reason only fast records were made during the localization tests.

(2) The largest part of the disturbances recorded by the fast recorders travels less than 100 feet, and a small part of them travels less than 5 feet, as was determined from the following observations. One geophone was placed in hole 1 and the other in hole 2 (the separation between these holes was approximately 5 feet), and a 10-minute record was made of the noises. This procedure was repeated several times throughout the 9-day test period. Comparison of these records disclosed that 5 to 10 percent of the recorded noises were not coincident; that is, 5 to 10 percent of the disturbances received by one recorder were not received by the other. These noncoincidences were indicated by an excess (that is, one record showed more noises than the other), by a mutual difference (that is, both records showed the same number of noises but a part of them on one record was not present on the other), or by a combination of both (see fig. 5). This test procedure was repeated, the first geophone being left in hole 1 but the second geophone moved to hole 3, and so forth, until the remaining holes were tested. Thus the separation between the geophones could be varied from 5 to 175 feet. Employing the coincidence method, the results of this procedure showed that approximately 90 percent of the noises recorded by the fast recorder traveled less than 100 feet and over 50 percent traveled less than 50 feet.

(3) These "small" noises originate in solid rock and not in the loose rock in the stope, as was originally supposed. This was deduced from the fact that the distance from the stopes to the geophones was greater than the distance these small disturbances were propagated. This was verified further by moving loose rock in the stope. The character of these noises was found to be different, particularly in that the high-frequency components were absent. Furthermore, these created noises gave rise to coincidences.

(4) These "small" noises originate in rock under pressure. The occurrence of small noises in pressure areas has been determined in several ways. For one thing, in the stopping sequence used in this mining method (see fig. 4) the area most subject to rock bursts is in the remnant above the high stope.
Figure 5.—Record of small noise in vicinity of 44-level stope. Record A shows a large excess over record B. Separation between geophone holes was 175 feet.
The coincidence tests showed that this area is the source of most of the small noises, and as the distance from this area to the detecting geophone was increased, not only did the total number of recorded noises decrease but also the number of noises originating near the geophone. For example, when 603 noises per 10 minutes were recorded in hole 1, 498 per 10 minutes were recorded in hole 5 (including 386 coincidences), 250 per 10 minutes in hole 11 (238 coincidences), and 103 per 10 minutes in hole 13 (all coincidences). A rock burst occurred approximately 5 hours after these data were taken in the face of the high stope. On the following day, a similar series of tests gave the following: Hole 5 (now the noisiest), 213 noises per 10 minutes; hole 1, 85 noises per 10 minutes (74 coincidences); hole 9, 56 per 10 minutes (all coincidences); and hole 13, 20 per 10 minutes (all coincidences). Three days later the same test was repeated with this result: Hole 5, 515 per 10 minutes; hole 1, closed off owing to a slip; hole 11, 197 per 10 minutes (160 coincidences); and hole 13, 71 per 10 minutes (all coincidences). Approximately 7 hours after these data were taken, a burst occurred in the stope adjacent to the high stope directly below test hole 5. Assuming that the bursts occur in the zone of maximum pressure, these results indicate that the maximum number of disturbances originate in the area under maximum pressure. Further verification of this result was obtained at the Frood mine of the International Nickel Co. and will be discussed later in this report.

**Physical Properties of Small Rock Noises**

The small rock noises, besides being of much smaller magnitude than those produced when visible cracking occurs, have a predominant number of strong, high-frequency components. There was very little audible difference in the character of these noises when a 2,000-cycle high-pass filter was inserted. This difference in the spectrum of these noises makes it possible to identify them, using only ear phones.

Attempts were made to produce artificially a disturbance having the same characteristics. It was found that this small noise could be simulated by cracking (not crushing) a single grain of sand on a smooth surface in the wall of the drift by pressing on it with a blunt instrument. This indicates both the magnitude of these small disturbances and the sensitivity of the detecting apparatus.

**Prediction Tests**

For the prediction tests, one recorder was installed on the 43d level, a second on the 41st level (160 feet on the dip above the 43d level), and a third on the 40th level (320 feet on the dip above the 43d level). The geophone on the 43d level was placed directly above the operating stopes of the 44th level (see fig. 4), and the geophones on the 41st and 40th levels were placed as nearly as possible in a line above this stope. The recorders were turned on
just before the rounds for both the day and night shifts were fired and were allowed to run throughout the 4-hour supply period. No data were taken on Saturday afternoon, Sunday, or Monday morning. At the end of the fourteenth day, the stoping had come so close to the geophone on the 43d level that there was danger of the blasting damaging it, so it was moved 80 feet down the drift. The observations were made without further interruption for the remaining 26 days, the test period totaling 40 days. Several sections of these records are shown in figure 2.

During the same period, a record was kept of the time and place of occurrence of the rock bursts in this stoping area. This record is believed to be correct, with the possible exception of bursts that might have occurred on Sundays or during the blasting period.

The data obtained from these tests are of a statistical nature, and for their proper interpretation a number of factors must be considered. For one thing, the record taken during the first hour after blasting was not used because the noises during this interval were found to be so frequent that it was impossible to resolve the recorded noises sufficiently to permit counting them. A representative curve of the rate of occurrence of recorded noises during the 4-hour period after blasting is given in figure 6. Moreover, the record taken during the last hour of this interval often contained machinery and other created noises, so that this hour was disregarded. The actual data period was thus restricted to 2 hours.

In interpreting the data, not only the rate of occurrence of the noises but also their amplitude were considered. For this purpose, both the "fast" and the "slow" recorded noises were divided arbitrarily into three amplitude groups, giving a total of six classes of recorded noises. These are designated as follows:

Class 1. - Small-amplitude group, made by the fast recorder.
Class 2. - Medium-amplitude group, made by the fast recorder.
Class 3. - Large-amplitude group, made by the fast recorder.
Class 4. - Small-amplitude group, made by the slow recorder.
Class 5. - Medium-amplitude group, made by the slow recorder.
Class 6. - Large-amplitude group, made by the slow recorder.
Figure 6.—Representative curve showing the rate of occurrence of subaudible noises during the 4-hour period after blasting.
Figure 7.—42-day chart of subaudible noises (class 2 per 2-hour interval) Ahmeek mine, 44th level stope. Rock-burst predictions are indicated by the P's and actual rock bursts by marks along abscissa.
Besides these, two other classes were considered in analyzing the data,

**Class 7. - Total number of fast recorded noises; that is, sum of classes 1, 2, and 3.**

**Class 8. - Total number of slow recorded noises; that is, sum of classes 4, 5, and 6.**

The records were analyzed as follows; each 2-hour record was divided into four 1/2-hour sections. In each section, the number of recorded noises of each class was counted. Then the number of recorded noises per half hour, per hour, and per 2 hours for each of the eight classes (see fig. 7) was plotted upon a day-to-day basis, making a total of 56 charts for each recorder and a grand total of 138 charts for the complete test. The data were broken down in this rather laborious manner to see if there was any preferred period of time or amplitude class for prediction purposes. The results of this analysis showed that all 138 charts exhibited a general similarity in that the more prominent maxima and minima corresponded. However, the correspondence was not as well-defined for the results for the 41st and 40th levels. Further examination of the charts revealed that the recorders on the 41st and 40th levels had picked up only a small percentage of the noises registered by the recorder on the 43d level. Moreover, of the noises picked up on the 41st and 40th levels, less than one-third were coincidental with those registered on the 43d. These results indicate that the recorders on the 41st and 40th levels were placed too far from the pressure zone surrounding the 44-43 level stoping area to be useful.

To determine which of the remaining noise charts would serve best for prediction purposes, several arbitrary criteria were specified, each of which might be considered indicative of a dangerous condition or burst, such as a relatively high number of noises per unit time or a large percentage change in the recorded number of noises per unit time. Of the criteria tried, that found most satisfactory for prediction purposes was: “When the number of recorded noises increases in any interval (not exceeding 24 hours) by a factor of 2 or more a dangerous condition is indicated. Furthermore, if after such an increase, the number of noises continues to increase the state of danger is presumed to persist.”

When this arbitrary criterion was applied to the data each time the chart indicated a dangerous condition, the chart was marked at the point with a P, designating prediction. When these charts, so marked, were compared with the record of the 11 rock bursts that occurred in this stoping area during the 40-day test period, the chart found most satisfactory for prediction purposes was that of the class 2 noises per 2-hour interval; this chart is reproduced in
figure 7. On this chart, 14 predictions were made; 9 were followed by rock bursts within 12 hours or less. There were 5 predictions that were not followed by bursts, and 2 unpredicted bursts occurred on the same day. Regarding these 2 bursts, this much can be said. The record made after the 2 bursts (which occurred on the fourth day) showed a large increase in the number of subaudible noises. Possibly a sudden increase occurred before the burst but after the record made on the morning of the fourth day. Other records showed that increases of this amount have occurred in less than 5 minutes. It is interesting to note that no burst occurred after the large increase on the afternoon of the eighth day, whereas two bursts occurred before this for relatively much smaller increases.

That the class 2 noises per 2-hour period were most satisfactory for prediction purposes is at least partly understandable if the following factors are considered: First, a 2-hour interval is required for good averaging. The four 1/2-hour charts showed much larger variation, which probably was more of a statistical fluctuation from having too few noises per unit time. This same factor doubtless caused the data from the slow recorder to be more erratic, because only one-sixth as many noises are recorded by it as by the fast recorder. The noises recorded by the slow recorder may not represent local conditions as well because it records noises from much more distant points. Of the data taken by the fast recorder, the number of noises of the large-amplitude class (class 3) was too small for statistical purposes. The small-amplitude class (class 1) simulated class 2 rather closely, except that there was a general daily increase in the average number of noises with time, presumably due to the fact that, as the mining progressed, the stopes became closer to the geophones and hence the average number of noises increased. This was verified further when the geophones were moved at the end of the 12th day and the average number of noises dropped appreciably.

If these experiments were to be repeated, it would be much more satisfactory to employ at least two recorders on the same level to obtain a better average; this would tend to eliminate conditions too local in nature.

INVESTIGATIONS IN OTHER DEEP MINES

The type of subaudible noises noted at the Ahmeek mine undoubtedly depends, at least to some degree, on the type of rock in this mine. The question arose as to whether rock in other deep mines in different geological formations would develop subaudible noises and whether these noises, if present, would have characteristics similar to those at Ahmeek. To answer this question, preliminary tests were made at three other deep mines; these tests consisted of placing geophones in strategic places in the mine and listening to the amplified noises. With one exception, no attempt was made to localize the source of the noises. Because of this, the estimates in the following
discussion of the distance from the source to the point of observation and of the type of disturbance are based primarily upon the experience gained at Ahmeek.

Sunshine Mine, Sunshine Mining Co., Kellogg, Idaho

Geology and Mining Method

The geology of this district shows four rock formations, the Revett, St. Regis, Wallace, and Striped Peak, all of which are sedimentaries of the pre-Cambrian Belt series. The lowest is the Revett which is mainly white, thick bedded quartzite. Above it is the St. Regis, consisting of purple and green indurated shales and quartzitic sandstones. Next highest is the Wallace, comprising thin-bedded calcareous shales, with siliceous magnesian limestone and calcareous quartzite in their middle part. The highest of the four is the Striped Peak, consisting of shales, sandstones, and shaly quartzite.

The mine is operating at present mainly in the Revett and St. Regis beds, which have been subjected to compressive stresses, as evidenced by folding. The main minerals are predominately sericitic quartz. The vein dips approximately 60° to 75°. The rock is comparatively hard and shows no tendency to develop small cracks. There is very little visual evidence of pressure, such as spinal cracking and hourglassing, in the drifts or pillars of the mine.

Rock Bursts

The mining method at the Sunshine Mine is a modified flat-back square-set, and most of the rock fill is obtained from development work. The mine has been opened to the 3,700-foot level, which is approximately 3,700 feet below the surface at the collar of the Jewell shaft and 5,000 feet at the east end of the mine. At the time of these tests the lowest stope area was on the 3,100-foot level, which is approximately 3,100 feet below the surface measured at the collar of the shaft and approximately 4,000 feet below the surface measured in the vicinity of the stope area.

The Sunshine mine has a type of rock burst quite distinct from the others discussed in this report - a severe jar or bump causing a severe earth tremor. The ground does not tend to heave, throw rock, or crush timber. In other words, the magnitude of the rock displacement is small enough to be called seismic. The principal hazard in this type of disturbance is the tendency for these bumps to jar or shake loose large pieces of back, particularly in the stoping areas.
These bursts are infrequent. On the average, there is about one a month. During 1940 the largest number reported in any one month was three, and there were periods of over 2 months in which none occurred. Since October 1941 there has been a marked decrease in frequency.

The bursts usually are felt over large sections of the mine, as well as on the surface, and often it is difficult to localize the exact center of the disturbance. In comparing this type of disturbance with those in other mines probably the Sunshine mine bursts would correspond most nearly to the pressure bursts in the Witwatersrand, as described by Weiss.9/

Rock Noises

Listening tests were made on two successive days in a 2-hour interval between shifts. Six test holes were drilled in the hanging-wall side of the drift on the 3,100-foot level. A test lasting about 20 minutes was made in each hole. Both large and small types of rock noises were noted in this mine. The large reports would be classified as intense (class 5), and although it was estimated that the source was some distance from the point of detection, the sounds still contained a predominance of higher frequencies. The smaller noises (classes 2 and 3) were similar to the small noises at Ahmeek. No attempt was made to localize the source of the small noises or the pressure zone (in fact, this test was made before that at Ahmeek, and this interpretation was not understood at the time of these tests). The results show primarily that rock of this type gives rise to subaudible noises similar to those heard in other ground. Although the number of disturbances heard was not high, it must be remembered that these observations probably were not made near the focus of any pressure zone.

Frood Mine, International Nickel Co., Copper Cliff, Ontario

Geology and Mining Method

The walls of the Frood ore body10/ are metamorphoses sediments and greenstones, which are the oldest rocks in the district. These are part of a formation known as the Sudbury series and are equivalent to the Timiskaming series of the Cobalt district. The ore body is contemporaneous with the


Figure 8.—Map showing area tested on 3,100-foot level, Frood mine, International Nickel Co. Numbers indicate location of test holes.
Sudbury nickel eruptive and belongs to the Keweenawan series; its average dip is 65°. Chalcopyrite and pentlandite in an igneous gangue are the principal ore minerals.

The ore body is mined by the horizontal cut-and-fill method. The sedimentary rocks are relatively hard (crushing strength, estimated at 10,000 to 20,000 p.s.i.), whereas the crushing strength of the ore is much lower (estimated at 5,000 p.s.i. or less). The present operating depth is 2,000 feet to 3,500 feet vertically. The ore body differs sharply from the others reported herein in one respect; it is 100 to 300 feet thick.

There is considerable evidence of pressure, particularly in the ore body, where large cracks occur, the floor is heaved in places, and the timber is squeezed. Where the drifts run through wall rocks there is also cracking, often at a considerable distance from the ore body.

**Rock Noises**

Listening tests were made on two consecutive nights at a time when the mine was inoperative. The first tests were made on the 2,800-foot level in the vicinity of the No. 6 hoist station, which is approximately 550 feet from the ore body in the hanging wall. The effects of pressure in this area are evidenced by numerous cracks in and surrounding the hoist station. The tests disclosed numerous intense rock noises (probably of classes 5 and 6); some of them could be heard without the equipment, but small noises of a local nature were absent. This was taken to indicate that when this test was made the area was not in an active pressure zone but presumably had been at some previous date, as indicated by cracking. The source of these rock noises was estimated to be approximately 1,000 feet from this point of observation. The nearest stoping area was approximately 650 feet from this point on the 3,100-foot level and was decided to be the most logical place to look for the source of these disturbances. Accordingly, on the following morning 20 test holes were spotted in this area, but before these were drilled a burst in the center of this area, crushed timber in both drifts, heaved the floor, and threw several tons of rock from the face of the drift. Test holes were subsequently drilled around this area, as indicated in figure 8. That night listening tests were made in this area, with the following results: In test hole 1, the number of rock noises was high, estimated to exceed 100 a minute; there were many loud reports (some of which were audible without the apparatus), as well as a background of small noises, apparently of a very local nature. In test hole 2, the noises were not as frequent (estimated at 50 a minute), with a proportionately larger decrease in the small noises. When the noises from test holes 1 and 2 were listened to simultaneously (using two geophones and amplifiers), it was found that many of the noises did not coincide, indicating that they were
of local origin. In test hole 3, the number of rock noises was estimated at 20 a minute; most of them coincided with those in test hole 2 and apparently were not of local origin. At this time (3:50 a.m.) a second burst occurred in the area (see shaded area, fig. 8), which broke more timber and threw several tons of rock into the drift. A test was next made in hole 4, and it was found to be quieter than hole 3. Apparently holes 3 and 4 were out of the pressure zone. Hole 5 was found to be very noisy - about the same as No. 1. Finally hole 6 was tested and found to be even noisier than Nos. 1 or 5. The disturbances were estimated at 200 a minute; when it is considered that many of the noises were of relatively high intensity, this ground was judged to be the noisiest observed in any mine to date.

Lake Shore Mine, Lake Shore Mines, Ltd., Kirkland Lake, Ontario

Geology

According to Robson, the productive veins of the Kirkland Lake district lie within a belt of metamorphosed tuff, conglomerate, and graywacke that occupied the synclinal trough in the old Keewatin basement. This syncline is narrow in the vicinity of Kirkland Lake, is about 2 miles wide, and extends about 100 miles in a direction east by west. The ore bodies at Lake Shore were deposited in preore fault zones. Two main veins, designated as the No. 1 or south vein and the No. 2 or north vein, lie roughly parallel and are about 400 feet apart at the surface. The dip ranges from about 75° to 87°. The ore body has been subject to considerable post-ore cross faulting of great magnitude; in addition, strike faults of even later age are common. The mineralized section of the mine is mostly porphyry and syenite. The porphyry tends to slough off the wall and back, sometimes in masses, whereas the syenite is characterized by smooth fracture faces and is likely to be mineralized with chlorite. The rocks at Lake Shore are classed as hard and brittle, which, with the fracture and jointing, tend to favor the occurrence of rock bursts.

Rock Noises

A series of tests similar to those conducted at the Sunshine and Frood mines were conducted at Lake Shore. The first area tested was on the 38th level (approximately 3,800 feet below the surface) near the main crosscut on the vein. A few local and a few distant noises were heard; the total did not exceed two disturbances a minute, on the average. It was noted that in this ground the noises of higher frequencies appeared to predominate. The second test was conducted on the 4,325 foot level approximately 700 feet west of the main crosscut on the north vein. This ground was considerably noisier. Practically all the noises heard were apparently of a local nature, and none

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could be heard without the equipment. It was found that this rock transmits sound with very little attenuation. Rock drills could be heard running on adjoining property at least 1,500 feet away; at times the noise they made was sufficiently intense to obscure at least part of the local disturbances. It is difficult to estimate the distance to the source of these disturbances when the sound transmission is so good. Owing to the predominance of high frequencies in the rock noises, high-pass filters might assist in eliminating the drilling noises. A third test in this area was begun a short time before the rounds were fired and continued for about 2 hours. The rock in this section was found to be noisier even before blasting, than that tested the preceding day. After blasting there was a relatively large increase in the number. A few of the noises were audible, and one was of such intensity as to be classified as a small strain burst. It was not determined whether this did any damage. An hour after the blasting period the rate of the disturbances had become nearly constant at 10 to 15 a minute. In a fourth test, made the following day on the 4,200-foot level, two sets of apparatus were used, and the geophones were separated by approximately 500 feet. The noises were found to be largely local; that is, the large part of the disturbances was not simultaneous in the two receivers. The number of disturbances ranged between 8 and 22 counts a minute about one-half hour after blasting had been completed.

SUMMARY

This summary includes a discussion of the work reported herein and reviews certain phases of previous investigations that bear directly on this problem. This general review purposes to show that methods of detecting subaudible noises have been studied sufficiently to permit certain generalizations to be made concerning the occurrence of rock noises.

The apparatus used in the present investigations has been evolved from that originally designed to measure the pressure on rock pillars. The geophone and high-gain amplifier are essentially the same as before, and the listening tests described in this report therefore can be compared with those made previously. The principal differences in the present apparatus are the inclusion of the graphic recorder and the change from battery operation to operation from an alternating-current source. The graphic recorders make a permanent record of the subaudible noises, which heretofore could be subjectively recorded using earphones. Discriminating circuits in the recorders effectively integrate the impulses in such a way that both the intensity of the disturbance and the distance from the source to the point of detection can be estimated. Furthermore, operation of the recorders from the power supply makes it possible to synchronize the recordings so that the simultaneous record made by any disturbance can be identified on each of the recordings. Comparison of the simultaneous records of a given disturbance,
as recorded by two or more recorders, makes it possible to approximate both the direction and the distance to the point of origin.

Besides the rock noises, other noises often present in the rock (due to such causes as rock drilling, operation of the skip and pumps, and movement of ore in passess) tend to interfere with and often obscure the recording of the rock noises; the most objectionable of these is due to rock drills. The physical properties of both the drilling and rock noises were studied to see if the drilling noises could be eliminated sufficiently, by means of selective filtering, to permit the recording of rock noises.

Analysis of the spectrum of the rock and drilling noises made at the Ahmeek mine shows that the frequency range of the drilling noise completely overlaps the rock-noise spectrum. Moreover, if the distance from the drilling to the point of observation was less than 200 feet, it was found that the intensity of the drilling noise exceeded that of the larger part of the rock noises. Thus, within a 200-foot radius, no combination of filters would make it possible to discriminate between the rock and the drilling noises. At distances greater than 200 feet, it was found that a high-pass filter would reduce the drilling noise enough to permit the louder rock noises to be recorded; at 500 feet, with the aid of the filter, all but the smallest class of rock noises could be recorded satisfactorily. The distance at which a satisfactory recording can be made from an operating stope depends on the ability of the particular rock to transmit sounds and therefore would vary from mine to mine. For example, in the highly absorptive disseminated rock of the Miami Copper Co. it is possible to record satisfactorily within 200 feet of an operating stope without the aid of a filter, whereas in the ore bodies consisting primarily of harder types of rock, such as that of the Cliff Shaft mine of the Cleveland Cliff Iron Mining Co. or the Lake Shore mine of the Lake Shore Mines, Ltd., the distance at which a satisfactory recording could be made would exceed 1,000 feet, even with the aid of filters.

The inability to discriminate between the rock and drilling noises in certain mines restricts the observations to periods when the mine is inoperative or to areas remote from operating stopes, a disadvantage that, to date, it has been impossible to circumvent.

The test at the Ahmeek mine to determine the origin of rock noises disclosed two important facts; first, the majority of rock noises are very local, usually traveling less than 100 feet. Noises of this type have been referred to throughout this report as "small noises," and because they are propagated such short distance the area in which they originate can be localized. Second, it was found that these small noises originate in areas under pressure, as was demonstrated by probing in an area suspected of being under
### Figure 9: Summary of observations in 9 mines

<table>
<thead>
<tr>
<th>Mine and company</th>
<th>Present vertical operating depth below surface, feet</th>
<th>Ore</th>
<th>Immediate country rock</th>
<th>Visual evidence of pressure</th>
<th>Measured pressure</th>
<th>Rock noises (maximum)</th>
<th>Rock bursts</th>
<th>Physical properties of ore and rock</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leadwood mine, St. Joseph Lead Co., Leadwood, Mo.</td>
<td>300 to 500</td>
<td>Galena replacement Dolomitic limestone in limestone</td>
<td>None; large open stopes; no timbering</td>
<td>Small</td>
<td>None</td>
<td>None</td>
<td>Rock: Fine grain, strong, tough; crushing strength, 20,000 to 35,000 p.s.i.</td>
<td></td>
</tr>
<tr>
<td>Miami Copper Co., Miami, Ariz.</td>
<td>600 to 1,100</td>
<td>Disseminated chalcopyrite and oxidized copper</td>
<td>Ore shows squeeze; block caving; heavy timbering</td>
<td>Small</td>
<td>Occasional disturbances of local origin</td>
<td>do.</td>
<td>Very low crushing strength.</td>
<td></td>
</tr>
<tr>
<td>Cliff shaft, Cleveland-Cliffs Iron Co., Ishpeming, Mich.</td>
<td>100 to 1,100</td>
<td>Hard hematite and magnetite</td>
<td>Sedimentary, intruded and metamorphosed by basic igneous rocks (jasper and slates)</td>
<td>Occasional interruptions; very small disturbance</td>
<td>Occasional (1 in 5 minutes); very small disturbance</td>
<td>do.</td>
<td>Ores: Hard; crushing strength, 20,000 p.s.i. (Jasper: Hard and friable).</td>
<td></td>
</tr>
<tr>
<td>FLOOD mine, International Nickel Co., Copper Cliff, Ont.</td>
<td>2,000 to 3,500</td>
<td>Magnetic deposit containing magnetite, pyrrhotite, and pentlandite in igneous gneiss</td>
<td>Metamorphosed sedimentary; graywacke, quartzite, and gneiss</td>
<td>Considerable evidence, cracking in pillars; large cracks and squeeze in drifts; spinal cracking in drifts</td>
<td>300 a minute in pressure zones; large and small disturbances</td>
<td>2 to 4 a month; severe bums; no rock displaced</td>
<td>Rock: Moderately hard to hard; crushing strength, 10,000 to 20,000 p.s.i.? Ores: Relatively weak</td>
<td></td>
</tr>
<tr>
<td>Sunshine mine, Sun-Shine Mining Co., Kellogg, Idaho</td>
<td>2,000 to 4,000</td>
<td>Siderite and quartz with argilliferous tetrarhodite</td>
<td>Quartzitic sandstones, shales, and chlorite with argilliferous tetrarhodite</td>
<td>Occasional indications; cracking in drifts</td>
<td>---</td>
<td>---</td>
<td>Rock: Moderately hard to hard; crushing strength, 10,000 to 20,000 p.s.i.? Ores: Relatively weak</td>
<td></td>
</tr>
<tr>
<td>Magma Copper Co., Superior, Ariz.</td>
<td>2,000 to 4,600</td>
<td>Bornite-quartz vein with pyrite and chalcopyrite</td>
<td>Quartzite and diabase</td>
<td>Occasional disturbance; 1 in 5 minutes; usually loud</td>
<td>---</td>
<td>Occasional disturbance; 1 in 5 minutes; usually loud</td>
<td>Rock: Moderately hard; crushing strength, 10,000 to 15,000 p.s.i.; Ores: Low crushing strength.</td>
<td></td>
</tr>
<tr>
<td>Lake Shore mine, Lake Shore Mines, Ltd., Kirkland Lake, Ont.</td>
<td>3,800 to 6,200</td>
<td>Siliceous gold vein</td>
<td>Metamorphosed tuff, conglomerate, and greywacke</td>
<td>Cracking in drifts; pillars show evidence of weight</td>
<td>20 a month; may be higher in pressure zones</td>
<td>6 a month, of which about 85 percent are minor bursts</td>
<td>Rock: Relatively hard, brittle, cross fractured and jointed; crushing strength, 10,000 to 15,000 p.s.i.</td>
<td></td>
</tr>
<tr>
<td>Ahmeek mine, Calumet &amp; Hecla Consolidated Mining Co., Ahmeek, Mich.</td>
<td>3,000 to 5,000</td>
<td>Native copper</td>
<td>Amygdaloid</td>
<td>Considerable evidence; pillars cracked and hourglassing; drifts cracked and spinel cracking; floor heaved</td>
<td>Large; approaches</td>
<td>200 a minute in zones under heavy pressure; large and small disturbances</td>
<td>1 a day; largest part minor bursts, many displacing less than 2 tons of rock</td>
<td>Rock: Moderately hard to hard; crushing strength, 5,000 to 15,000 p.s.i.?</td>
</tr>
</tbody>
</table>
excessive pressure and correlating the number of rock noises with the occurrence of rock bursts. It was found that in an area which subsequently burst the number of noises was relatively higher than in the surrounding rock. Similar results were obtained at the Frood mine of the International Nickel Co. The occurrence of rock noises in pressure areas has particular significance, because it makes possible a method of determining pressure areas in underground mining, a point that has been one of the ultimate objectives of the general program of investigation being conducted by this laboratory. A means of detecting pressure areas can be useful, not only for determining areas subject to rock bursts but for studying the effect of general mining practices, such as the effect of cutting drifts or shafts in an ore body or for studying the advantages or disadvantages of various stopeing sequences.

Besides the data on rock noises that have been discussed in this report, observations have been made in five other mines before the investigations reported herein were begun. These observations comprised measurements of the pressure on mine pillars, measurements of the physical properties of the rock and ore, and listening tests to determine whether subaudible noises were present and, if so, to what degree. These data are summarized in tabular form in figure 9; the name of the mine and mining company, the present operating depth vertically below the surface, and the predominant ore appear in columns 1, 2, and 3 respectively. The immediate country rock (that is, the rock immediately surrounding the ore body as observed from the drifts, crosscuts, and other mine openings) is stated in column 4. Column 5 presents such evidences of pressure as could be observed from visual inspection. In three of the mines, measurements have been made by velocity of sound method of the pillar pressure, with results in column 6. In column 7 an estimate of the maximum number of rock noises per unit interval of time is given. Except for the Ahmeek mine, this number is only approximate because it was obtained from only a short period of observation. An estimate of the number of rock bursts per given interval of time and their relative severity is found in column 8, and in column 9 the physical properties of the ore and rock are reported. The rock and ore referred to here are restricted to those in which the listening tests and observations were made and in which the subaudible noises, if present, were thought to originate.

A number of conclusions can be drawn from a study of this chart. First, at the mines visited rock bursts do not occur at depths less than 2,000 feet, a finding consistent with the report of other investigations of rock bursts in mining districts throughout the world. Second, under normal mining conditions rock noises seldom occur at depths of less than 1,000 feet. However, it is possible and from the experience indicated herein, likely, that, if mining operations were practiced in which excessive pressures were developed, rock noises would occur, even in shallow mines. Third, it is evident that the number
of rock noises increases, in general, with the depth of the mining operation. Assuming "a priori" that the pressure increases with the depth, this fact is consistent with the observation that the rock noises originate in rock under pressure. It is interesting to note that the mine of the Magma Copper Co., Superior, Ariz., is the only deep mine that is entirely free from rock bursts, and this mine also has by far the fewest number of rock noises per unit time. Fourth, the presence of rock noises is not restricted to any particular type of geological formation; in fact, the results presented herein indicate that rock noises occur more or less independent of the geology. In this respect it has been observed that the occurrence of rock noises can be correlated better with the physical properties of the rock than with their geology.

The rock and ore that showed the least tendency to give rise to rock noises under conditions where they would normally be expected, as indicated from visual evidences of pressure, are the disseminated porphyries and schists of the Miami Copper Co. It is thought that this ore is particularly quiet due to the presence in the cracks and joints of the rock of sericite and talc, which act as lubricants and tend to prevent the formation of sound when movement occurs.

The results and conclusions presented above are used as the basis for the following qualitative generalization, namely, that rock noises result from excessive pressure on the rock and, except in degree, are independent of the geology; and, conversely, the occurrence of rock noises can be taken to indicate excessive pressure.

The results obtained at the Ahmeek mine on the prediction of rock bursts by the use of subaudible noises indicate that the number of rock noises before a rock burst increases sufficiently to serve as a means of predicting rock bursts, at least with moderate accuracy. This accuracy no doubt could be improved if continuous observations could be made throughout the day; however, owing to the noise of drilling, it was impossible to make observations during the working day, and hence it was necessary to base these predictions upon data obtained during supply periods only. The results indicate that, for this particular mine, a satisfactory criterion for the prediction of rock bursts is (1) that a rock burst shall be anticipated if the number of subaudible noises per unit time increases by a factor of 2 or more over that of the preceding observation and (2) that a condition subject to the occurrence of rock bursts shall continue to be anticipated if observations following one showing a twofold increase show a further increase. This criterion was based upon observations over a 40-day period. The accuracy of the predictions might be improved if observations covered a longer period.

Such a criterion as this depends on local conditions and not only might vary from mine to mine but also with mine conditions, such as changes in the mining method or in the physical properties of the rock and ore.