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REPORT ON THE PERCEPTION OF SUBTERRANEAN SOUNDS AND THE PLOTTING OF SUBTERRANEAN WORK BY SOUND

TRANSLATED AND EDITED AT THE
ARMY WAR COLLEGE

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WAR DEPARTMENT,
WASHINGTON, *August 8, 1917.*

The following Report on the Perception of Subterranean Sounds and the Plotting of Subterranean Work by Sound is published for the information of all concerned.

[062.1, A. G. O.]

BY ORDER OF THE SECRETARY OF WAR:

TASKER H. BLISS,
Major General, Acting Chief of Staff.

OFFICIAL:

H. P. McCAIN,
The Adjutant General.

WAR DEPARTMENT,
THE ADJUTANT GENERAL'S OFFICE,
Washington, June 19, 1917.

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By order of the Secretary of War:

H. P. McCAIN,
The Adjutant General.

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REPORT ON THE
PERCEPTION OF SUBTERRANEAN SOUNDS
AND THE
PLOTTING OF SUBTERRANEAN WORK BY SOUND.

Methods and Instruments Prescribed by the Military Telegraph Service.

[Translation of a French official document of June, 1916.]

SECRET AND CONFIDENTIAL—FOR OFFICIAL USE ONLY—NOT TO BE TAKEN INTO FIRST-LINE TRENCHES.

REPORT ON PERCEPTION OF SUBTERRANEAN SOUNDS.

The present report is divided into three parts—

I. Sound perception proper, comprising (1) Natural and makeshift methods of sound observation; (2) Description of the instruments for sound observation actually in use and their method of employment.

II. Methods for determining the direction or position of a subterranean sound and the critical examination of the results, anomalies, etc.

III. Concise account of instruments now antedated, the types of which may still be found in the armies.

PART FIRST.

PERCEPTION OF SUBTERRANEAN SOUNDS.

NATURAL METHODS—MAKESHIFT METHODS.

Sounds transmitted through the earth and heard in the air generally have slight intensity. This comes from the fact that the density and rapidity of the diffusion of sound in the earth

and in the air being very different, the sound waves are largely reflected on the surface of separation of the two media, which are therefore acoustically almost entirely separated.

In certain cases, however, subterranean sounds can be perceived by placing the ear close to the ground. In this case the sound perception is due to the fact that the vibrations of the earth are transmitted by contact to the little air space between the surface of the soil and the tympanum.

The instruments ought not to be applied to plank linings or foreign bodies (old sandbags masked under a thin layer of earth, etc.). The results can only be successful if the instruments rest on the natural ground, carefully smoothed and cleared with the spade of the detritus of every kind which may be found there. It is evidently wrong to place the instruments on planking, which is only in contact with the earth at unknown points. When a shock is produced on a plank lining, it is impossible to determine the direction of the impact, because the entire planking, by its many points of contact with the earth, produces a great many points of sound emission scattered along its surface. When a direction is sought in these conditions, no result is obtained; the direction remains vague and confused.

Consequently, sound perception ought to be practiced only on the natural ground, and only those results ought to be accepted as valid which are perfectly clear and obtained without hesitation; others should not be preserved.

The same rules must be followed when two instruments are placed on the same vertical line against the walls of a shaft. It will be very convenient to prepare a series of little platforms with niches on a vertical line and to install the instruments there.

The perception of the sound may also be improved by burying any large receptacle in the ground, filling it with water, and completely immersing one's ear in the water of this vessel far enough to cover part of the face and the cranium. Instead of placing the head in the water, a soldier's canteen may be used, after removing the cloth covering. It is placed on the ground and filled with water, except that a small air space is left in the upper part of the neck. By fitting onto the small neck of the canteen a rubber tube terminating in a suitable metal tip placed in the ear the subterranean sounds will be heard. The little air space imprisoned in the upper part of the canteen will serve the same purpose as the air confined in the ear in

the previous experiments. (For more details, see Part Third.) The results thus obtained are generally slight, except in the case of the canteen, but they can be greatly improved by the use of stethoscopes,[1] or of special microphones, which also offer the advantages of permitting the determination, with reasonable accuracy, of the direction of the subterranean sound and sometimes even the position of the source of the sound.

Nature of the sounds.—It is not enough that a geophone be sensitive to sound; it should alter as little as possible the sounds which it transmits and cease resounding as soon as it is no longer excited. Otherwise distant shocks (proceeding either from one's own side or the enemy) blend in a confused buzzing in which the ear can distinguish nothing clearly. One geophone more sensitive than another in detecting an isolated shock might be less useful in distingushing the same shock in the midst of complicated sounds.

But subterranean and aerial sounds are not identical; for instance, the metallic sound produced in the air by the impact of a pick against a stone is very different from the dull sound transmitted by the earth from the same concussion.

The listeners must acquire a clear sense of discrimination of the sounds that are most important for them (blows of the pick, boring, scraping, or the dragging of cases) as modified by the different kinds of terrains (sand, chalk, etc.), where they might have to operate. Of course, they should make these trials where no perception of the sound heard can reach them through the air. For instance, the one who strikes the blows and the listener will be at the bottom of two pits or two trench elements several meters apart and kept in communication by a liaison agent (necessary for avoiding loss of time).

Listening instruments.—The instruments constructed by the Military Telegraph fall into two classes: (1) Instruments which permit the observer to listen at close range (stethoscopes or ordinary mine detectors). (2) Instruments which permit him to hear at a distance (microphones or long-distance mine detectors). The instruments of these two classes actually in use in the armies may be designated generically as seismophones; they are both based on the single principle of the seismographs.

[1] Stethoscopes of different models are employed by physicians in listening to the action of the heart. A stethoscopic effect is also utilized in telephone receivers, the little air chamber inclosed between the vibratory plate and the vulcanized disk, which is perforated in the center by the hole to which the ear is applied, acts like a medical stethoscope.

The aim sought has been to produce an instrument having two distinct parts; one which, placed on the ground, shares all the vibrations or trepidations of the earth; the other which, mechanically insulated from the first and from the earth by means of a device, does not participate in the vibrations.

If these two distinct parts form the sides of a small watertight cavity inclosing a little air space, the variations of pressure in this air will become perceptible when the small cavity is connected with the ears by means of rubber tubes (seismostethoscopes or ordinary mine detectors) which will make it possible to hear the subterranean sounds directly.

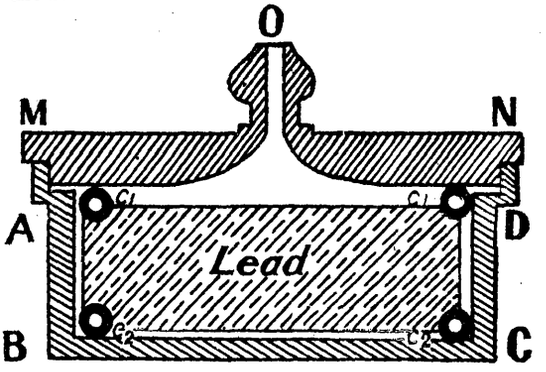


Fig. 1.

If between these two parts, the one which is mechanically insulated and the other which is placed on the ground, a microphonic contact is established, the carbons of which have their point of contact with each of these parts, respectively, a microphone sensitive to subterranean sounds (seismomicrophone or long-distance detector) will be produced.

It remains for us to show how the above-mentioned conditions have been practically realized.

1. *Seismostethoscope, or ordinary mine detector No. 1.*—It is formed in the following manner: A box of stamped brass ABCD is closed by a cover MN, the cross section of which is represented in figure 1. The cover is pierced in the center by an opening O. The box contains a cylinder of lead insulated from the

box and cover by two tubes of rubber, the sections of which appear in the figure as C_1 and C_2.

To make sound observations, a rubber tube thick enough to avoid obturation from bending is fitted to the knob with the opening O. Its length is 90 centimeters. To listen with both ears, a second stethoscope exactly like the first is used, having a similar rubber tube 90 centimeters long.

For the convenient transmission of the sound to the ears, either an elastic earpiece (fig. 2) or two single earpieces

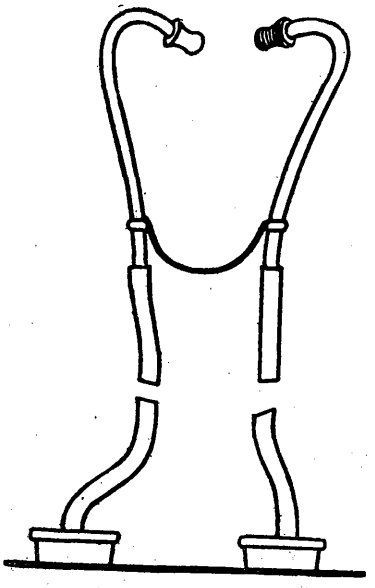


Fig. 2.

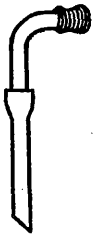


Fig. 3.

(fig. 3) to be held in the hand, are fastened to the free ends of the two rubber tubes.

The extremities of the tubes of the elastic earpieces are curved from the front backward, so as to penetrate more conveniently into the ears. The tips are distinguished by means of different colors. The white tip should be inserted in the left ear, the black tip in the right. In this way the earpiece is properly adjusted.

The seismostethoscopes are kept in pairs in a box containing the rubber tubes and the earpieces.

These instruments reproduce with great fidelity all the subterranean sounds. They will not get out of adjustment, but

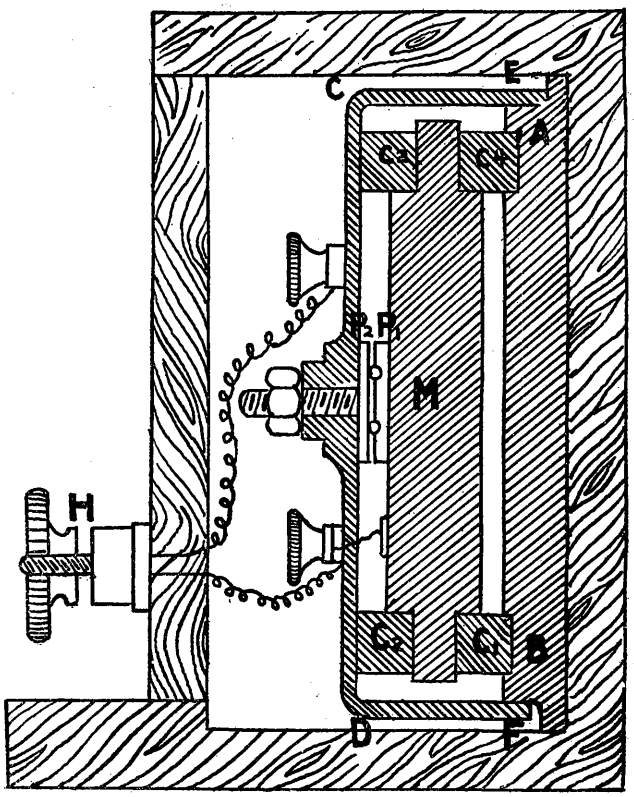


Fig. 4

the introduction of any sand into the interior destroys their efficacy. Keeping the rubber tubes constantly attached will prevent this difficulty.

Placing the instruments.—They are placed on the natural soil, after it has been smoothed carefully and freed of all débris, such as old sand bags, stones, etc., or they are held in the hands and applied to a vertical surface.

Seismomicrophone or long-distance mine-detector No. 7.—The equipment employed is almost the same as in the preceding instrument. A brass box contains a base AB and a cover CDEF. Within is the inert mass mechanically insulated from the box by compact rubber rings C_1 and C_2 (fig. 4). Two carbon disks P_1 and P_2, the first of which is indented with six sockets, are fastened to the mass M and the cover, respectively. Each of the sockets of the disk P_1 contains four granules $1\frac{1}{2}$ mm. in diameter.

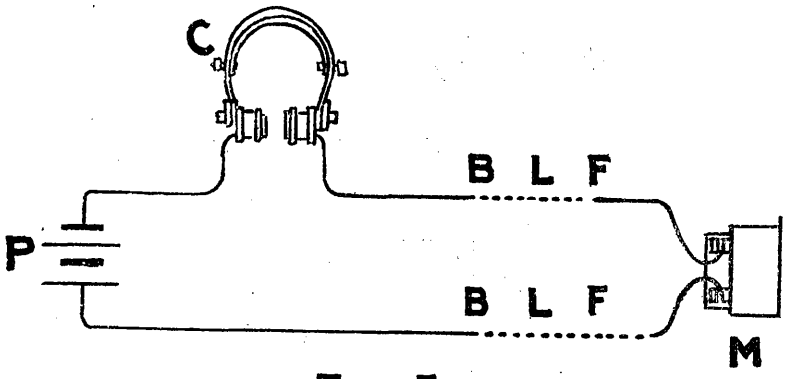


Fig. 5.

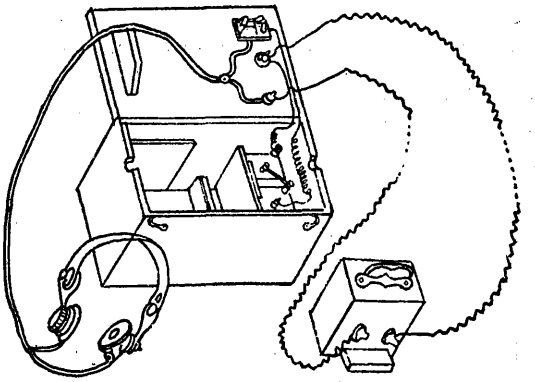
Two binding posts are attached to the cover CD; one of them, insulated in respect to this cover, is connected with the mass M by flexible insulated wire. In this way the two carbons P_1 and P_2 can be connected with the two poles of a battery. The whole instrument is fastened by four screws to the bottom of a wooden protecting box, which is provided on the outside with two binding posts connected, respectively, with the two binding posts of the cover.

Use of the instrument.—The microphone is placed on the ground with the handle up. It is only necessary to connect the two exterior binding posts H by a wire of suitable length to the two binding posts of a receiving box containing two batteries of the Military Telegraph, Model O, and a telephone headpiece of 20 ohms resistance. (See scheme in fig. 5.)

It is advisable in listening to hold the telephones very close to the ears, if necessary with the hands, or by inserting the two bands of the headpiece into a close-fitting cylindrical fiber tube that will pass under the chin.

The microphone is expendible. It affords particular opportunity for detecting sounds that might be produced near a loaded mine chamber, where it is deposited with the charge. It seems

Fig. 6.



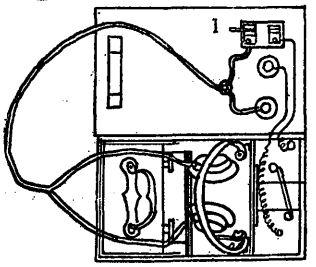


Fig. 7

advisable, when the microphone becomes inaccessible, as in the present case, to make it water-tight by using it with the impermeable cover which is discussed later. (See also note 1, "Practical Observations," chap. 1, Part II.)

Receiving box.—The connections made in the receiving box are those mentioned above. (Figs. 5, 6, and 7.) The binding posts of the receiving box are attached to the lid, together with

a switch I which, to save the batteries, is only closed when the instrument is in use.

The receiving box contains three compartments. (Figs. 6 or 7.) That on the left serves as repository for the microphone when not in use; that in the center is reserved for the headpiece with the telephones folded as shown in figure 7; that on the right holds the batteries. When the case is not in use, the headpiece band is folded over compartments 2 and 3 before the lid is shut.

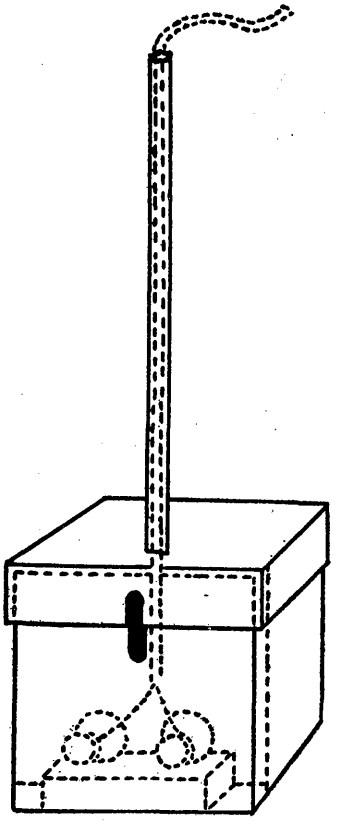


Fig. 8.

Two notches, seen in figure 6, cut into the sides of the box, serve as openings for the wires of the headpiece and the double cable, so that the box can be closed, if desired, while the instrument is in use.

As is evident, the box contains no transformer; consequently, for long-distance listening, it is necessary to use a cable of ample conductivity, well insulated (secondary cable with two conductors). There is no objection to using 150 or 200 meters of this cable.

The microphone is placed on the natural soil after it has been carefully smoothed and cleared of all débris (as for the stethoscopes).

Characteristics of the microphone.—The seismomicrophone offers a high degree of sensitiveness and great reliability; it will not get out of adjustment, and does not give scraping noises, provided all the binding posts of the electric circuit (binding posts of the batteries, etc.) are kept tightly

screwed.[1] Its sensitiveness can be reduced, if so desired, by using only one battery instead of two. The instrument is not only sensitive to subterranean noises, but it also faithfully repeats words spoken near it.

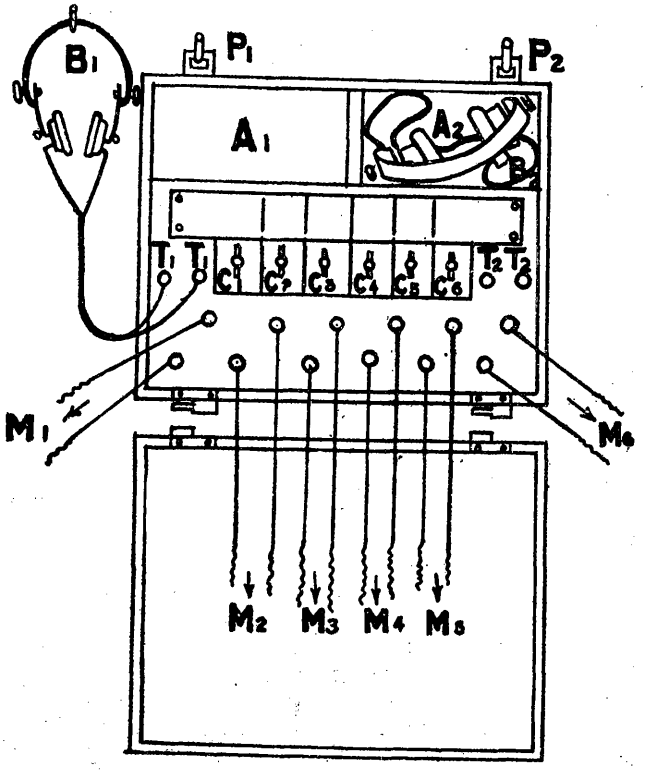


Fig. 9.

Water-tight cover for the seismomicrophone.—A water-tight metallic cover has been designed for the microphones which are

[1] With a single battery, microphones do not scrape. With two batteries it sometimes happens that they start with slight hissing sounds, which may be stopped at once by tapping the microphone.

left for a long time in galleries or mine chambers partly flooded, where the binding posts might become short-circuited. This consists in a steel box closed by a lid. The lid is pierced by an aperture surmounted by a long brass tube (fig. 8).

This tube affords a means for inserting the cable (lead-sheathed duplex cable) to connect with the binding posts of the microphone inclosed in the metallic case. The microphone fits snugly into the case.

A coat of black varnish applied to the lid and case makes it possible to mark the corresponding faces and properly fit the lid to the case.

To insure perfect impermeability at the mouth of the brass tube, a thick binding of Chatterton will be laid over the lead sheath of the cable and the tube of the lid. To insure perfect impermeability between the lid and the box the former will be soldered to the latter.

The properties of the microphone thus inclosed are not perceptibly altered.

Listening station with central.—It is important that a single observer should be able to control several microphones; thus an economy in time and personnel will be effected. The use of a central makes it possible also, as will appear later, to determine the position of a hostile work. (See Part Second, Microphonic method.)

The equipment comprises:

(1) A central case with six keys, containing batteries and telephone, enabling the operator to listen to the microphones successively.

(2) Six microphones of equal sensitiveness.

(1) THE CENTRAL FOR SIX DIRECTIONS. The spring keys C_1 C_2 ——— C_6 are mounted side by side (fig. 9). By their agency each of the six microphones M_1 M_2 ——— M_6 can be connected successively with a telephone by means of two battery cells (Military telegraph, model zero) contained in the interior of the case (not represented on figure 9 but in the cut 10). The line wires are attached to the binding posts as in the figure. Provision has really been made for the use of two telephones, which can be deposited in the compartments A_1 A_2. One or both telephones, as desired, can be attached to the binding posts T_1 T_1 and T_2 T_2. If one person wishes to listen alone, he will connect the bands of the headpiece B_1 to the binding posts T_1 T_1 while the second headpiece B_2 remains unattached to the binding posts T_2 T_2 (as

in fig. 9). To listen to any one of the microphones, it will only be necessary to lower the key corresponding to this microphone while the five other keys remain raised. To pass to one of the other microphones the key previously lowered is raised with one hand, and the new key is lowered with the other. In this way one can run over the entire series instantly.

If a second person wishes to listen at the same time, to check the observations of the first, he will attach to the binding posts T_2 T_2 the second headpiece B_2, which will thus be mounted parallel with the first. We should note, however, that simultaneous listening diminishes somewhat the intensity of the sound perception.

Two attachment clamps P_1 P_2 provide for hanging the central on a vertical surface, and in this position the lid hangs vertically beneath the case. Furthermore, the lid may be removed, since it is fitted with pin hinges (fig. 9). Notes on the sound observations may be registered on little plates of celluloid fastened by the side of the keys.

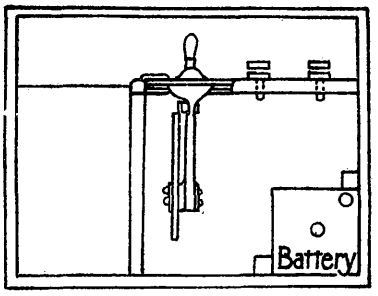


Fig. 10.

Precautions to be observed. By tapping near each microphone, when in place, make sure that the microphones are in working order and that there is no error in the connections.

Avoid the short-circuiting of the different binding posts of the wires of the microphones. When not listening, do not forget to raise the keys so as to save the batteries.

To replace exhausted batteries, unscrew and remove the surface board which supports the keys.

(2) CASE WITH COMPARTMENTS FOR MICROPHONES. Six microphones, as nearly alike as possible, are placed for transportation or convenience of arrangement in a box provided with six compartments lined with felt.

PART SECOND.

This part deals with the determination of the direction or the position of subterranean sounds, and to the instruction of the personnel.

It is divided into three chapters; the first will describe the methods actually employed, it being understood that the determinations are made in a homogenous terrain; the second will deal with heterogenous terrains, and point out the errors that are committed in them; the third will deal with the instruction of the personnel.

CHAPTER I.

There are at present two independent methods for locating a subterranean sound, and these will be designated in the course of the present report by the terms Stethoscopic Method and Microphonic Method. The instruments used in the two methods respectively are seismostethoscopes (or geophones) and seismomicrophones.

1. *Stethoscopic method (or intersection method).*—This method affords a means for discovering the direction of a sound transmitted by the earth, and then of ascertaining by the intersection of several directions, judiciously selected, the position of this sound.

1. *Direction.*—The rule which makes possible the discovery of the direction is based on the experimental fact that anyone—or almost anyone—who listens with both ears can distinguish whether a sound comes from his right or left; for instance, if some bystander makes any sound, speaks, claps his hands, etc., it is recognized immediately whether the sound heard through the air comes from the right or left; just as readily is it perceived whether the sound originates in front, or in other words, comes neither from right nor left.

When one is already facing in the general direction, the most accurate way of facing the origin of a sound above ground consists in turning the head freely to the right, for instance, far enough for the sound to become perceptible to the left ear, then to the left until the same sound becomes perceptible to the right ear. By turning the ear alternately to right and left, the sound is made to pass successively from right to left and left to right. By decreasing progressively the range of these oscillations of

the head, one will stop in a position exactly facing the sound. The simplest way of practicing this experiment is to have somebody clap his hands at a distance of about 12 meters in the open air. One turns in the general direction with the eyes closed, and then turns one's head two or three times a second, reducing the range of the oscillations in the manner just indicated. When the sensation seems to be equal on right and left, the head is stopped in this middle position. The eyes are opened and one finds oneself exactly opposite the person who is clapping his hands. One may practice in the same way on an aircraft in the sky and determine with precision the vertical plane passing through the aircraft. The sensation of the passage of the sound from one ear to the other is most important. On this sensation depends the stethoscopic determination of subterranean sounds.

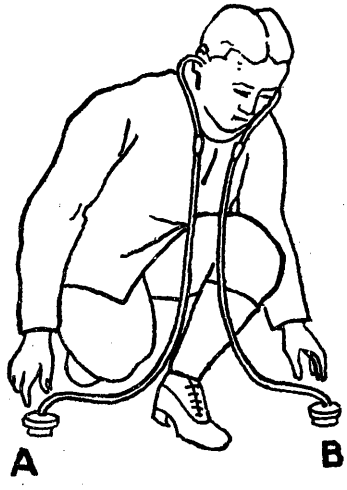


Fig. 11.

The method of procedure for discovering the direction in the ground and on the ground is the following:

Two seismoscopes A and B (fig. 11) are placed on the ground with an interval of 60–80 cm. between them, the instruments being provided with rubber tubes of the same length (a length of 90 cm. is very convenient). These tubes terminate in a double earpiece or two simple earpieces. (See figs. 2 and 3.) This manner of procedure really amounts to placing both ears to the ground at the same time. As soon as a subterranean sound is heard the observer notes by instinct whether the sound comes from right or left. He then shifts A and B with his hands and succeeds by a series of tentative changes in their combined position in finding a place for them where the sound seems to come from the front and not from the right or left. A perpendicular erected half

way between A and B will therefore give the direction of the source of the sound, or, more accurately, the projection of this direction on the horizontal plane passing through A and B.

2. *Position.*—Another line of direction of the propagation of the sound may be obtained by the repetition of the same operations as above in another place (whether or not situated on the same level as the first point). These two lines of direction are

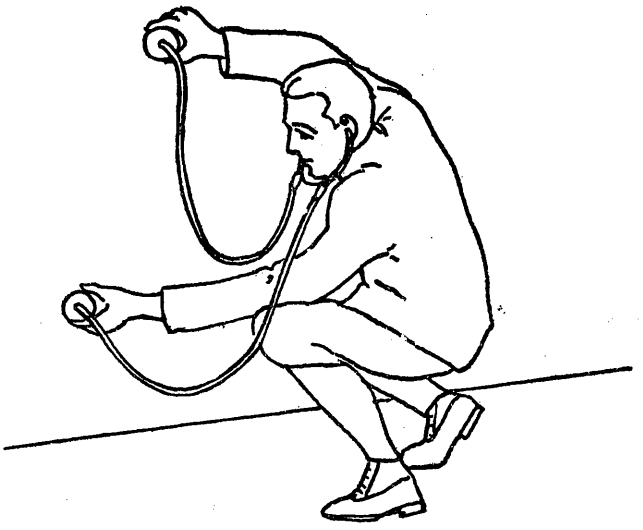


Fig. 12.

projected on the plane of the mines. Their intersection gives at once the source of the sound, if the two successive listening points and the point of impact are on the same horizontal plane.

If the latter condition is not realized, the projection M of the point of impact on any given plane (the plane of the mines, for instance), is thus determined.

If it is desired to find the position in space of the point of impact—that is, to discover the vertical level of this point—it

is only necessary to make an additional test analogous to the two preceding, but this time on a vertical surface (fig. 12).

Let P P^1 (fig. 13) be the line of the vertical surface, O the position of the observer, and M the inaccessible projection of the point of impact M (in space) on the plane of the mines. To trace the direction obtained by the observer in the vertical plane, it is only necessary to let this plane revolve in a horizontal sense on P P^1 as axis, letting P O Z be the angle between the direction found and the horizon. By dropping the perpendicular Mh from m on P P^1, and by prolonging it to its junction N with the ascertained direction O Z, it is evident that the distance hN (equal to Mm) represents the unknown level of the point of impact of the sound M, reckoned from the horizontal plane passing through the point O.

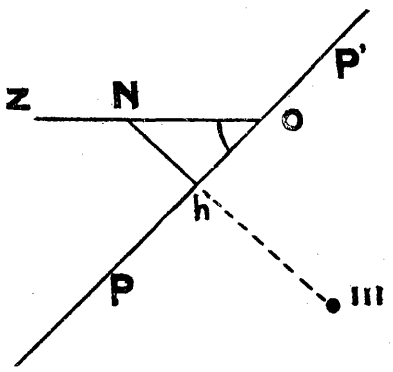


Fig. 13.

Details of the operations.—The principle of the determinations being thus exposed, it remains to enter into the details of the operations.

Suppose a determination is to be made at the head of a mine gallery R_1 R_2; the seismostethoscopes S_1 and S_2 are placed on the ground at A and B (fig. 14). The observer is not represented in the figure, but the double earpiece E will represent his position conventionally. With the instruments in the position A B, if the observer hears sounds on the right he may, to face these sounds, either revolve the position of both instruments, or, more conveniently, move one only, the other remaining stationary. In the present case the stethoscope S_2 must be moved far enough from the direction of the source of the sound, which is on the right, for the sound to pass definitely to the left, so as to bracket at once the position facing the sound. The instrument S_2 should therefore be moved from B to B^1.

We are then confronted with two possible situations: Either the removal from B to B^1 is sufficient for the sound to be heard on the left, or it is insufficient, and the observer still hears on the right. In the first case the correct position of S_2 is included between B and B^1 on the arc of the circle described (fig. 14): The point of impact is situated in the angle xOy. In the second case, to make the sound pass to the left, S_2 must be drawn farther back, or, what amounts to the same thing, the stethoscope S_1

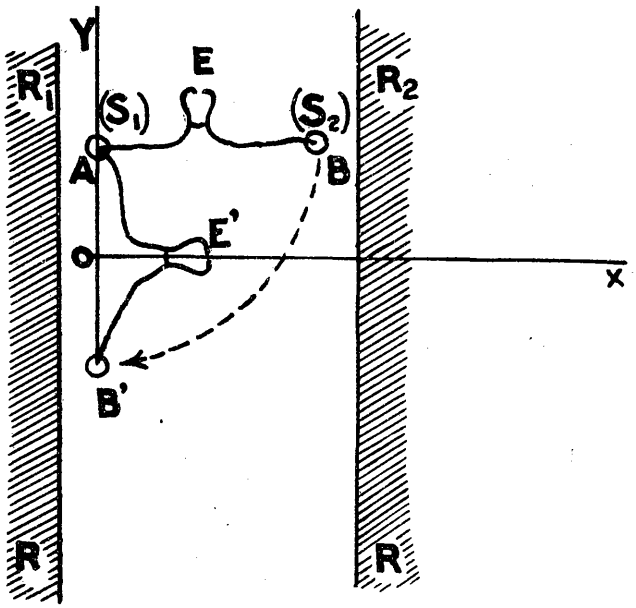


Fig. 14.

must be advanced from A. The instrument S_2 will then be left in place at B^1, and S_1 will be moved from A to A^1 (fig. 15). The observer will then have his back to the end of the mine gallery and will obviously, this time, hear the sound on his left. The correct position for S_1 will be included between A and A^1 on the arc of the circle described. The point of impact will be situated in the angle xOy^1.

To complete the determination, in the first case, for instance (fig. 14), the method of operation is as follows:

Since in the position A B, the sound is heard on the right, while in the position A B^1 it is heard on the left, the instrument S_2 should be moved to and fro in such a way that the sound will

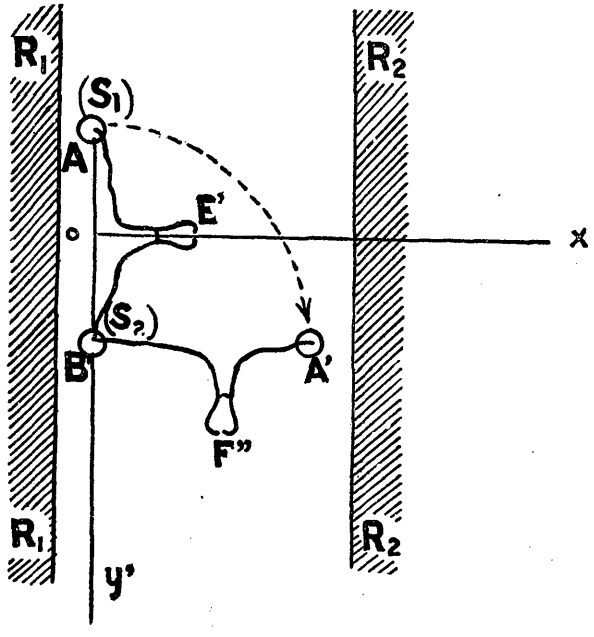


Fig. 15.

pass from one ear to the other with a constant reduction of the range of the displacements.

Consequently, the instrument S_2 is placed successively in the positions marked 1, 2, 3, 4 (fig. 16), selected in such a manner that the sounds are heard alternately on right and left: In positions 1, 3, 5 the sound is on the right, and in positions 2, 4, 6 the sound is on the left. These positions are immediately marked on the terrain by successive lines scratched with any pointed

object. These lines are represented on figure 16.[1] Thus two groups of lines are developed confining ever more closely the correct position.

There comes a moment in this series of tests when the distinction between the sensation on the right and left becomes imperceptible as one approaches the desired position,[2] as, for instance, when the position 7 is tested after 5 and 6. It is advisable, then, to ignore the doubtful position 7, and only to register the posi-

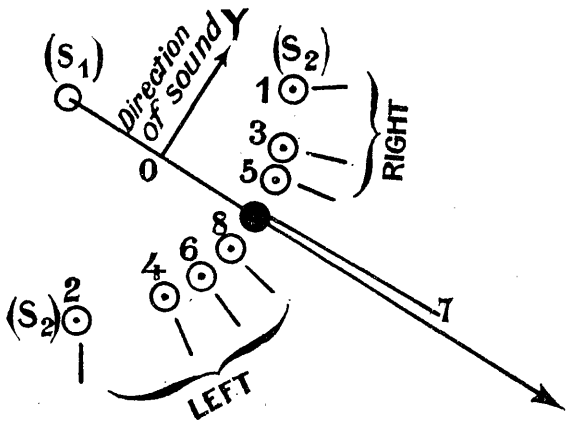


Fig. 16.

tions where the distinction of the sound as coming from right or left was clearly defined (positions 5 and 6); the line marked 7 should therefore be obliterated.

To consummate the determination, the instrument S_2 should be replaced in position 5 (the last one where the position of the

[1] The practice of marking lines on the ground is convenient for preserving a record of the successive positions occupied by the movable instrument, and thus avoiding a return to positions already observed.

[2] If the movements are too short, it may happen that the side of the perception was not reversed.

sound was still clearly discernible as on the right), then moved to 8, for instance, to see whether the sound passes clearly from one ear to the other. If this is so, the position 8 will be marked on the ground. As the positions 5 and 8 are near enough, one may, without committing a serious error, assume that the position sought is halfway between the marks 5 and 8. In actual practice it will often happen that the positions 5 and 8 of the seismostethoscope almost coincide. After the desired position has been found it remains to erect the perpendicular OY on OX, O being the center of the space between the two stethoscopes.

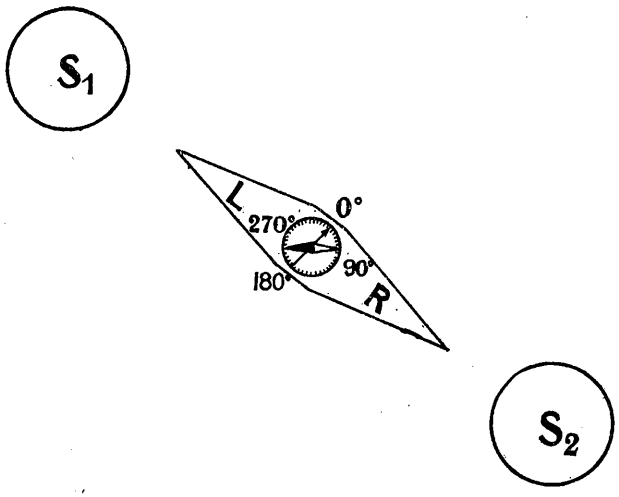


Fig. 17.

If the operator is skillful, the complete determination can be made very quickly without the necessity of marking the successive positions of the instrument S_2 on the ground.

Use of the compass.—It is necessary to determine the ascertained direction OY in respect to some known direction, as, for instance, that of the magnetic north.

For this purpose the points of the board on which the compass rests are set toward the stethoscopes S_1 and S_2 (fig. 17) in such a way that the letter L painted on the board is toward the left

and R toward the right of the observer as he faces in the direction of the sound. The arrow traced on the compass will then point in the direction to be determined; it remains to read the graduation marked opposite the blue point of the needle. In the present case this angle is about 230°.

Remarks.—The method described generally gives good results, provided (1) there are listeners adequately trained in the use of the instruments, (2) the instruments are in good condition and installed in the proper places.

It is nevertheless important to note the following remarks:

1. Listeners must be carefully selected and trained at the rear in listening schools, whenever this is possible. The necessary courses of exercises will be described later. It is enough to insist here that the one fundamental quality of a good listener is an alert and clear perception of the passage of a sound from one ear to the other.

2. The listening instruments must be in good condition. After each use they should be carefully cleaned and deposited in their respective cases. It is important that the instruments having the same number should be placed in the same case, since they are joined in pairs to facilitate the determination of the directions.

It has already been remarked that it is indispensable to avoid the introduction of foreign substances in the air chamber. Keeping the rubber tubes on the stethoscopes from the moment they are taken out of their box prevents any such introduction.

The rubber tubes must have precisely the same length. In fact, the direction of sounds can not be correctly determined unless this condition is fulfilled. Consequently, if for any reason one tube is reduced in length to remove an unnecessary section at the extremity, the other must be similarly shortened.

The seismoscopes must not be placed on planking or other foreign substances (old sandbags concealed under a thin stratum of earth, etc.). The results can only be successful if the instruments stand on the natural earth, carefully smoothed and cleared of all the detritus of every kind that might be there (broken stones, etc.); the stethoscopes must rest solidly and directly on the ground.

The instruments must not be placed on planking, because sound is not transmitted in the same way through wood as through the ground, and because the boards are in contact with the earth at unknown points only.

It should also be noted that when a shock is produced on the plank lining of the enemy's work it is impossible to determine the direction of the point of impact, because, in reality, the entire plank lining, by its many points of contact with the earth, produces a large number of points of sound emission scattered along its length. An attempt to discover a direction in these circum-

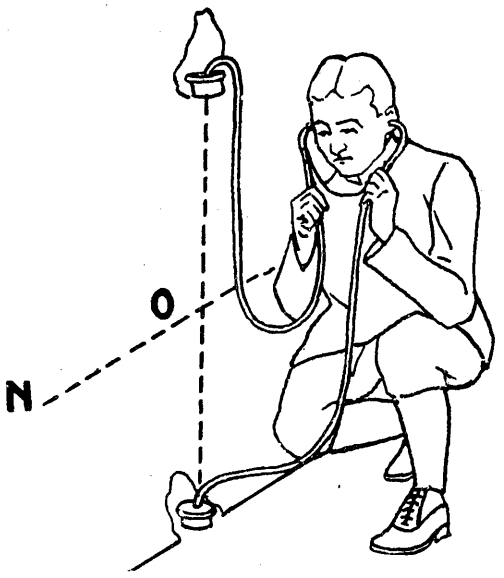


Fig. 18.

stances leads to no results; the direction remains vague and confused.

In conclusion, it is therefore necessary to listen only on the ground and to admit as trustworthy only the results considered perfectly clear and obtained without hesitation.

Level of the point of impact.—The determinations of direction made on a vertical surface are somewhat more difficult, because it is necessary to hold the instruments by hand (fig. 12),

and the friction of the fingers and of the earth on their surface creates annoying accessory sounds. Accordingly, it is often considered sufficient to try to discover whether the source of the sound is above or below the level of the listener, who can then avoid holding the instruments by placing them in the same vertical line, one on the ground, the other on a ledge in the wall of the mine (fig. 18). In reality, this experiment only shows whether the sound is produced above or below the level ON, O being the center of the vertical line joining the two instruments. If one wished to find the exact level of the point of impact by this method, it would be necessary to proceed, as above, all along the sides of a vertical shaft, bearing in mind the observations made above. One must avoid particularly applying the instruments to woodwork.

The case of different sounds.—The determinations are often complicated in practice by the existence of several sounds being produced simultaneously. One may learn by habit, however, to analyze the different sounds, which are easily distinguished by their intensity, rythm, etc. It is possible to determine successively the direction of each of them all the more readily, as these sounds are often alternative and not simultaneous.

On the other hand, if it is a question of finding the *position* of each of them, or only of the one most intense, the difficulty becomes very great, because two listeners stationed at two different points and operating at the same time do not as a rule choose the same sound. Moreover, this sound may not be the most intense for both the listeners at the same time. Therefore the intersection obtained by the two determinations of direction will not have any significance.

This difficulty may be obviated by installing a communication by telephone between the listeners, so that they can agree on the sound chosen, recognizable by its rhythm. If a telephone operator is associated with each of the listeners, the latter can easily concur upon the same sound and reach correct results. It is necessary, of course, to employ a group of four operators accustomed to work together, two of them listeners and two telephone operators. The telephone operators should only use duplex cable for communication, and never grounding, so as to avoid being heard on the enemy's telephone lines. They should speak low.

2. *Microphonic method (or method by sectors).*—The second method for determining the subterranean sounds employs the

complete central microphonic station described under "Listening Station in the Central," Part I. This listening post includes (1) a central for six directions; (2) a box of compartments containing six seismomicrophones (fig. 19). (See also figs. 9 and 10.)

The simultaneous use of six microphones disposed in six different points is somewhat like using six ears applied closely to the ground and far enough apart to produce a difference in the intensity of the sound reaching each of them. It will be under-

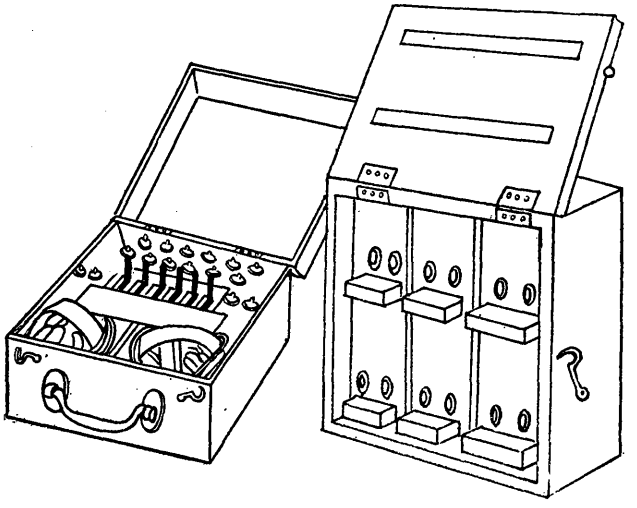


Fig. 19.

stood, then, that, if a sound reaches each of these microphones with variable intensity, the order of the different degrees of intensity is determined exactly by the distance of the point of origin of the sound from each of the instruments, and that, inversely, the order of the different intensities generaly fixes an exact position for the point of origin of the sound. This determines the method which will presently be described in detail, with an example. (Other examples will be given subsequently.)

Of course, the essential condition for success is to be able to hear a succession of equal sounds, and to hear them by means

of different microphones. This requires that the microphones should be sufficiently close to the point of impact so that the sound will be heard on several of them, and yet far enough away to afford sufficient variations in intensity.

Let I, II, III, IV, V, VI be the six seismomicrophones placed at the heads of galleries (fig. 20). The six positions chosen are considered to be in the same horizontal plane; otherwise the following conclusions would be erroneous. 0 is the central post (the choice of locality of the central is naturally entirely arbitrary, and without influence on the result).

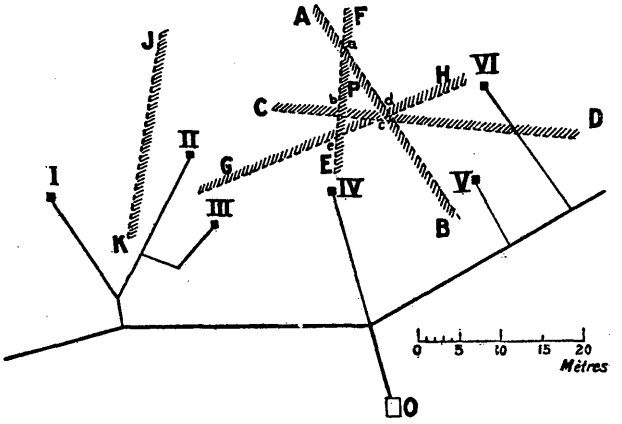


Fig. 20

The observations obtained on each of the microphones are graded in the following manner, for instance, in the order of their intensity:

	Seismomicrophones.	Sound.
Table	IV	Very loud.
	VI	Loud.
	V	Rather loud.
	II	Medium loud.
	III	Feeble.
	I	Zero.

With the help of this data it is possible to locate on the plane of the mines the point of impact, by observing the following remarks:

1. Each perpendicular erected at the center of the straight lines joining any two microphones divides the plane into two regions.[1]

2. Of these two regions, only one is of importance; it is the one containing the point of impact; that is, the one containing the microphone on which the stronger sound is heard.

3. The table contains the classification of the microphones in the descending order of their intensity.

4. To delimit the region which can contain the point of origin of the sound it is not necessary to consider all the perpendiculars that can be drawn at the center of the straight lines joining any two microphones, but only five perpendiculars obtained in considering the microphones two by two in the order in which they appear in the table; that is, in the order of their intensity.

5. Each of these perpendiculars divides the area into two regions, as has been said. The important region is indicated by a border of hachured lines along the perpendicular that bounds it on the side of the microphone that sounds louder.

These general remarks make it possible to confine the location of the point of origin of the sound within a very small compass.

In accordance with 4. we must trace the five perpendiculars erected at the center of the straight lines joining IV and VI, VI and V, V and II, II and III, and finally III and I. Let AB be the first of these perpendiculars, CD the second, EF the third, GH the fourth, and JK the fifth (fig. 20).

In accordance with 5, each of the perpendiculars must be bordered by hachured lines traced on one side of the perpendicular in the region containing the microphone with the louder sound, according to the classification of the intensities, as has been done in figure 20.

The examination of these five straight lines AB, CD, EF, GH, JK, of figure 20, bordering the shaded regions (which must *contain the point of impact*) suggests the two following remarks:

1. The point of impact is located within the quadrilateral abcd, since the borders of hachured lines of the sections ab, bc, cd, and da are all on the interior of this quadrilateral. It is the *only region* on the plan where the hachured borders are all in the interior.

[1] In case the microphones were not placed in the same horizontal plane, the problem would be more complicated; it would be necessary to consider the perpendicular plane at the center of the straight line joining any two microphones, which plane divides the space into two regions.

2. We have only had occasion to use four of the perpendiculars to delimit the region of the point of impact abcd; the fifth perpendicular JK adds no further useful information and does not need to be taken into consideration. It frequently happens that certain perpendiculars add no information to the data furnished by others. The data which they do afford is, however, correct. In this case, for instance, the region of the point of impact is situated on the shaded side of the perpendicular JK.

It remains for us to complete the determination of the point of impact by the aid of the data. Thus far we have only used

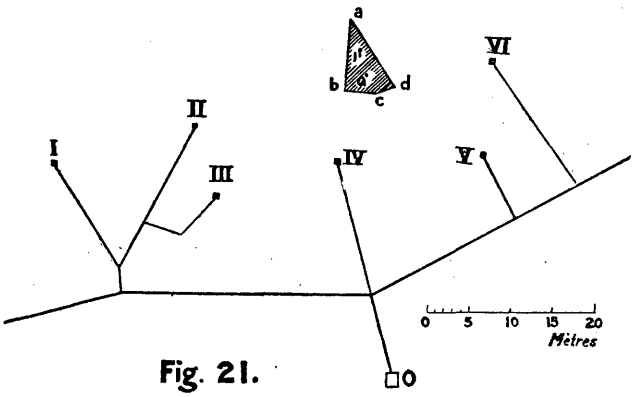


Fig. 21.

the first column of the table. The data contained in the second, which has not yet been used, will enable us to determine the position with greater precision. This table displays, in fact, a very noticeable disparity in the respective intensities of the different microphones. Accordingly, the point of impact can not be near the perpendiculars ab, bc, cd, and da, and is clearly situated in the interior of the quadrilateral abcd. The solution of the problem will be determined with sufficient accuracy by choosing two points, P and Q, in the interior of the polygon (fig. 21) and by ascertaining which of the two is more suitable. For this purpose, the distances from P and Q to the different microphones is measured on a strip of paper, and combined on two lines (fig. 22). On the second line, then, we notice two large intervals, one between IV and VI, the other between V and II, while the spaces VI and V and (especially) II and III

are short. The distribution of the intensities corresponding with this allotment of the distances does not accord with the indications in the second column of the table. The distribution for the point P evidently accords better. There is good reason, then, for adopting P as the point of impact.

Experience has shown that in sufficiently homogeneous terrain the determination carried out in accordance with the rules just indicated does not involve an inaccuracy of more than 3 or 4 meters, and very often not more than 1 or 2.

Summary of the microphonic method.—To sum up: The microphones are arranged in order of their intensities in a descending scale (IV, VI, V, II, III, I in the example cited). The star-shaped open polygon IV, VI, V, II, III, I is traced. Perpendiculars are erected at the center of each side of this polygon. The perpendicular on the side IV VI is shaded on the side of IV; the perpendicular VI V is shaded on the side of

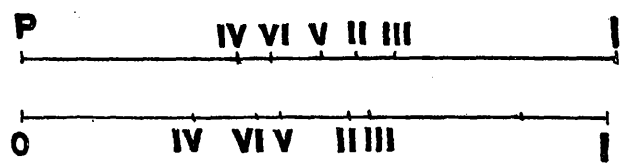


Fig. 22.

VI, etc. In this way a polygon is obtained (either open or closed) bordered uninterruptedly by hashured lines inclosing the point of impact. The determination is completed by means of the qualitative observations accompanying the classification.

General remark.—The method of determining the position of subterranean sounds is based on the division of the terrain in regions by perpendiculars erected at the center of each pair of microphones, taking every possible pair. By using six mocrophones in this way we will have 15 perpendiculars dividing the field into 101 regions. It is the advantage of the large number of these regions which makes this method successful.

Particular cases.—It may happen that several microphones register the same intensity. We shall examine the three following situations:

Two microphones register the same intensity. This case frequently occurs. *The point of impact is then situated on the*

perpendicular erected at the center of the straight line connecting these two microphones.

Example: We find the following order of classification for the six microphones:

IV
V and VI
II
III
I

By shading (fig. 23) the perpendiculars in the way indicated we readily discover that the sound must be situated on the section AB of the perpendicular erected at the center of the interval V VI. To fix more closely the position on this section we must

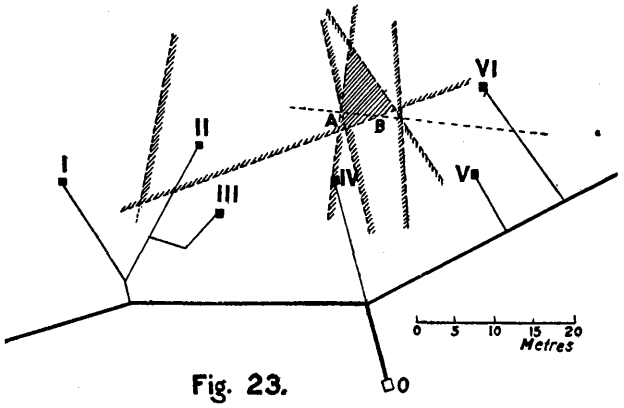


Fig. 23.

consider the qualifying circumstances involved in the order of the microphones. For the sake of brevity no mention has been made of these.

2. Three microphones register the same intensity. This case will be quite rare. The point of impact is then situated at the center of the circle passing through the three points.

3. Several microphones register no intensity at all.

First example: Assume that the order of classification is as follows:

IV
II
III
I, V, VI (no intensity).

We readily get the triangle ABC as the only possible region (fig. 24). Thanks to microphone VI, this region is bounded by the side AC. Since, moreover, the microphone VI gives no perceptible sound, we may be sure that if II, III, and IV give a sufficiently intense sound the unknown point of impact can not be near the side AC. The possible region will thus be reduced to the doubly-shaded triangle aBc. To determine the position of the unknown point with greater accuracy it would be necessary to ascribe certain qualifying data to the microphones IV, II, and III. If the silent microphones had not existed we should have been reduced to the unlimited region DBE.

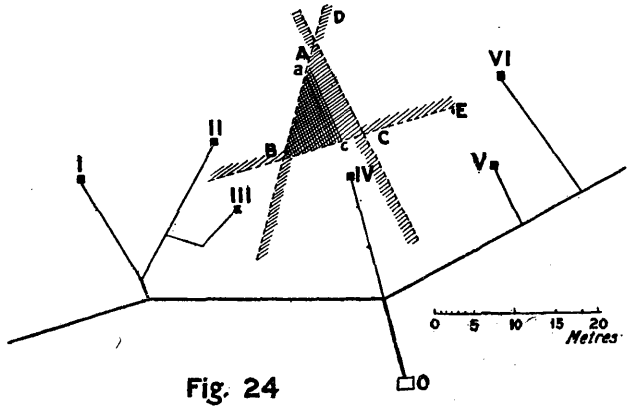


Fig. 24

Second example: All the microphones are silent except two. We then have:

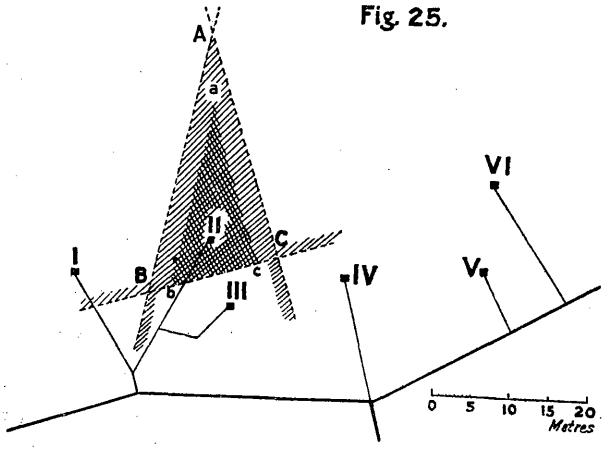
II
III
I, IV, V, VI (zero).

If the microphones I, IV, V, VI did not exist we would have as possible region the whole region situated above the unlimited line BC (shaded side of this line) (fig. 25). Thanks to the existence of the silent microphones I and IV, we can confine this region to the triangle ABC, and, if the sound registered by microphones II and III is not feeble, to a smaller triangle (doubly shaded) such as abc. By this example we perceive clearly the evidence furnished even by microphones that are silent by reason of their remoteness. It would naturally be much better if

they were near enough to furnish positive data capable of defining more closely the point of impact. If the microphones II and III are both quite clearly heard the point of impact is included between the straight line bc and the microphone II; but if the microphones II and III render only a feeble sound the point of impact is situated on the other side of microphone II toward the summit a.

Practical remarks.—From the practical point of view it is expedient to consider the remarks already made in respect to the seismostethoscopes.[1] The instruments should rest solidly on the earth with the handle up. They ought not to be placed on a timber lining.

Fig. 25.



When the instruments are not installed at the head of the mine galleries, other places may be used by removing the timber lining from the vicinity of the point selected. It is advisable to hollow out a nitch of some depth, so as to remove the microphone from the remaining timber lining and to protect it from the laborers. Completely finished mine galleries will naturally be used as far as possible. But since others will also be used it will be advisable to take every precaution against the laborers up-

[1] The remarks made on the seismomicrophones in Part First will also be consulted. Air-tight cases may also be employed in cases of necessity, any tension of the cable likely to make the microphone unsteady being carefully avoided.

setting the microphones or injuring the cables. Prudence would suggest that the electric lines be hung by cleats along the ceiling of the mine galleries. Special care in respect to electrical insulation ought to be observed in the installation of the cables.

It is absolutely necessary to verify the perfect working condition of each microphone after its installation, and particularly the exact correspondence of each microphone with the corresponding key of the central, as mentioned in Part First. The operator should speak into the microphone or tap it with the finger. It is convenient to arrange the connections so that the order at the central will be the same as that of the microphones on the terrain.

Inasmuch as the six microphones have been grouped with care, it is not advisable to substitute any microphone for one of them. Whenever, in consequence of an accident, certain of them are out of order, it is best to provide oneself with a new case of six and to reserve the instruments which are still serviceable for other uses, such as the supervision of a loaded mine. But if it is desired to complete a partial set with other microphones, the equivalence of the new microphones with the old ones must be established by placing all the microphones side by side in a restricted space and comparing them by means of the central with six directions. Regular blows with a pick handle delivered at a great distance should be heard in an identical manner, whichever microphone is used.

Of the six instruments, it is advisable to place at least two in a direction roughly perpendicular to the front (for example, the microphones II and III or IV and VI of fig. 20.) These barrage microphones make it possible to detect immediately a hostile penetration into the network of the mines. The perpendiculars erected at the center of the Groups II and III or V and VI divide the terrain into an exterior and interior zone.

As for the disposition of the six microphones, it is often imposed by the arrangement of the mine galleries. Yet one should avoid, as far as possible, symmetrical dispositions which reduce the number of the sectors. The number of the sectors is 101 in the general case. It is reduced considerably in the case of symmetrical dispositions. For instance, if the six microphones occupied the points of a regular hexagon, there would be only 12 sectors. The most irregular dispositions possible ought therefore to be adopted. Avoid especially placing several microphones on the same straight line.

Method of making determinations.—It has already been explained in Part First how one or two observers can use the central of six directions. Thanks to the rapidity with which one can listen to the six microphones successively, it is easy to tell whether work is in progress in an excavation chamber or in several simultaneously. In fact, there is generally a certain rhythm in the handling of a tool, and, since it takes only a few seconds to run over the six microphones, if the same rhythm is noticed on all the instruments it will be concluded that there is only one excavation chamber.

The observations made will be noted rapidly. It is of the greatest importance to repeat several times, for, however rapidly the observation may have been made, the different blows heard may not have been delivered with the same force. In this case the microphone which has registered the greatest intensity is not the closest to the point of impact. But this cause of error will be eliminated if the number of observations is great enough.

When the microphones have been classed in the order of their intensity, the qualitative indications resulting from the average intensity of the strokes heard will be placed opposite. By means of this information the point of impact can be located at leisure on the plan of the mines.

COMPARISON OF THE STETHOSCOPIC AND MICROPHONIC METHODS.

It remains for us to explain the advantages and disadvantages of the two methods for the solution of one of the three following problems: (1) To determine the existence of an excavation chamber; (2) to determine the direction of the chamber; (3) to determine the exact position of the chamber.

(1) *Stethoscopic method.*—The seismostethoscopes are easily handled and permit the taking of observations without any previous installation. Their trustworthiness is greater than that of any microphone, and their sensitiveness, although somewhat inferior, is still very satisfactory. Their use is therefore especially appropriate for determining the existence of an excavation chamber.

The same advantages exist in the determination of the direction of an excavation chamber, except that in this case the observer should have special instruction.

But if it is desired to fix the exact position of the point of impact, we have seen that two skilled observers are needed,

working with two telephone operators. The simplicity of this method is therefore lost, especially since it is imprudent to trust to a single intersection. Nevertheless, if one is convinced that there is only one excavation chamber, the same observer may make the different intersections without danger of mistake.

Another disadvantage of these instruments is the impossibility of using them in inaccessible places.

(2) *Microphonic method.*—The disadvantages of this method are the following: One or six telephone lines must be laid, according as one wishes to perform a simple act of listening or to fix the position of the point of impact. Moreover, the instruments are less trustworthy than the seismostethoscopes.

On the other hand, the method offers the following numerous advantages:

I. The perception of the sound can be effected if a position become inaccessible, such as a mine charged and tamped, a mine filled with gases after an explosion, a flooded mine, a position incompletely concealed.

II. A single operator watches over an extensive zone (in the case of the central), thus effecting an economy in personnel.

III. The method requires no preliminary training.

IV. The rapidity of determination is very great.

V. A single group of operations reveals directly the position of the point of impact and not merely the direction.

VI. The precision is equivalent to that of the seismostethoscopes.

(3) *Advantages in the simultaneous use of the two methods.*—It is not to be assumed, from the numerous advantages of the microphonic method, that the stethoscopic is to be rejected. We shall see at the end of Chapter II the advantage of using the two methods concurrently.

Listening rod.—Borings several meters long and several centimeters in diameter, such as are often made, can be used for listening. For this purpose a listening rod is employed.

The listening rod is a long wooden pole composed of sections clamped together end to end (listening sticks of the Field Park Mechanical Transport Column). It receives the sound through its rounded extremity at the bottom of a boring (or at the end of a gallery rendered temporarily inaccessible) and transmits it without noticeable waste to the geophone introduced into the handle attached to the last stick. Rubber insulators prevent noticeable leaks into the ground.

In mounting the rod it is necessary to be sure that there is no lack of contact between any two consecutive sticks. Such a gap would be as harmful as the interruption of a telephone line.

The ordinary case of listening sticks contains 12 sticks, each about a meter long; but several sets may be used to reach the desired length.

CHAPTER II.

In the preceding chapter the use of the methods in the case of supposedly homogeneous terrains has been described, but the situation is not always of this character. The causes of heterogeneity are many,—the existence of mine galleries (lined or not), layers of rock, areas disturbed by explosions, subterranean

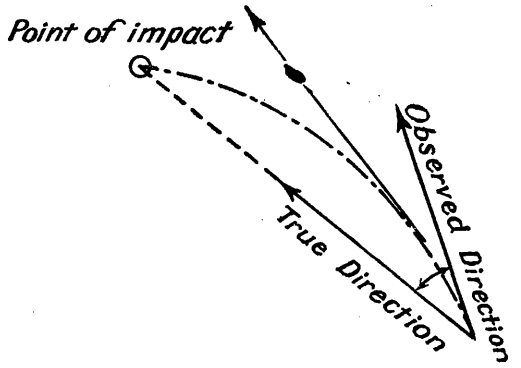


Fig. 26.

foundations, etc. The strict application of the methods heretofore described would expose one to mistakes or impossible situations. It is clear that the ear alone would also commit errors, since they would be due to the nature of the terrain.

No universal method for the sclution of the problems of heterogeneous terrain can be given, but it is often easy in each individual case to determine a region containing the point of impact restricted enough to serve as useful information.

General observations.—When a terrain is not homogeneous, the acoustic waves which are propagated through it undergo modifications manifested in changes of velocity, of direction,

and of intensity. It follows that the listener will be deceived in his estimations, whether he receives the sounds directly or uses the listening instruments. In particular the seismostethoscopes will render erroneous directions and the seismomicrophones will give abnormal intensities. Such irregularities have actually been observed.

1. *Stethoscopic method.*—It is often observed that the direction, although clearly marked, is inexact. This is due to the fact that there is a constant variation in the sound direction from the point of impact to the point of listening (fig. 26).

Evidently the position of the point of impact can not in this case be found by an intersection.

It is therefore first necessary to determine more than two directions for the same point of impact, so as to have several intersections. If the different points found are grouped in the same region, the point of impact will probably be located there also.

Sometimes it has been found impossible to obtain any direction at a selected point. The only remedy, if the cause of the impossibility is not connected with the source of the sound itself, is to undertake the determination at another point. (See in this connection the above remarks concerning shocks derived from an enemy plank lining.)

2. *Microphonic method.*—It has been assumed that, after the classification of the microphones in the order of their intensity, it was only necessary to trace the sector of the impact bounded by the perpendiculars erected at the centers of the straight lines joining the suitable pairs of microphones. But the abnormal conditions of the terrain often complicate the results. In actual experience the place of equal intensity for two microphones is rarely a straight line; it is a band, more or less straight, but not rectilinear. The sector of impact is therefore limited otherwise than on the theoretical design, and the point sought may lie outside the given sector. In theory, furthermore, one is generally apprised of the heterogeneity of the terrain by the impossibility of obtaining a sector corresponding to the classification of the microphones. In fact, the six microphones can be arranged in order of intensity in the 720 possible permutations in the order of the six microphones, supposing that all the intensities are different. But as there are only 101 sectors, therefore the number of impossible cases is 720—101, or 619. When one of these cases is observed, one may be certain that the terrain is hetero-

geneous,[1] but it does not follow that the terrain is homogeneous if one chances to fall upon one of the 101 possible permutations.

Example: It will be shown by a simple example that, even in certain cases theoretically impossible, a sufficiently exact solution can often be found, *provided the terrain is not heterogeneous in all parts*, a situation in which no conclusion would be possible.

Example:	Data.
V	Very loud.
III	Rather loud.
II, IV	Medium.
VI	Feeble.
I	Zero.

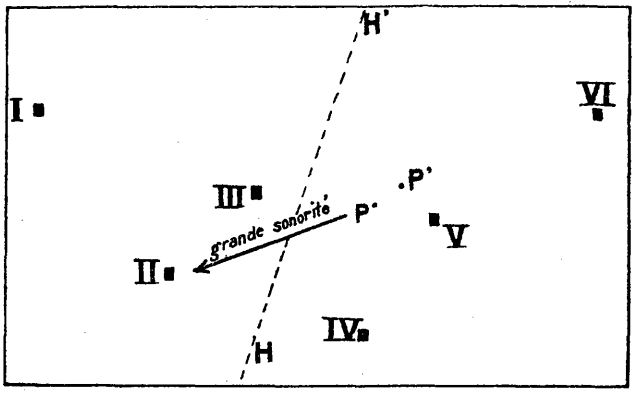


Fig. 27.

Figure 27 shows that the data is incompatible. In fact, there can not be identity in the intensity of microphones II and IV and at the same time a greater intensity in V than in III. There is a glaring abnormity.

[1] Other circumstances, not ascribable to the terrain, may lead to erroneous conclusions, and one should make sure that none of these are involved. These are (1) the disparity in the sensitiveness of the microphones, (2) the fact that the microphones do not rest firmly on the ground, (3) errors of perception (errors arising from different blows heard not having been delivered with the same force), (4) the existence of more than one excavation chamber. These different causes of disturbance may be eliminated.

But it ought to be possible to correct data that can not be satisfied (if the terrain is not entirely heterogeneous) by considering all the conditions to be fulfilled.

If we consider the simplest (but not the only) method of making the data compatible, it will appear that it is only necessary to change the equality given by the microphones II and IV to an inequality, with the microphone IV giving the greater intensity. This inequality suggests itself if one considers all the other data, namely, the very great intensity of V and greater intensity of VI than of I.

The point P will be adopted, although not on the perpendicular HH^1 erected at the center of the interval (II–IV), because this point is sufficiently in accord with the other data.

The corrected order of the microphones is then as follows:

V	Very loud.
III	Rather loud.
IV	Medium.
II, VI	Feeble.
I	Zero.

Experience has shown that, in reality, the point of impact (P^1) is near the point P^1 selected. It follows that the terrain displays a special sonority between P and the point occupied by the microphone II. If the point of impact had been in another region, the microphone II might have given normal results, for the abnormity observed is the result of a special character of the ground between P and the microphone II.

This manner of procedure, which aims to make the best of a combination of incompatible data, must be made only with great circumspection.

To sum up, the geometrical construction of the perpendiculars described in Chapter I gives the complete solution in cases which are practically normal, but its inflexibility is an obstacle to the location; in the case of heterogeneous terrains, of the situation of the point of impact. It is better, then, not to adhere too closely to the construction, but to be guided rather by the aim of making all the data furnished by the sound of all the microphones as compatible as possible.

Conclusion.—Given the complications due to the possible heterogeneity of the terrains, it is advisable to have recourse to all means at one's disposal; in other words, to the combination of the two methods described, and to the use of them in the most critical spirit.

The principles on which the two methods are based are quite different. In the microphonic method, only the intensity of the sounds is involved, and each instrument is heard separately. In the stethoscopic method, on the contrary, while the two instruments are heard simultaneously, the impressions produced are not absolutely simultaneous, and this gives rise to a certain delay which undoubtedly exercises an important influence in the sensation of distinction between right and left.

The two methods will therefore be mutually helpful, and will exercise a mutual control.

CHAPTER III.

INSTRUCTION OF THE MINE LISTENERS.

The mine listeners should be trained as often as possible at the rear, because only there can direct verification of the directions and the situations of the impact be obtained. It is at the rear, also, that imperfectly trained listeners should be developed by progressive exercises, and that the faults committed by listeners already trained should be corrected.

The use of seismostethoscopes or similar instruments requires a sustained training. The periods of instruction should be short and frequent.

The use of the seismomicrophones is simpler and does not require the same degree of skill. It is advisable, however, that some lessons be given at the rear, to familiarize the listeners with the instruments and show them the results that may be expected.

1. *Seismostethoscopes.*—The methods and remarks set forth in Part First and in the first chapter of Part Second will be used as guides. The exercises can be performed either on the surface of any terrain (as far as possible homogeneous, so that the exercises may not be complicated at first), or in a listening shaft with a circle of impact used in the listening schools. (See the provisional instruction for the listening schools.)

When the operations are conducted on the surface of the ground without special preparations, a natural terrain may be chosen. The grass and its roots will be removed on a space of a square meter, and the ground will be worked to a perfectly level surface. The seismostethoscopes will be installed on this surface.

COURSE OF INSTRUCTION.

Exercise I: The two seismostethoscopes S_1 and S_2 remain in the same position, the eyes of the listener being closed. The ground is tapped with the finger between the two instruments, the finger moving several times from S_1 to S_2 and from S_2 to S_1 along the straight line connecting S_1 and S_2. The listener should sense the passage of the sound from right to left and from left to right. He should be able to discern the moment when the finger passes the center of the space. The listener can practice alone by closing his eyes and then observing whether he has succeeded in discovering by the sound the center of the interval S_1 S_2.

Exercise II: With the listener in the same position, an assistant strikes the ground with a pick handle along a line parallel with the straight line connecting S_1 and S_2. This exercise is similar to the former, except that the ground is struck beyond the instruments instead of between them. At first a parallel line will be taken 5 meters from the instruments, then successively lines at 10 meters, 15 meters, 20 meters, etc. The listener should stop the man who strikes the blows whenever the point of delivery seems to be directly in front of him. At this moment the position of the pick should be on the perpendicular erected at the center of the straight line S_1 S_2. This exercise becomes increasingly difficult with the greater distance of the parallel on which the blows are struck.

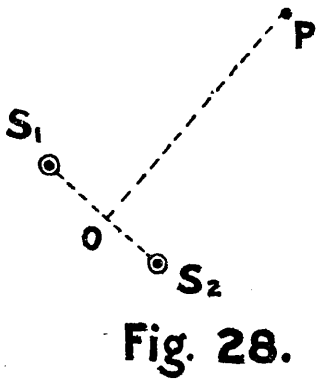


Fig. 28.

Exercise III: Practice determinations in a listening pit two meters deep and a meter and a half in diameter with blows delivered at a number of points in a striking circle traced or dug with the pit as center and a radius of 8 or 10 meters. The man will handle the instrument as previously explained. When the listener thinks that he has suitably arranged his instruments S_1 and S_2 (fig. 28), he will often be able to improve and correct their position by striking with his finger at O, at an equal dis-

tance from S_1 and S_2, and timing the blows of his finger with the blows of the pick in the enemy's work. Directly after each blow heard the listener will tap with his finger at O with an intensity calculated to render the same impression on his ears as the blow of the pick. If the instruments are suitably placed, the finger taps will seem to have the same origin as the strokes of the pick. If the instruments are not suitably placed, the strokes of the pick will at once seem to be on the right or on the left of the center, and the listener will be led to correct the position of the two instruments. One may find on the straight line S_1 S_2, to right or left of the point O, some point where the finger strokes seem to be delivered in the same position as the blows of the pick. If this point, m, is somewhat to the right of O, S_2 must be moved back a little; if the point is somewhat to the left of O, S_2 must be moved forward. Then by striking at the center of the space S_1 S_2 a sensation similar to that of the blow of the pick should be produced.

Remark.—By operating methodically, as has been described, and by tracing all the positions "right" and "left" on the ground, it is impossible to make a mistake in the choice of the field for the determined direction. The observer will always face the sound. Yet experience has shown that listeners left to themselves do not always proceed systematically, and that, having found a position in which the sound is "in front," they really have their backs to its source. To avoid such serious mistakes, it may be serviceable to accustom the listeners to recognize the direction of the sound on the line determined. For this purpose, the line S_1 S_2 is traced on the ground, and at its center a perpendicular is erected on both sides representing the direction of the enemy sound. The two instruments are placed on this perpendicular—that is to say, across the former position of the two seismostethoscopes. The sound will then be heard indubitably on the right or left, and this will determine the direction of the enemy work.

Exercise IV: Use of the compass (see above). To avoid all confusion, the compass is graduated from zero to 360. To any direction there corresponds but a single degree on the scale.

Exercise V: Determination of the level of the impact (see discussion concerning fig. 18). Repeat along a slope the experiment described (fig. 18).

Repeat Exercise III on varied terrains.

2. *Seismomicrophones.—Exercise I:* Install six seismomicrophones on a homogeneous terrain. Remove the grass on the six emplacements selected on a surface 20 cm. square, and make it as level as possible.

The microphones should be placed at intervals of from 12 to 20 meters from one another. Any plan of arrangement may be adopted, as, for instance, that of figure 20.

Begin by plotting the emplacement of the microphones on a sheet of paper. Measurements are made with a double decameter and transferred to the paper, according to scale, by means of the compass. This map will serve eventually to locate the point of impact.

The microphones will be installed on the emplacements chosen, perfect contact with the soil being assured. The different instruments will be connected in the order in which they are situated with a central masked behind a wood. The ground will be struck as hard as possible with the pick, so that the blows will be heard in as many microphones as possible.

When the listener has made the plan of the intensities, leave the pick in place and measure the distances from the pick to the two nearest microphones. The location of the pick will be plotted on the map as soon as the listener shall have determined it. The error involved will be calculated by the distance from the point chosen by the observer to the true point (the location of the pick).

Remarks.—The central includes two telephones: One of them will be used by the instructor to control the observations of the listeners being trained. Be sure to connect the positive pole of the batteries as marked on the central with the band of the headpiece painted white at its extremity.

When any microphone has a tendency to whistle, lift the instrument and set it down firmly on the ground, giving it a shock; all whistling will then cease. Never fail to raise a key that has been lowered before lowering another.

Exercise II (Graphic exercises): 1. With the locations of the six seismomicrophones plotted on the paper, trace the 15 possible perpendiculars erected at the center of each pair of instruments, using every possible combination, so as to obtain a division of the terrain in sectors. The 101 sectors will, of course, not be obtained within the limits of the sheet of paper, but, nevertheless, a considerable number will be obtained.

2. Try to modify the emplacements of the microphones on the paper so as to realize, in a region arbitrarily chosen, a division of the terrain into a large number of sectors of small surface.

Remark.—To simplify these graphic exercises, we may begin with a smaller number of microphones; as four, for instance.

PART THIRD.

The first two parts of the present edition aimed to describe the listening instruments of the military telegraph of the latest models, and their employment.

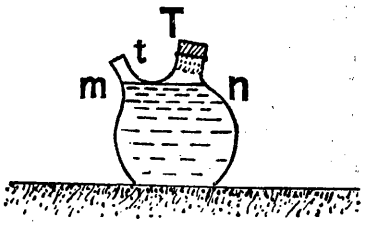


Fig. 29.

As there are still in the armies different types of listening instruments of former models, it is advisable to mention them in this Part Third. They have been described, together with the methods for obtaining the direction and location of subterranean sounds, in the first edition of this report (May, 1915). We shall confine ourselves, therefore, to a brief résumé of their nomenclature.

1. *Water stethoscope (canteen).*—This makeshift instrument may be used for lack of others. It acts either buried or simply placed on the ground.

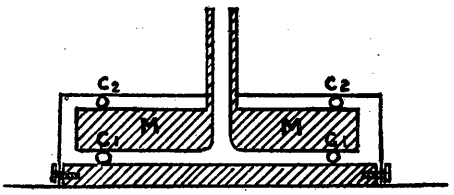


Fig. 30.

When the canteen has been entirely filled with water and placed on the ground, the operator blows very gently through the small mouth t, to which a rubber tube is attached, so as to expel a certain quantity of water, which passes through the large mouth T (fig. 29) until bubbles of air

appear at T. T is then corked. At this moment the level m n of the water is properly adjusted. A Y-shaped earpiece is then attached to the rubber tube so that both ears can be used.

2. *Air stethoscope.*—Two types of air stethoscopes have been employed for ascertaining the direction (fig. 30 and fig. 31). In the first, the inert mass M was mechanically insulated from the rest of the instrument by two rubber rings, C_1 and C_2 (fig. 30). In the second, a thin brass plate f (fig. 31) insulated the mass M. This second type was the more common, and is still found in the armies.

3. *Microphones.*—Two former types are still in use, the water-tight microphone and the simplified microphone.

I. *Water-tight microphone.*—This microphone consists of a metallic case absolutely water-tight, one of the sides of which is a vibratory plate 12 cm. in diameter and three-tenths mm. thick, protected against shock by a metallic screen (fig. 32).

The microphonic contacts in carbon are borne by the vibratory plate and the rigid pieces of the metallic case respectively. The water-tight microphone is used by being immersed vertically in a steel vessel full of water, which is buried in the ground up to its upper part, the ground being heaped up around it.

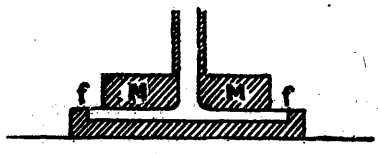


Fig. 31.

The vibrations of the earth act through the medium of the water on the vibratory plate.

With each microphone are issued a receiving box containing two batteries, a little transformer with sliding primary (used to make the sensitiveness vary), and a headpiece with earpieces of 2,000 ohms (sic. probably means 20 ohms). The headpiece has two independent bands, mounted in parallel when only one water-tight microphone is used. When two water-tight microphones are available the bands are used separately, each telephone of the headpiece being connected with one of the microphones. This arrangement makes it possible to determine whether a sound is projected from a point nearer one or the other of the two microphones.

Simplified microphones (fig. 33).—This microphone, intended for the perception of sounds produced near a charged mine cham-

ber, consists of a microtelephonic disk (the model used in the microphones of the military telegraph) deprived of a part of its protecting metal plate. A curved steel wire, forming a spring, is soldered to one of the sides of a parallelopipedic can-

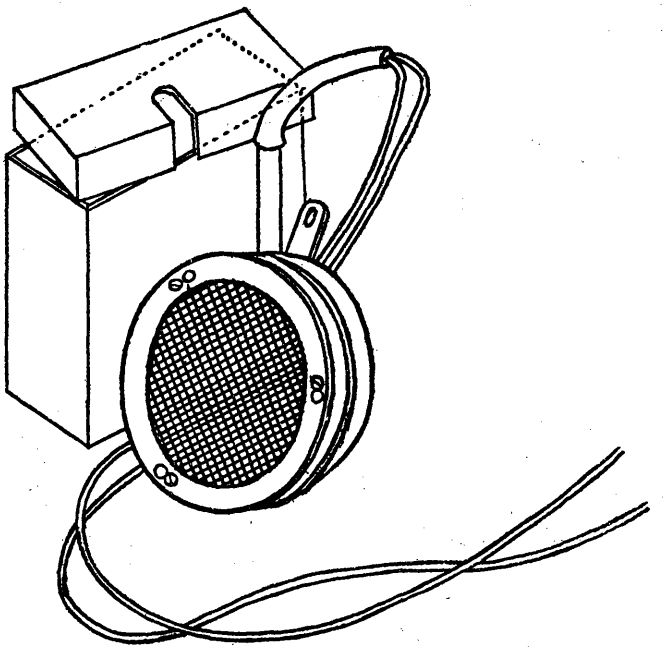


Fig. 32

teen of thin steel. This wire rests on the center of the carbon plate of the microphonic disk.

The canteen is filled with water when the microphone is to be used. It simply rests on the ground.

A reception box accompanies each microphone. This box contains two compartments, one reserved for two battery cells in a

series, the other for the telephonic headpiece formed of two earpieces of 10 ohms mounted in series.

This receiving box, like that of the seismomicrophones, may be used alike for the simplified microphone, the water-tight microphone, and the seismomicrophones. It does not contain a transformer.

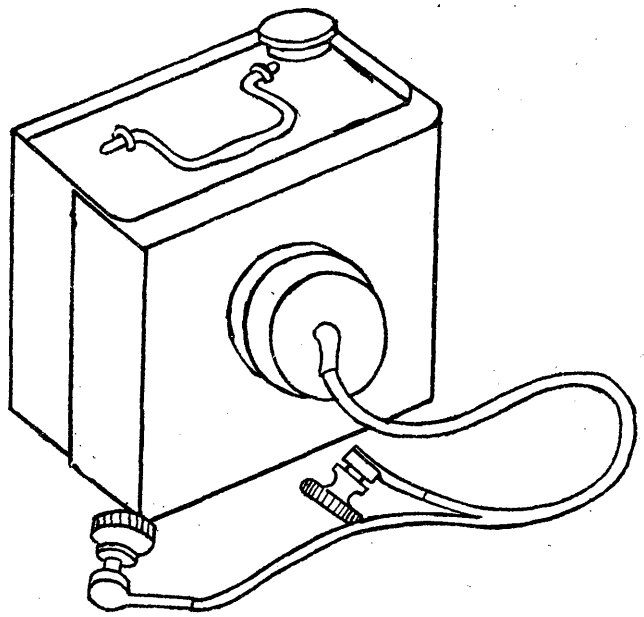


Fig. 33.

Remarks.—The instruments just described may still be found in the armies, as well as in certain engineer parks or reserve stores, where they can be procured.

To simplify as far as possible both the manufacture and use of the material, the only instruments constructed by the military telegraph are the seismostethoscopes and seismomicrophones of which the characteristics and advantages have been presented in Part First of this report.

APPENDIX I.

MILITARY TELEGRAPH SOUND PERCEPTION INSTRUMENTS FOR MINES—DESCRIPTIVE CATALOGUE OF THE INSTRUMENTS AT PRESENT MANUFACTURED.

Shipments include, according to the orders, (1) complete packages; (2) separate instruments.

1. Complete packages of material.

There are three categories of complete packages. (See I, II, III.)

Fig I.



I.

Nonelectric Instruments.

Case of seismostethoscopes (fig. 1).
This case contains:

2 seismostethoscopes.
2 rubber tubes, 90 cm. long.
1 double elastic earpiece.
2 simple earpieces.
1 compass with graduated scale 0°–360°.

II.

Electric Instruments.

Case of seismomicrophones (fig. 2).

This case of three compartments contains:

1 seismomicrophone (see also fig. 5).

1 telephone headpiece, with 2 earpieces, each of 10 ohms mounted in series.

2 batteries of the Military Telegraph, model O.

There is also sent (1) a water-tight case for the seismomicrophone (see fig. 6), serviceable when the seismomicrophone has

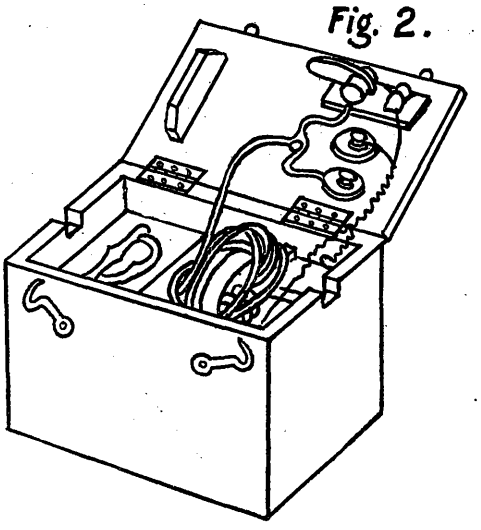


Fig. 2.

to remain long in water; (2) 75 meters of secondary duplex cable and Chatterton.

III.

Complete microphonic central station (figs. 3 and 4). The central station includes:

1 central of six directions (fig. 3), including 2 batteries and 2 telephones of 20 ohms.

1 compartment case of 6 seismomicrophones (fig. 4).

6 rolls of secondary duplex cable of 150 meters each.

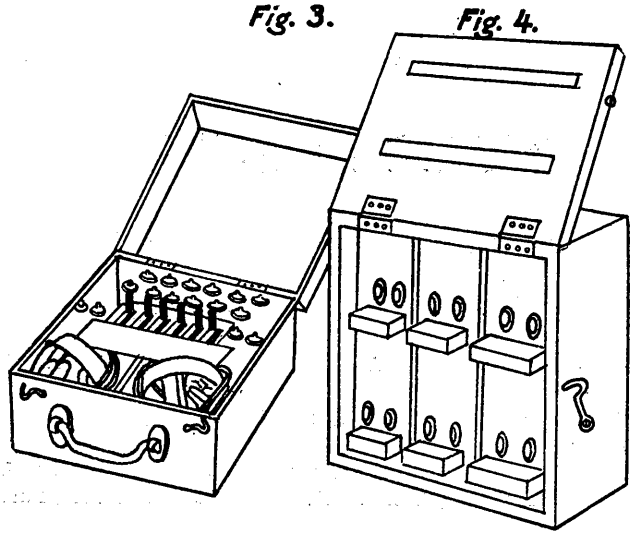
6 water-tight cases (fig. 6), Chatterton.

2. Packages of separate instruments.

Certain separate articles forming a part of the above equipments can be supplied. These articles are the following:

1. Compass with scale graduated from 0° to 360°.
2. Rubber tubes 90 cm. long.
3. Double elastic earpiece.
4. Simple earpieces.
5. Seismomicrophone: The seismomicrophones ordered separately ought to be used only to replace those of the cases represented in figure 2 and not those of the cases in figure 4. In fact,

Fig. 3. Fig. 4.



the latter have been selected with a view to all six possessing the same sensitiveness, and any seismomicrophone chosen at random can not replace one of them. If one or more seismomicrophones of the case (fig. 4) are destroyed, order a new case (see 7), and use the remaining microphones for the same purpose as those of figure 2.

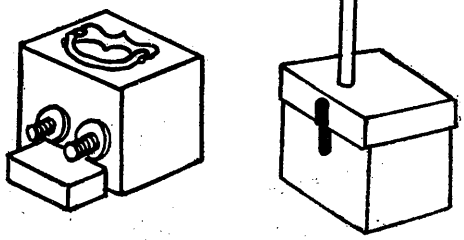
6. Water-tight case for the seismomicrophone (fig. 6).
7. Compartment case of 6 seismomicrophones (fig. 4).
8. Central of six directions (fig. 3).

9. Telephones of 20 ohms (2 earpieces of 10 ohms in series). This telephone suits the seismomicrophone case as well as the central of six directions.

10. Substitute batteries of the Military Telegraph No. 0. These batteries suit the seismomicrophone case as well as the central of six directions.

Fig. 6.

Fig. 5.



11. Double secondary cable (rolls of 150 meters). Give the number of rolls.

12. Double lead-sheathed cable. Give the length.

13. Chatterton.

Orders are filled by the Central Establishment for Special Engineers Material (E. C. M. S.), 39, Rue de Bellechasse, Paris.

APPENDIX II.

USE OF THE MILITARY TELEGRAPH SOUND-PERCEPTION INSTRUMENTS FOR MINES.

The following directions comprise—

(*a*) Various uses of the instruments.

(*b*) Advantages derived from their use.

(*c*) Disadvantages involved in their use in certain cases.

Nonelectric Instruments.

I. CASE OF SEISMOSTETHOSCOPES (FIG. 1).

(*a*) *Uses.*—

1. Making sound observations on the spot.
2. Determining a direction on the spot.

(*b*) *Advantages.*—These instruments, quite convenient to handle, afford the means for perceiving sounds and determining their direction without any preliminary preparations.

(*c*) *Disadvantages.*—(1) It is not always easy to observe sounds on the spot (lack of concealment, mine filled with the gases of an explosion, a loaded mine chamber). (2) Even if listeners are fitted to make ordinary sound observations, a preliminary training is necesary for determining the direction. (3) The operations necessary for making an intersection are sometimes quite difficult.

ELECTRIC INSTRUMENTS.

II. CASE OF SEISMOMICROPHONES (FIG. 2).

(*a*) *Use.*—Making sound observations at a distance.

(*b*) *Advantages.*—Making sound observations in inaccessible or dangerous places:

Such as—Charged and tamped mine.
Mine filled with gases after an explosion.
Flooded mine.
Incomplete concealment.

III. COMPLETE MICROPHONIC CENTRAL STATION (FIGS. 3 AND 4).

(*a*) *Uses.*—

1. Observation of an extensive zone by a single listener.
2. Location of subterraneon sounds at a distance.

(*b*) *Advantages.*—1. Economy in the personnel.

2. The method requires no preliminary training.
3. The rapidity of the determination is very great.
4. A single group of operations gives directly the position of the point of impact, and not simply a direction.
5. The accuracy corresponds to that of the seismostethoscopic method by intersections.

(*c*) *Disadvantages.*—Six lines of cable must be installed.

APPENDIX III.

Advantages of the Simultaneous Use of the Stethoscopic and Microphonic Methods.

The seismostethoscopes and seismomicrophones make possible the location of subterranean sound [I (2) and III] by two absolutely independent methods; the two methods afford, therefore, a mutual check.

For further details consult the new edition of the Report on the Perception of Subterranean Sounds (Methods and Instruments Prescribed by the Military Telegraph). This report includes sound perception proper, methods of determining the direction or position of a subterranean sound, critical examination of the results, abnormities in direction, etc.

