Dec. 8, 1942. J. P. MINTON 2,304,739

ELECTRICAL PROSPECTING

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Fig. 1.

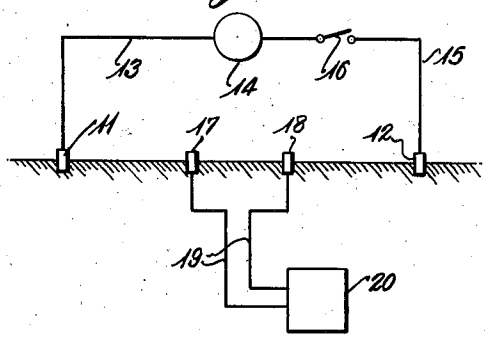


Fig. 2.

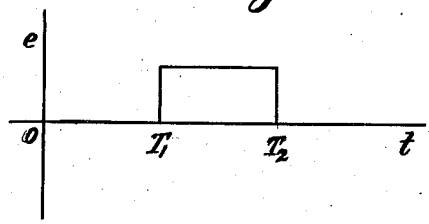


Fig. 3.

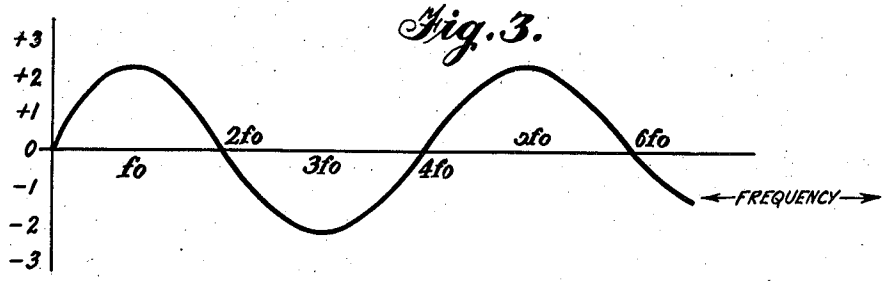


Fig. 4.

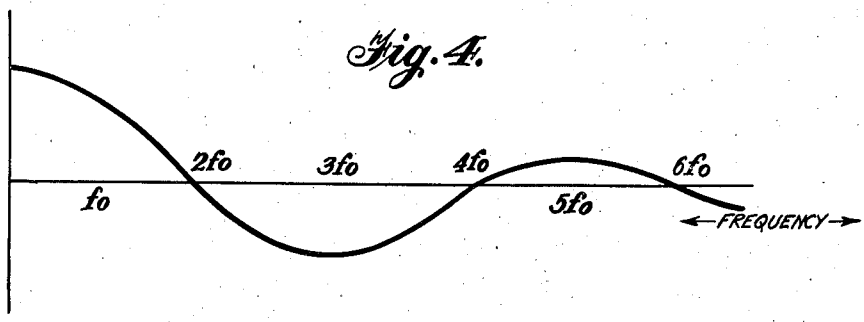
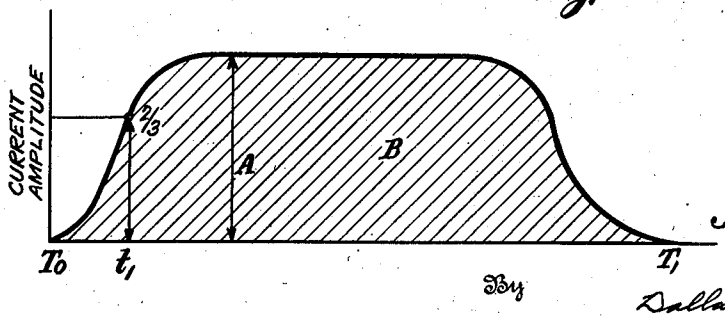


Fig. 5.



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Fig. 6.

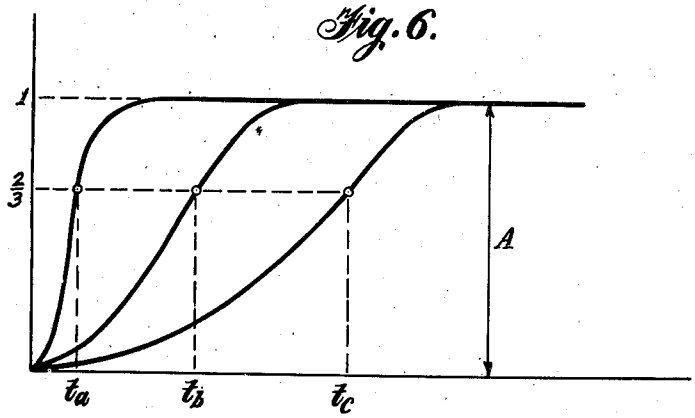


Fig. 7.

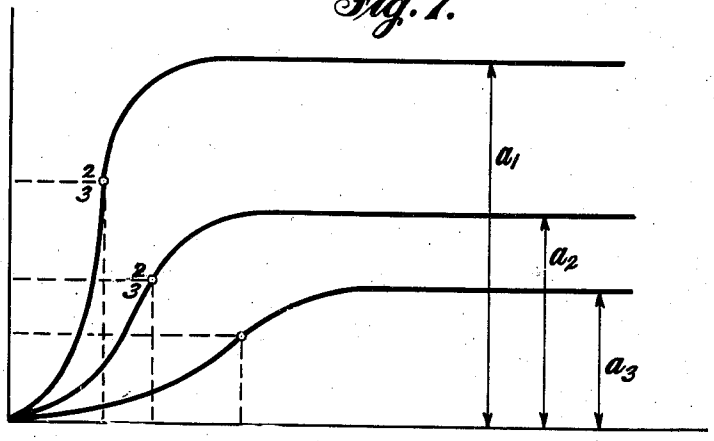
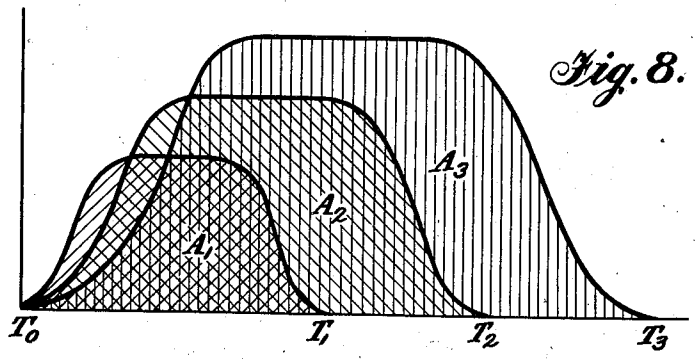


Fig. 8.



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UNITED STATES PATENT OFFICE

2,304,739

ELECTRICAL PROSPECTING

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Application February 5, 1941, Serial No. 377,457

5 Claims. (Cl. 175—182)

This invention relates generally to the art of geophysical prospecting and more particularly to electrical methods and apparatus for determining the presence of minerals, oil and other deposits in the substrata. This is an improvement over the methods disclosed by L. W. Blau in Patent No. 1,911,137 and J. J. Jakosky in Patent No. 2,211,125.

Blau's method, commonly known in the art as the "Eltran" method, relies upon information gained by measuring the build-up time of an electrical transient which has been introduced into the surface of the earth, that is, the time required for an impulse whose wave form has a square top, to reach its maximum value after having been introduced into the earth's surface by suitable electrodes. Jakosky's method differs from Blau's in that after a transient has been introduced into the earth's surface and the initial impulse is over, the maximum amplitude of the steady state current is measured. Jakosky uses these maxima to compute apparent electrical resistances for various spread distances. This is a direct current method. The "Eltran" method is a relatively high frequency method and as a result does not permit of deep exploration.

The instant invention allows exploration at intermediate frequencies and in addition gives data on both the "Eltran" and Jakosky methods.

Therefore, the primary object of this method resides in the provision of a method and apparatus whereby data can be obtained from which a profile of the substrata can be made.

Another object of this invention resides in the provision of a method and apparatus whereby not only the data obtainable by the Eltran and Jakosky methods can be obtained but additional valuable and more reliable data can also be recorded.

Other objects and advantages of this invention will become apparent from the following detailed description, when considered with the accompanying drawings in which:

Figure 1 is a diagrammatic illustration of the method and apparatus for introducing electrical currents into the earth's surface and detecting this current by suitable electrodes;

Figure 2 is an illustration of a square top electrical wave or impulse;

Figure 3 is a curve which has been plotted with frequency as abscissae and amplitude as ordinates;

Figure 4 is another curve which has been plotted in a similar manner to that disclosed in Figure 3, except that the value of f_0 has been changed;

Figure 5 is a curve illustrating the total data obtainable by the present method;

Figures 6 and 7 illustrate the manner in which Jakosky and Blau obtain their data; and

Figure 8 illustrates the data obtainable in addition to that obtainable by the Blau and Jakosky methods.

Referring to the drawings in detail, particularly Figure 1, there is illustrated a surface strata 10 of the earth's surface. Electrodes 11 and 12 are spaced at any desired distance dependent upon the electrical characteristics of the area that it is desired to explore. A conductor 13 leads from the electrode 11 to a source of current 14. Another conductor 15 leads from the electrode 12 through the switch 16 to the source of current 14. Current induced into the surface of the earth is detected by electrodes 17 and 18 which are placed between, but in line with electrodes 11 and 12. The spacing of electrodes 17 and 18 may be varied to suit any required conditions. In fact, as disclosed by Jakosky, electrode 12 can be made to move along the surface while the data is being obtained. Currents detected by the electrodes 17 or 18 are passed by means of the conductors 19 to a recording means 20, such as a cathode ray oscilloscope. These currents are recorded in coordination with time.

The general practice in electrical surveying has been heretofore to introduce an electric current into the earth's surface. This current passes between a pair of spaced energizing electrodes, the electrodes being electrically connected to the earth. This current passing between the electrodes creates, at a position on the earth's surface having no special relationship with respect to these energizing electrodes, a quantity which is dependent on the path of flow of the current and the electrical characteristics of the earth traversed by the current. Data are taken between potential electrodes for each of a plurality of spacings of the energizing electrodes and it is customary to change the spacing between the energizing electrodes by moving one or both of the electrodes to different positions. It is also customary to change the spacing between the potential electrodes by moving one or both of these electrodes when the current electrodes are being moved, but a movement of all electrodes simultaneously is undesirable since this would introduce so many variables that it would be impossible to determine the position of structures or anomalies that lie near the earth's surface.

The basis for the instant invention is an analysis of the square top wave utilizing both the

building-up portion of the impulse applied at a time T_1 and the dying down portion applied at a time T_2 (see Figure 2). The Fourier integral method of analysis is similar to that given in Shea's book entitled "Transmission Networks and Wave Filters." This wave, as disclosed by Figure 2, is composed of one wave changing from

$$-\frac{E}{2} \text{ to } +\frac{E}{2}$$

at a time $t=T_1$ and another that changes from

$$+\frac{E}{2} \text{ to } -\frac{E}{2}$$

at a time $t=T_2$.

Therefore this combined wave contains no direct current value. The total pulse is represented by

$$e=\frac{E}{\pi}\int_0^\infty \frac{1}{\omega}\sin\omega(t-T_1)d\omega-\frac{E}{\pi}\int_0^\infty \frac{1}{\omega}\sin\omega(t-T_2)d\omega \quad (1)$$

$$=\frac{E}{\pi}\int_0^\infty \frac{1}{\omega}[\sin\omega(t-T_1)-\sin\omega(t-T_2)]d\omega \quad (2)$$

But

$$\sin x-\sin y=2\sin\frac{x-y}{2}\cos\frac{x+y}{2}$$

$$\therefore e=\frac{E}{\pi}\int_0^\infty \frac{1}{\omega}\left(2\sin\omega\frac{T_2-T_1}{2}\right)\cos\omega\left(t-\frac{T_2+T_1}{2}\right)d\omega \quad (3)$$

For an origin at

$$t=\frac{T_2+T_1}{2}$$

the wave would therefore be symmetrical about the voltage axis and composed of cosine terms. The coefficients of the components are altered by the factor

$$2\sin\omega\frac{T_2-T_1}{2}$$

Call T_2-T_1 the half period, and let its frequency be f_0, then

$$f_0=\frac{1}{2(T_2-T_1)}$$

or

$$T_2-T_1=\frac{1}{2f_0} \quad (4)$$

whence, by substitution

$$2\sin\frac{\pi}{2}\frac{f}{f_0}=2\sin\frac{\pi}{2}\frac{\omega}{\omega_0} \quad (5)$$

The curve for this factor is as shown in Figure 3. Multiplying this factor by

$$\frac{E}{\pi\omega}d\omega$$

then Equation 3 coefficients become

$$\frac{E}{\pi}\frac{d\omega}{\omega}\left(2\sin\frac{\pi}{2}\frac{\omega}{\omega_0}\right)$$

and this is a curve like that shown in Figure 4. Additionally,

$$\frac{E}{\pi}\frac{d\omega}{\omega}\left(2\sin\frac{\pi}{2}\frac{\omega}{\omega_0}\right)=\frac{E}{\omega_0}\frac{\sin\left(\frac{\pi}{2}\frac{\omega}{\omega_0}\right)}{\frac{\pi}{2}\frac{\omega}{\omega_0}}$$

So transmission of a direct current pulse requires transmission of a continuous band of frequencies. If f_0 is taken as the fundamental frequency, it is observed that the important energy regions are at harmonic frequencies which are important in the Fourier series of a rectangular wave. So the Fourier integrals degenerate into something like a Fourier series zero coefficients at $2f_0$, $4f_0$, etc. and large coefficients at f_0, $3f_0$, etc. Now f_0 may be varied at will and the system can be built with means to vary f_0 to suit the exploration needs. Pictures could be observed and taken on a cathode ray screen at each value of f_0.

By making sure that f_0 covers a wide range of frequencies from zero up, one could make sure that the resultant pictures covered from deep to shallow depths, i. e. $f_0=0$, means deep explorations, and f_0 high, means shallow exploration.

From the above it is apparent that data as illustrated by the curve of Figure 5 is obtainable. The Eltran method, as illustrated in this figure, deals with the period of time T_0 to t_1. The Jakosky method relies upon the current amplitude as illustrated by the ordinate A in this same figure. The additional data obtainable by the instant invention is represented by the total area B under the curve and is taken over the period of time from T_0 to T_1. These results could not be obtained by using either the Eltran or Jakosky methods alone for no consideration is given to the period of time throughout which the current dies down. As shown in Figure 6, the Eltran method is only interested in the build-up times as illustrated by t_a, t_b, t_c for the three curves illustrated and the Jakosky method is only interested in the maximum obtainable steady state amplitude as represented by the ordinate line A. In this illustration, current values are used which regardless of the rate at which they build up, reach an equal maximum value.

The curves of Figure 7 illustrate the manner in which the build-up time can vary simultaneously with the maximum amplitude obtainable. As illustrated by Figure 5, it is not only possible with the instant invention to obtain the data illustrated in Figures 6 and 7, but additional valuable information represented by the entire area underneath the curve. The instant invention is specifically directed to this phase of electrical prospecting.

Referring to Figure 8, it is seen that by varying the rate of application of the current impulses into the earth's surface, curves of widely varying areas can be obtained. For example, the curve A_1 represents the time from T_1 to T_0. Curve A_2 represents the time from T_2 to T_0, and curve A_3 represents the time from T_3 to T_0. Since, as illustrated above, f_0 can be varied at the will of the operator, the rate of application that is most suitable from a penetrating point of view can be selected for the particular area being explored.

I claim:

1. In a method of geophysical prospecting in which electrical current pulses are introduced into the earth's surface and caused to flow between spaced electrodes, the improvement which comprises varying the rate of application of the current to the earth's surface until the rate which gives the penetration desired is found, causing the current pulses to flow between the electrodes, detecting the current thus caused to flow through the earth's surface between a second pair of spaced electrodes as a function of time and recording parameters of the current pulses from which anomalies in the subsurface strata can be located.

2. In a method of geophysical prospecting in which electrical current pulses are introduced into the earth's surface and caused to flow between spaced electrodes, the improvement which comprises varying the rate of application of the current to the earth's surface until the rate which gives the penetration desired is found, causing the current pulses of this frequency to flow between

the electrodes, detecting the current thus caused to flow through the earth's surface between a second pair of spaced electrodes and simultaneously recording the time required for a square top wave to reach its maximum, the maximum steady state value of the current after the passage of the build-up transient, and the dying out time from which anomalies in the subsurface strata can be located.

3. In a method of geophysical prospecting in which electrical current pulses are introduced into the earth's surface and caused to flow between spaced electrodes, the improvement which comprises varying the rate of application of the current to the earth's surface until the rate which gives the penetration desired is found, causing the current pulses to flow between the electrodes, detecting the current thus caused to flow through the earth's surface between a second pair of spaced electrodes as a function of time and recording an integral of a function of the current pulses from which anomalies in the subsurface strata can be located.

4. In a method of geophysical prospecting in which electric current pulses are caused to flow through the surface of the earth for a predetermined time, the improvement which comprises the steps of detecting the current pulses between spaced electrodes along the surface of the earth, indicating a function of the detected pulses by means of an oscilloscope, photographing the indicated function and integrating the photographed function to determine the area beneath the curve forming the function from which anomalies in the subsurface strata can be located.

5. In a method of geophysical prospecting in which electrical current pulses are caused to flow through the surface of the earth, the improvement which comprises the steps of selecting a rate of application of current pulses to the earth that will give the desired penetration into the substrata thereof, detecting the current between spaced electrodes along the surface of the earth and indicating the detected pulses by means of an oscilloscope and determining the area beneath the curve forming a single impulse from which irregularities in the subsurface strata can be located.

JOHN P. MINTON.