THE INFLUENCE OF SUB-SURFACE GEOLOGY UPON THE PROPAGATION OF ELECTRO-MAGNETIC WAVES

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BY

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INTRODUCTION

The ice sheets which deployed over the Great Lakes region during the Pleistocene epoch left in their wake a mantle of glacial drift covering the surface of Michigan to depths ranging up to 1200 feet (Fig. 1, p. 2). As a result of glaciation, rock exposures, especially in the southern part of the Lower Peninsula, are extremely rare. The geologist, therefore, is dependent upon well-log data and geophysical methods for the determination of sub-surface geology.

Glacial drift also offers a serious problem to the geophysicist, particularly in seismic work, as the unconsolidated character of the material causes marked energy losses. Moreover, in gravitational methods, especially that employing the torsion balance, similar difficulties are encountered, since the presence of large boulders near the surface are responsible for considerable changes in density, and therefore in the recorded value of gravity within the same material. Electrical resistivity has been employed successfully in outlining areal geology but is definitely limited in its application to the vertical measurement of rock sections.

In view of the limitations placed on the application of geophysical methods in drift covered areas an investigation of radio reception was made in an attempt to provide an additional

Fig. 1. Thickness of Glacial Drift in Michigan.

means of sub-terrane interpretation. This paper presents the results of researches carried out in this particular field.

HISTORICAL

It is well known that certain localities yield poor radio reception from stations that seemingly should give a good radio signal. Such areas may be divided into two groups; one of very local proportions, not exceeding several hundred feet, and the other of considerable magnitude, covering, perhaps, several hundred miles. In either instance, since the present investigation involves primarily the geological aspects of radio reception, the penetration of an electro-magnetic wave into the ground must be considered.

Local Fading*-- In the case of local fading a radio signal has a low intensity or becomes entirely inaudible over a certain area, although the signal may be strong on either side. Local fading and so-called "dead spots" in Maryland and Wyoming have been shown by Cloos (4) to be associated with faults and steeply dipping rock contacts when the materials on either side of the fault or contact have marked differences in physical properties,

* All fading from man-made causes such as transmission lines, telephone wires, steel structures, etc. are disregarded as their presence is easily detectable.

Both of the regions investigated by Cloos are unglaciated and the boundary condition responsible for fading is known to be at or near the surface. It can be postulated, therefore, that in glaciated regions, where the geologic discontinuity is buried, the effect, though not pronounced, might be detectable with sensitive measurements and be used geophysically.

Poor Reception over Large Areas.- Poor reception of large areal extent is characterized by a general loss of signal intensity. A s an example of this type the problems encountered by the Radio Division of the Michigan State Police may be cited. Prior to 1936 and 1937 communication with mobile units was transmitted from only one station, WRDS (1642 kilocycles, 3000 watts), located at East Lansing. Exceedingly bad reception occurred over a large area in the southwestern part of the state and in a smaller area in the vicinity of St. Clair, although a good signal could be obtained at equal distances in other directions. In the northern part of the Lower Peninsula the signals became unreliable as the distance from the station was too great to be covered by a 3000 watt transmitter. No further mention of the St. Clair area will be made as no detailed work has been done in that vicinity.

In 1935, E. D. Shipley, under the supervision of R. C. Higgy, both of Ohio State University, conducted a series of field studies in cooperation with C. E. Winans of the Michigan State Police Radio

Receiver Division. The purpose of the investigation was to solve certain engineering problems, involving an expansion program, for the improvement of reception in the aforementioned areas.

According to the method employed by Higgy and Shipley (8), based upon the Sommerfeld theory, the only ground constant that influences radio field strength is electrical resistivity. Since the ground acts as an electrical mirror in the propagation of electro-magnetic waves, transmitter location sites are chosen where the conductivity is as high as possible. It is the practice in field intensity surveys to run radial traverses from a portable transmitter, record the field strength at given intervals, and then plot the resulting figures in (microvolts per meter) as ordinates against the distance (in miles) as abscissas. The resulting graph may be called an E-D curve. Finally, the ground conductivity is calculated from the data thus obtained.

Field studies were made at a number of locations in Michigan; including Lansing, Paw Paw, Benzonia, Kalkaska, Grayling, Roscommon, Mio, Cadillac, and McBain. With the single exception of Lansing, these are situated in either the southwestern or northern areas of poor reception previously mentioned. As a result of the investigations two subsidiary stations were installed; WRDP (1642 kilocycles, 1000 watts) at Paw Paw in the Spring of 1936, and WRDH (1642 kilocycles, 1000 watts) at Houghton Lake in the Fall of 1937. The T-type transmitting antenna at WRDS was then replaced by a vertical type and the power was later increased to 5000 watts.

The writer has examined the report submitted by Shipley and has conferred with Winans relative to the results of their studies. Certain abrupt changes in slope on many of the E-D curves seem to agree quite markedly with formational boundaries. The strata underlying the areas investigated are Pennsylvanian and Mississippian in age. The boundaries which seemed particularly effective were those between the following geologic formations; Parma sandstone and the Michigan series, the Michigan series and Napoleon sandstone, and the Marshall sandstone and Coldwater shale. The glacial drift in the northern area is several hundred feet.

If the effect noted on the E-D curves is actually due to the underlying formations then a considerable penetration of radio waves in the broadcast band is implied. It should be noted, however, that the conductivity as determined by a field intensity survey is an average over the depth penetrated and that the absolute depth is a factor that can be ignored from the standpoint of the radio engineer. To the geophysicist, on the other hand, a knowledge of the extent of penetration is of utmost importance.

Penetration of Radio Waves.- According to Eve and Keys (6, pp. 251-252) radio waves in the broadcast band reach to considerable depths under certain ground conditions. In June, 1926, an experiment was conducted in the Mount Royal Tunnel, Montreal, Canada. Waves of 411 and 1300 metre lengths could be detected throughout the $3\frac{1}{2}$ mile tunnel which has a maximum overburden of

300 feet. Waves of 40 metre length vanished at 1500 feet from the entrance although the overburden was only 48 feet at this point.

In the summer of 1927 a similar experiment was carried out in the Caribou mine, Colorado. Broadcast signals of 267 metres from Denver, 50 miles away, were received clearly at a depth of 220 feet, and with difficulty 550 feet underground. It was not known, however, whether the waves came through the rocks, through openings, or along numerous rails, cables and pipes in the shaft.

Eve and Keys (6, p. 252) state, "In order to remove all further doubt Dr. F. W. Lee selected the Mammoth Cave, Kentucky, which was entirely free from conductors, which had about 300 feet of overburden, mostly limestone, and was so long and circuitous that transmission through the mouth was definitely proved ineffective.

Using a three-hundred foot horizontal antenna in River Hall, morse signals were received from six different long-wave stations, while speech and music was made audible with a loud speaker, 300 ft. underground, received from Cincinnati (700 kc., 429 m.) 200 miles away; from Louisville (820 kc., 366 m.) 90 miles away, and from Nashville (650 kc., 461 m.) about 100 miles away. These signals unquestionably penetrated 300 ft. of rock."

It should be noted that in none of the experiments involving underground reception has any mention been made of a glacial cover or that the ground conditions differ from those in Michigan.

Summary.- Previous research has shown that there are two unrelated causes of poor radio reception both of which are geological in character. The first, recorded by Cloos (4) as occurring at faults or steeply dipping rock contacts, is probably the result of reflection and refraction analogous to similar phenomena in light. The second type of poor reception, a general loss of energy over a relatively large area, may occur where formations are horizontal. The latter type can be explained by the theory of propagation of electro-magnetic waves, a discussion of which will be taken up in the next section of this report.

Finally, if radio field intensity is to be employed for geophysical interpretation in glaciated areas, considerable penetration through the drift must occur. Experiments have proved that radio signals may be received through several hundred feet of rock. Field intensity data in Michigan seems to indicate that a similar penetration may occur in drift and that the underlying formations may materially influence the signal strength.

THEORY OF PROPAGATION OF ELECTRO-MAGNETIC WAVES

A radio wave is an electro-magnetic disturbance of the ether which is propagated outward from the transmitting antenna with the velocity of light. It consists of a carrier wave which is modulated with sound. Modulation under 100 per cent does not effect the energy of the carrier wave so that in the present consideration modulation may be disregarded. The carrier is a pure sinusoidal wave having an alternating electric field and an alternating magnetic field which are 90 degrees out of phase with each other both with respect to time and to space The carrier wave is plane-polarized. At a considerable distance from the transmitter, near the surface of the earth, the wave front becomes approximately cylindrical in form. Ground conductivity causes the electric vector to assume a vertical position and the magnetic vector a horizontal position. The energy of the wave is equally divided between the two fields.

There are at least two types of waves to be considered in radio reception. The first, received directly from the transmitter, is usually called a ground wave but will henceforth be referred to as a surface wave to avoid confusion with the ground wave as defined by Sommerfeld. The second is reflected from the Heaviside layer and is known as the sky wave. It will not be considered in this discussion.

If a wire, exposed to electro-magnetic radiation, is oriented parallel to the electric vector an emf is generated. Such an emf expressed in microvolts per meter has arbetrarily been chosen as the unit in field strength measurement.

If the earth were a perfect conductor the only attenuation of a radio wave would be the geometric spread of the wave. Then the intensity at a specific point would be given by the formula (See reference 4, pp. 350-351 for derivation)-

$$E_o = KIH/Wr \qquad (1)$$

where

E_o is the field intensity

K is a constant, depending upon the units chosen

I is the height of the transmitting antenna

W is the wave length, and

r is distance.

Since there are losses in transit due to the electrical constants of the ground the actual intensity at a given point is equal to Eq. (1) multiplied by an attenuation factor. Several empirical formulas for absorption have been worked out. One of the most reliable is that of Austin-Cohen (1, p. 661). The formula takes the form

$$e^{-aDf^{\frac{1}{2}}}$$

where

f is the frequency.

D is the distance.

a is to be evaluated for the particular conditions.

The most widely known and used transmission formula of a purely mathematical nature is that of Sommerfeld (13). This is based upon the theory of a ground wave defined as a wave traveling at the boundary of two semi-infinite media (earth and air) of very different electrical properties. The equation is in the form of an infinite series and because of its complexity was seldom used by radio engineers. Rolf (12) has constructed a set of graphs of the Sommerfeld formula covering a wide range of ground conditions which has made the equation more adaptable to field intensity work.

A more exact formula was derived by Weyl (15), in which the only assumption made is that the point in question be far enough away so that the transmitting antenna appears as a dipole. It can be shown (3) that Weyl's formula differs from that of Sommerfeld by exactly the ground wave component. Experiments by Burrows (3) have proved that the ground wave is not present in ordinary transmission and that Sommerfeld's formula and Rolf's graphs are in error in all cases in which the dielectric constant of the ground cannot be neglected.

The attenuation factors corresponding to the formulas derived by Sommerfeld and Weyl may be set down as follows (15) -

$$S = A + B/2 \qquad (2)$$

$$W = A - B/2 \qquad (3)$$

where

S is the attenuation factor of Sommerfeld.

W is the attenuation factor of Weyl

$$A = 1 + \sum_{n=1}^{\infty} \frac{x^n e^{2in(z + \pi/4)}}{1 \cdot 3 \cdot 5 \cdots (2n - 1)} \qquad (4)$$

$$B = (2\pi x)^{\frac{1}{2}} e^{-(x/2)\sin 2z + i((x/2)\cos 2z + z + \pi/4)} \qquad (5)$$

$$C = -\sum_{n=1}^{\infty} \frac{1 \cdot 3 \cdot 5 \cdots (2n - 1)}{x^n e^{2in(z - \pi/4)}} \qquad (6)$$

$$x e^{2iz} = \frac{2\pi r/w}{k - 2is/f} \qquad 0 \leqq z \leqq \pi/4 \qquad (7)$$

"These follow from expressions given by Wise (16) when the magnitude of k - 2is/f is large compared with unity." (15)

Using the approximate form (6) and substituting (7) the resulting attenuation factor corresponding the Weyl is -

$$C = -\sum_{n=1}^{\infty} \frac{1\cdot3\cdot5\cdots(2n - 1)e^{2in\pi/4}\, v^n(kf - 2is)^n}{(2\pi rf^2)^n} \qquad (8)$$

where

v is the velocity of light.

f is the frequency..

r is the distance.

s is the ground conductivity.

k is the dielectric constant of the ground.

While the formula may be of some value in showing the manner in which the intensity is influenced by the ground constants it cannot be employed in making geophysical calculations. It is valid only at a relatively great distance from the transmitter. The conductivity and dielectric constant appearing in the formula are average or overall values for the distance covered and the depth penetrated. It cannot be used, therefore, in evaluating these constants for definite intervals.

If it is assumed, as is usual in field intensity work, that the dielectric constant does not change appreciably over a particular region then the intensity for a given frequency and power at the transmitter becomes a function only of conductivity and distance. If the intensity as measured in the field is plotted against the distance from the transmitter a change in slope should be apparent where changes in resistivity occur. If the intensity is primarily influenced by material underlying the glacial drift measurements of field intensity should be of value in outlining sub-surface geology.

<u>Tilt of the Electric Vector</u>. - If the ground were a perfect conductor the electric vector would everywhere be perpendicular to the surface of the earth. Hund (9, p. 352), employing the Sommerfeld theory, has shown that a theoretical tilt of the electric vector should exist and that the angle of inclination is a function of the ground constants. He gives the formula -

$$\tan T = \sqrt{\frac{f/18.10^8 s}{(1 + (kf/18\cdot 10^8 s)^2)^{\frac{1}{2}}}} \qquad (10)$$

where

T is the angle of tilt

s is the specific conductivity in 1/ohm cm.

f is the frequency in kilocycles per second

k is the dielectric constant

From the foregoing it appears that in the field a measurement of the angle of tilt of the electric vector might also be of value in making geophysical determinations.

Penetration of a Radio Wave. - For future reference the following formula, also developed by Hund (9, pp. 334-335), for the penetration of a radio wave into the ground is given as -

$$H_z = H_o e^{-bz} \qquad (9)$$

where

H_o is the field intensity at the surface.

H_z is the field intensity z cm. below the surface.

$b = 2\pi(fu/p)^{\frac{1}{2}}$

f is the frequency in cycles per second.

u is the magnetic permeability, assumed unity.

p is the resistivity in abohm-cm.

METHOD OF MEASUREMENT

If the plane of a loop antenna is oriented perpendicular to the magnetic vector of an electro-magnetic field the condition for maximum pick-up is obtained since in this position the greatest rate of change of flux occurs. The induced emf under such conditions (2, p. 403) is represented by the formula -

$$V_i = 2\pi fENA/v \qquad (11)$$

where

V_i is the induced emf in volts.

f is the frequency in cycles per second.

E is the electric field intensity in volts per cm.

N is the number of turns in loop.

A is the area of loop in sq. cm.

v is the velocity of light in cm. per second.

The terminal voltage of a tuned loop circuit because of resonance, is much greater than the induced voltage. The ratio of the terminal emf to the induced emf is known as the step-up ratio of the loop.

Taylor (14) has described a means of measuring field intensity directly. The more common practice, however, is to employ some form of comparison.

Direct Comparison Method. - In the direct method a current indicating meter is usually placed in the plate circuit of the i.f. detector of a superheterodyne receiver. The loop is adjusted for maximum pick-up. The deflection of the meter caused by the signal being measured is noted. The loop is then turned through 90 degrees where theoretically there should be no pick-up. A locally generated voltage of the same frequency as the signal is induced into the loop circuit either across a known resistance drop or by means of a calibrated mutual inductance. Before entering the loop circuit the current is first measured by means of an ammeter and then attenuated until it gives the same deflection on the receiver meter as the signal, in which case the induced voltages of the signal and oscillator are equal. The field strength may then be calculated from Eq. (11).

Several difficulties are encountered with this method. Turning the loop through 90 degrees does not always completely cut out the signal. Since the loop is always attached to the receiver the oscillator and attenuator must have perfect shielding to prevent stray pick-up. The voltages dealt with are extremely small. Friis and Bruce (7) have avoided these objections by placing a calibrated attenuator after the i.f. detector. It is an advantage, however, to have the calibrating voltage and attenuator separate from the receiver, especially in checking against a standard voltage. For these reasons the indirect method is sometimes used.

Indirect Comparison Method. - The scheme differs from the direct method by applying the locally generated voltage directly to the terminals of the receiver with the loop disconnected. In this case larger voltages are used but the step-up ratio of the loop must be determined. The latter relation depends upon the resistance and reactance of the loop. Since the resistance may change with climatic conditions, the step-up ratio must be determined at the time of measurement.

Calibrated Receiving Set. - This method has the advantage of simplicity and low expense since much less apparatus is required. A superheterodyne receiver is employed and a current indicating device is usually placed in the plate circuit of the i.f. detector as in the other methods. The deflection of the meter is a measure of the field intensity when the loop is properly oriented. The plan is particularly good for relative measurements but may be employed for absolute values by calibrating the meter.

Apparatus Designed for Experimental Work. - In the present experiment there is no need for absolute values of field intensity and the only requirements of the apparatus are dependable relative measurements and reproducibility of reading under the same conditions. In other words, the receiver must be stable and retain its characteristics over a reasonable period of times.

A National NC-44 receiver was selected for the experimental work. Referring to Fig. 2, p.20, it will be noted that this set employes a 6K7 tube as second detector and an AVC with the control grid and cathode acting as a detector. In placing a micro-ammeter in the plate circuit of the tube it was noted that modulation very seriously affects the meter. The meter was then placed in the control grid circuit which would correspond to the plate circuit of an ordinary i.f. detector. In this position, not only was modulation objectionable, but the current change from signal to no signal was so small that no sensitivity could be obtained. Finally the meter was placed in the plate circuit of the second i.f. amplifer. The dc plate current change in this tube is controlled by the AVC and is, therefore, a measure of the field intensity. While no modulation effects were present, the current change was still too small to give the desired sensitivity. To overcome this difficulty a variable resistance, R_p (Fig. 2), was substituted for the meter and the voltage drop across it measured by means of a potentiometer. The resistance used is small and does not noticably effect the operation of the set.

The only factors likely to change the overall amplification of the receiver over a reasonable period of time are changes in plate current and in "B" voltage. To keep the plate current constant, a small variable 1-ohm resistance, R_a (Fig. 2), was placed in the "A" battery circuit in series with an ammeter. It was found that with a plate current of about 1.85 amps. small variations in

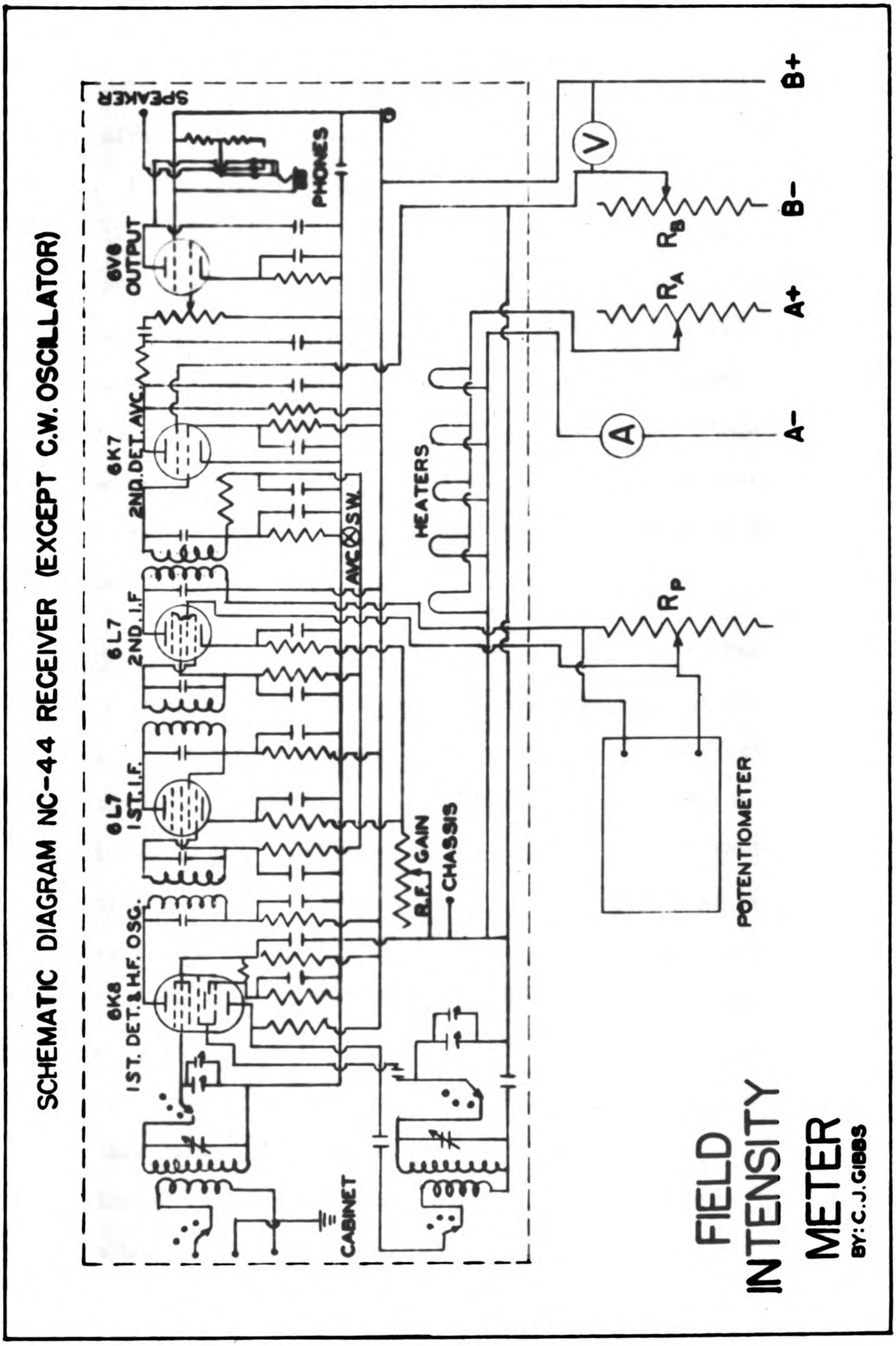

SCHEMATIC DIAGRAM NC-44 RECEIVER (EXCEPT C.W. OSCILLATOR)
6K8
1ST. DET. & H.F. OSC.
6L7
1ST. I.F.
6L7
2ND. I.F.
6K7
2ND. DET. AVC.
6V6
OUTPUT
SPEAKER
PHONES
AVC SW.
HEATERS
R.F. GAIN
CHASSIS
CABINET
V
A
R_B
R_A
R_P
B+
B-
A+
A-
POTENTIOMETER
FIELD
INTENSITY
METER
BY: C.J.GIBBS

FIG. 2.

either direction do not cause appreciable changes in the amplification. In the field, however, it was seldom found necessary to adjust the current. In order to maintain the same "B" voltage on the set at all times a voltmeter was placed across the "B" leads and an extra battery and a variable resistance, R_b (Fig. 2), were placed in series with the ordinary supply. While in constant use the "B" batteries polarize continuously so that more voltage must be added to the set by means of adjusting the variable resistance at each measurement. Finally the apparatus was mounted to make it portable as shown in Fig. 3, page 22.

<u>Procedure in making Field Intensity Measurements</u>. - The following procedure in making a field intensity measurement is employed. R_b is adjusted until there are 135 volts on the set as indicated by the voltmeter. R_p is then adjusted until the desired range is obtained on the galvanometer and this value of resistance is maintained throughout the field work. The receiver is then detuned. The potentiometer is set at .1 volt and the galvanometer brought to zero by means of R_b. Thus the same condition of the apparatus is obtained at each measurement since the only part that changes appreciably is the "B" voltage. The signal being measured is now tuned in and the voltage drop across R_p measured by means of the potentiometer. The value of intensity recorded is the ratio of the signal voltage drop to the no-signal voltage drop; thus no units are involved.

Fig. 3. Field Intensity Meter.

Additional Apparatus. - For the measurement of the tilt of the electric vector, a rod antenna was mounted on a horizontal axis which may be rotated by means of a dial (Fig. 4, p. 24).

A tuned loop antenna was constructed as shown in Fig. 5, page 25, especially for use in checking the direction of the wave.

FIELD WORK IN THE HOWELL, MICHIGAN, AREA.

Description of Area. - Since the Howell area is only 33 miles from East Lansing, and presents one of the most interesting geological problems in the state, it was chosen as an ideal place to carry out a detailed radio survey. Another point of advantage lies in the fact that the area is situated within the surface wave range of several large broadcasting stations. In addition, an electrical resistivity survey of the area has already been made (See reference 10).

One of the most pronounced geologic structures in Michigan is a large asymmetrical northwest plunging anticline extending from southeast to northwest across Livingston County. The crest of the fold extends through the city of Howell. There is a gentle northeast dip and a much steeper southwest dip from the crest. Some controversy has arisen as to whether the structure is a normal fold

Fig. 4. Rod Antenna.

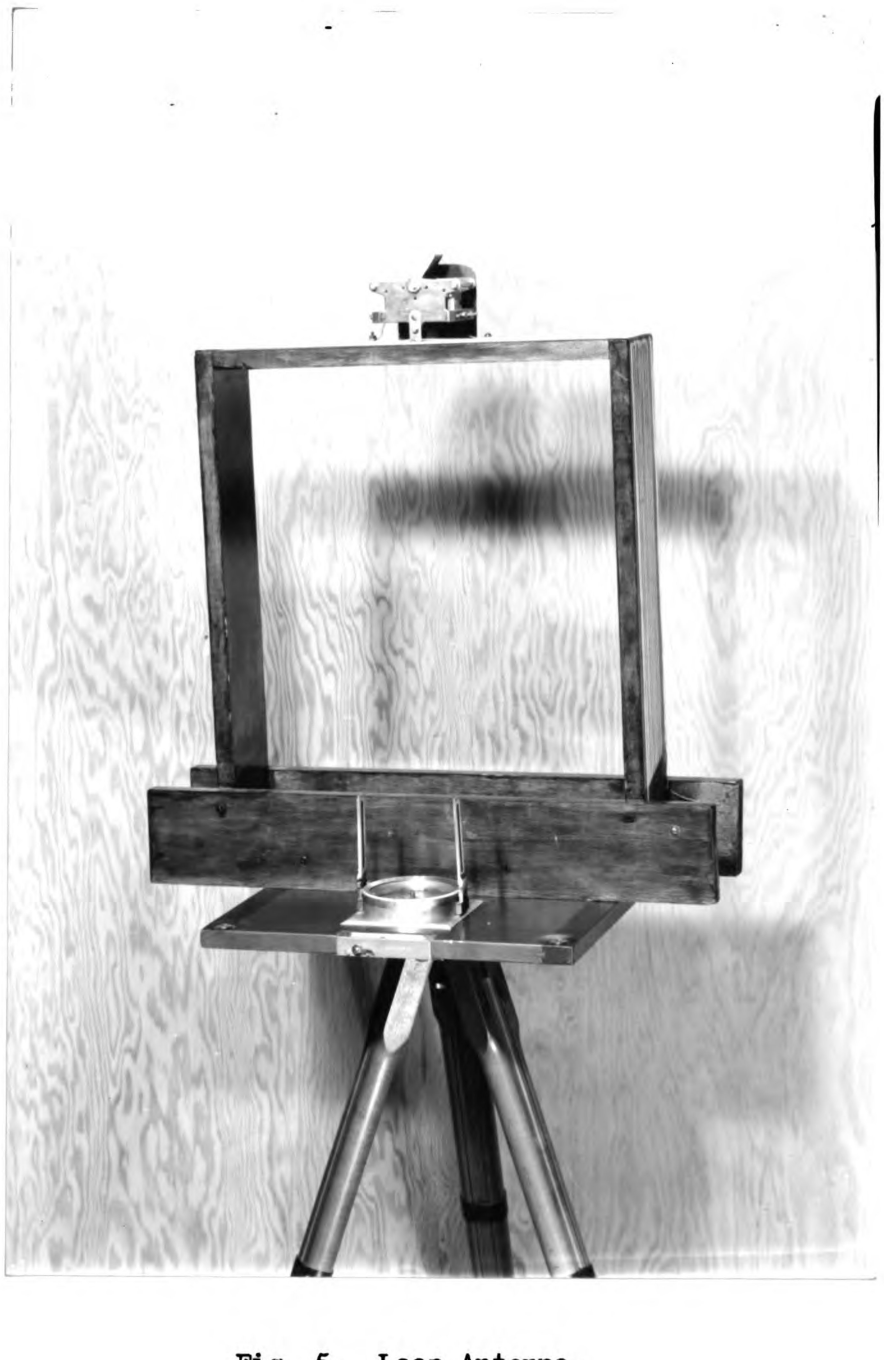


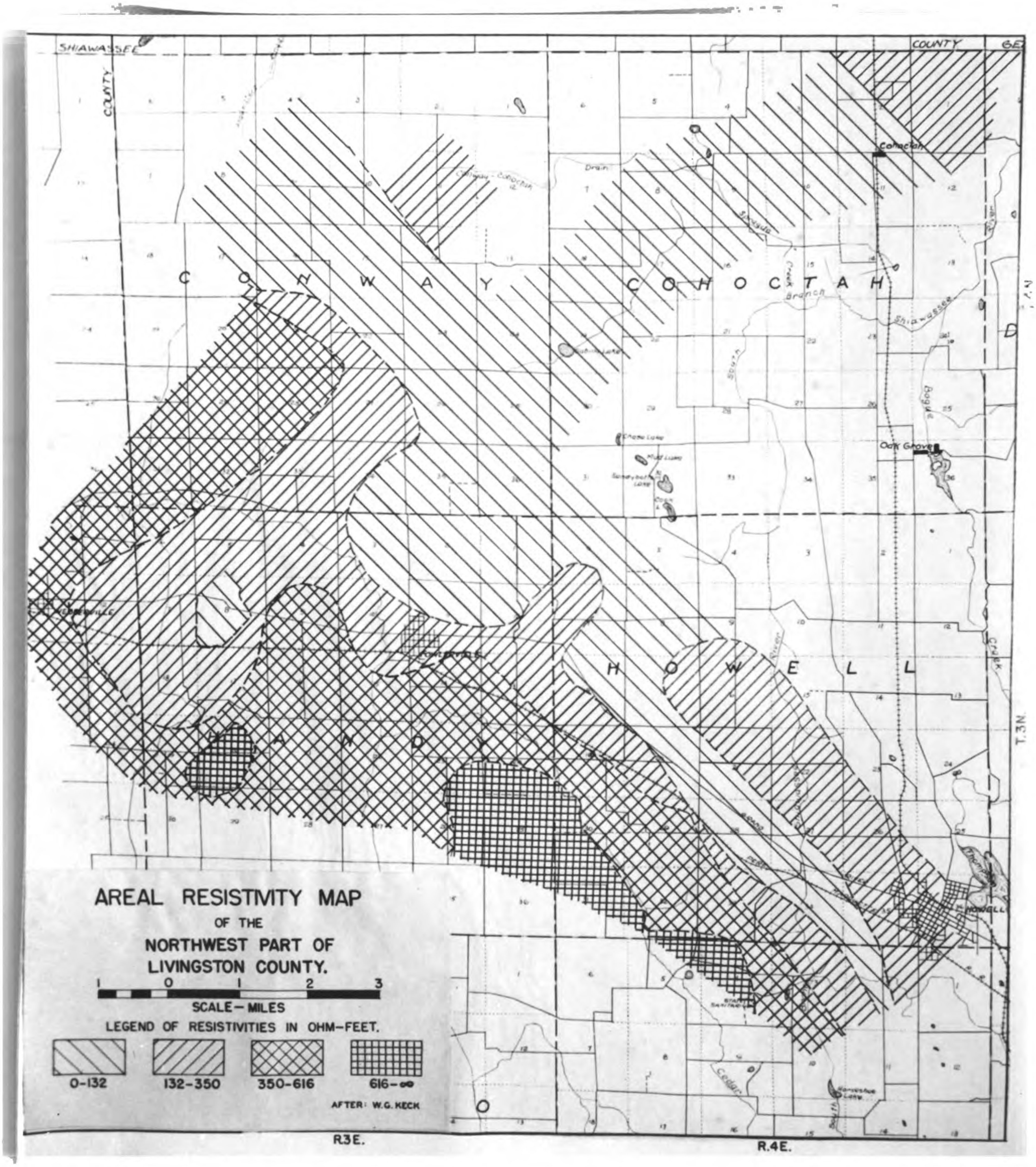
Fig. 5. Loop Antenna.

or whether the steep southwest dip is the result of faulting, as postulated by Newcombe (11). The Coldwater shale of Mississippian age underlies the axis of the structure and extends eastward across the county. On the southwest, because of greater dip, this formation is flanked by the Marshall sandstone, the Grand Rapids series and the Saginaw formation in order. The Coldwater shale is responsible for the zone of low resistivity as shown by Keck (10) in Fig. 6, page 27. The belts of higher resistivity are related to the Marshall sandstone, Grand Rapids series and Saginaw formation. The glacial drift varies in thickness from 50 feet on the west border of Livingston County to over 150 feet on the east side.

Field Work. - It was reasoned that an areal intensity survey might provide more information regarding the relation of sub-surface geology to propagation than could be expected from ordinary radial traverse.

All measurements were taken on WJR (750 kilocycles, 50,000 watts), Detroit, because this station gives the strongest signal in the area. Several attempts were made to determine the tilt of the wave and in all cases the electric vector was found to be exactly vertical. The survey of this factor was therefore abandoned.

The original plan was to use either the rod or loop on a plane table to maintain a level position. In such a set-up the effect of body capacity was extremely troublesome since it was necessary for the observer to be several feet from the antenna while operating the apparatus.



AREAL RESISTIVITY MAP
OF THE
NORTHWEST PART OF
LIVINGSTON COUNTY.
1 0 1 2 3
SCALE—MILES
LEGEND OF RESISTIVITIES IN OHM-FEET.
0-132
132-350
350-616
616-∞
AFTER: W.G. KECK
C O N W A Y
C O H O C T A H
H O W E L L
SHIAWASSEE
COUNTY
Cohoctah
Oak Grove
HOWELL
R.3E.
R.4E.
T.3N.

Fig. 6.

The plan finally adopted was to mount the apparatus permanently in an automobile using an ordinary whip antenna 72 inches long. Although the pick-up under these conditions is less than with a loop the effect of body capacity is avoided and considerable time is saved in loading and unloading the apparatus. Field intensities were recorded at intervals of one mile or less. In each instance a location as free from the influence of power lines, telephone wires and trees as possible, was selected.

In a survey of this kind the time variation of the signal must be considered. In the first place a power variation of 5 per cent is allowable at the trandmitting station according to regulation although the actual variation is probably considerably less. It has been shown(5) that intensity is influenced by climatic conditions, especially by barometric pressure. Therefore, results with much less than 5 per cent error cannot be expected unless a continuous record of signal strength is made at one position while the survey is being conducted or the measurements are made under nearly the same conditions. During the survey several field stations were repeated either on the same day or on a succeeding day as a check. The results showing this variation with time are recorded in Table I, page 29. Field intensities at the same location are grouped together when occurring on the same day, otherwise they are on the same horizontal line. It will be noted that measurements taken On May 10, 12, and 13 show variations of less than 5 per cent with the exception of those at field stations 15 and 172 which are probably in error. However, all intensities recorded on May 21 are

TABLE I.

RADIO FIELD INTENSITY VARIATION WITH TIME.

May 10		May 12		May 13		May 21	
Sta.	- Int.	Sta.	- Int.	Sta.	- Int.	Sta.	- Int.
(13)	48			(170)	49		
(14)	47			(171)	47		
(15)	49			(172)	53		
(17)	49						
(63)	51						
(18)	49						
(64)	50						
(74)	49	(122)	50				
(70)	52			(148)	52		
(66)	54			(187)	54		
(67)	50			(177)	52		
		(130)	48			(212)	45
		(131)	49			(213)	45.5
				(155)	52	(214)	47
				(156)	54	(215)	49
				(157)	52	(216)	47
				(158)	55	(217)	51

approximately 10 per cent lower than those recorded on either May 12 or 13. This may be accounted for by the fact that an extremely heavy rainfall occurred 12 hours previously. Thunder showers also occurred later in the day and the survey was brought to a close at this time.

The complete list of field stations, their locations and intensities are reproduced in Table II, pages 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, and 41.

The necessity of choosing proper locations with respect to wires is shown by field stations 61, 62, 90, and 91. At 61 a measurement was purposely made with the antenna within a distance of 10 to 20 feet of numerous telephone wires. The car was then driven across the road to field station 62 where the antenna was about 50 feet away and an increase in intensity of 17.5 per cent was recorded. Practically the same situation was encountered at field stations 90 and 91. In general, it appears that from 100 to 200 feet is a safe distance to avoid the shielding effect of wires.

The intensities recorded on May 10, 12 and 13 were plotted on a base map and contoured, See Fig. 7, following page 41.

TABLE II.

RELATIVE FIELD INTENSITIES IN LIVINGSTON AND INGHAM COUNTIES

Measurements taken May 10, 1939.

Field Station	Location	Intensity
1	NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, Sec.31, T.4N., R3E.	47
2	NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, Sec.32, T.4N., R.3E.	43.5
3	NE.$\frac{1}{4}$, NE.$\frac{1}{4}$, NE.$\frac{1}{4}$, Sec.32, T.4N., R.3E.	47
4	NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, Sec.34, T.4N., R.3E.	44
5	NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, NE.$\frac{1}{4}$, Sec.34, T.4N., R.3E.	45
6	NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, Sec.35, T.4N., R.3E.	48
7	NE.$\frac{1}{4}$, NE.$\frac{1}{4}$, NW.$\frac{1}{4}$, Sec.35, T.4N., R.3E.	48
8	NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, NE.$\frac{1}{4}$, Sec.35, T.4N., R.3E.	48
9	NE.$\frac{1}{4}$, NW.$\frac{1}{4}$, NE.$\frac{1}{4}$, Sec.35, T.4N., R.3E.	47
10	NE.$\frac{1}{4}$, NE.$\frac{1}{4}$, NE.$\frac{1}{4}$, Sec.35, T.4N., R.3E.	46
11	NE.$\frac{1}{4}$, NE.$\frac{1}{4}$, NE.$\frac{1}{4}$, Sec.36, T.4N., R.3E.	48
12	NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, Sec.32, T.4N., R.4E.	43
13	NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, Sec.33, T.4N., R.4E.	48
14	NE.$\frac{1}{4}$, NW.$\frac{1}{4}$, NE.$\frac{1}{4}$, Sec.33, T.4N., R4E.	47
15	SE.$\frac{1}{4}$, Sw.$\frac{1}{4}$, NE.$\frac{1}{4}$, Sec.28, T.4N., R.4E.	49
16	NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, SE.$\frac{1}{4}$, Sec.27, T.4N., R.4E.	45
17	NE.$\frac{1}{4}$, NE.$\frac{1}{4}$, SW.$\frac{1}{4}$, Sec.26, T.4N., R.4E.	49
18	NE.$\frac{1}{4}$, SW.$\frac{1}{4}$, NE.$\frac{1}{4}$, Sec.35, T.4N., R.4E.	49
19	NE.$\frac{1}{4}$, NE.$\frac{1}{4}$, NW.$\frac{1}{4}$, Sec.26, T.4N., R.4E.	47
20	NE.$\frac{1}{4}$, NE.$\frac{1}{4}$, NW.$\frac{1}{4}$, Sec.27, T.4N., R.4E.	47.5

TABLE II - Continued.

Field Station	Location	Intensity
21	NE.¼, NE.¼, NE.¼, Sec.28, T.4N., R.4E.	47
22	NE.¼, NE.¼, NW.¼, Sec.28, T.4N., R.4E.	48
23	NE.¼, NE.¼, NW.¼, Sec.29, T.4N., R.4E.	45
24	NE.¼, NE.¼, NE.¼, Sec.30, T.4N., R.4E.	44.5
25	NE.¼, NE.¼, NE.¼, Sec.25, T.4N., R.3E.	42
26	NW.¼, NW.¼, NW.¼, Sec.25,T.4N., R.3E.	50
27	NE.¼, NE.¼, NW.¼, Sec.26, T.4N., R.3E.	48
28	NE.¼, NE.¼, NE.¼, Sec.27, T.4N., R.3E.	46
29	NE.¼, NE.¼, NW.¼, Sec.27, T.4N., R.3E.	46
30	NE.¼, NE.¼, NE.¼, Sec.28, T.4N., R.3E.	46
31	NE.¼, NE.¼, NW.¼, Sec.28, T.4N., R.3E.	45
32	NE.¼, NE.¼, NE.¼, Sec.29, T.4N., R.3E.	46
33	NW.¼, NW.¼, NW.¼, Sec.29, T.4N., R3E.	48
34	NW.¼, NW.¼, NW.¼, Sec.30, T.4N., R.3E.	47
35	NW.¼, NW.¼, NW.¼, Sec.19, T.4N., R.3E.	45
36	NW.¼, NW.¼, NW.¼, Sec.20, T.4N., R.3E.	46
37	NE.¼, NE.¼, NW.¼, Sec. 2 0,T.4N., R.3E.	47.5
38	NE.¼, NE.¼, NE.¼, Sec.20, T.4N., R.3E.	47
39	NW.¼, NW.¼, SW.¼, Sec.16, T.4N., R.3E.	46
40	NE.¼, NE.¼, SW.¼, Sec.16, T.4N., R.3E.	47
41	NE.¼, NE.¼, SE.¼, Sec.16, T.4N., R.3E.	48
42	SE.¼, SE.¼, SE.¼, Sec.16, T.4N., R.3E.	49
43	SE.¼, SE.¼, NW.¼, Sec.22, T.4N., R.3E.	46

TABLE II - Continued.

Field Station	Location	Intensity
44	NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, SE.$\frac{1}{4}$, Sec.22, T.4N., R.3E.	47.5
45	NE.$\frac{1}{4}$, NE.$\frac{1}{4}$, SE.$\frac{1}{4}$, Sec.22, T.4N., R.3E.	47
46	NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, Sec.23, T.4N., R.3E.	47
47	NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, SW.$\frac{1}{4}$, Sec.14, T.4N., R.3E.	47
48	SE.$\frac{1}{4}$, SE.$\frac{1}{4}$, NW.$\frac{1}{4}$, Sec.14, T.4N., R.3E.	45
49	SW.$\frac{1}{4}$, SW.$\frac{1}{4}$, NE.$\frac{1}{4}$, Sec.14, T.4N., R.3E.	46.5
50	NE.$\frac{1}{4}$, NE.$\frac{1}{4}$, SE.$\frac{1}{4}$, Sec.14, T.4N., R.3E.	43
51	NW.$\frac{1}{4}$, NE.$\frac{1}{4}$, SW.$\frac{1}{4}$, Sec.13, T.4N., R.3E.	44
52	NW.$\frac{1}{4}$, NE.$\frac{1}{4}$, SW.$\frac{1}{4}$, Sec.18, T.4N., R.4E.	47
53	NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, SW.$\frac{1}{4}$, Sec.17, T.4N., R.4E.	43
54	NE.$\frac{1}{4}$, NW.$\frac{1}{4}$, SW.$\frac{1}{4}$, Sec.17, T.4N., R.4E.	49
55	NE.$\frac{1}{4}$, NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, Sec.17, T.4N., R.4E.	46
56	NE.$\frac{1}{4}$, NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, Sec.16, T.4N., R.4E.	47
57	NW.$\frac{1}{4}$, NE.$\frac{1}{4}$, NE.$\frac{1}{4}$, Sec.16, T.4N., R.4E.	47
58	SW.$\frac{1}{4}$, NW.$\frac{1}{4}$, NE.$\frac{1}{4}$, Sec.15, T.4N., R.4E.	45
59	SE.$\frac{1}{4}$, NE.$\frac{1}{4}$, NE.$\frac{1}{4}$, Sec. 15, T.4N., R.4E.	48
60	SW.$\frac{1}{4}$, SW.$\frac{1}{4}$, NW.$\frac{1}{4}$, Sec.14, T.4N., R.4E.	48
61	NE.$\frac{1}{4}$, NE.$\frac{1}{4}$, NW.$\frac{1}{4}$, Sec.14, T.4N., R.4E.	40
62	NE.$\frac{1}{4}$, NE.$\frac{1}{4}$, NW.$\frac{1}{4}$, Sec.14, T.4N., R.4E.	47
63	NE.$\frac{1}{4}$, NE.$\frac{1}{4}$, NW.$\frac{1}{4}$, Sec.14, T.4N., R.4E.	51
64	NE.$\frac{1}{4}$, SW.$\frac{1}{4}$, NE.$\frac{1}{4}$, Sec.35, T.4N., R.4E.	50
65	NE.$\frac{1}{4}$, NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, Sec.25, T.3N., R.4E.	51

TABLE II - Continued.

Field Station	Location	Intensity
66	SW.$\frac{1}{4}$, SW.$\frac{1}{4}$, NE.$\frac{1}{4}$, Sec.23, T.3N., R.4E.	54
67	SW.$\frac{1}{4}$, SE.$\frac{1}{4}$, NE.$\frac{1}{4}$, Sec.15, T.3N., R.4E.	50
68	SW.$\frac{1}{4}$, SW.$\frac{1}{4}$, NE.$\frac{1}{4}$, Sec.10, T.3N., R.4E.	49
69	SE.$\frac{1}{4}$, SE.$\frac{1}{4}$, NW.$\frac{1}{4}$, Sec. 9, T.3N., R.4E.	49
70	NE.$\frac{1}{4}$, NE.$\frac{1}{4}$, SE.$\frac{1}{4}$, Sec. 9, T.3N., R.4E.	52
71	NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, SW.$\frac{1}{4}$, Sec. 8, T.3N., R.4E.	52
72	NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, SE.$\frac{1}{4}$, Sec. 7, T.3N., R.4E.	52
73	NE.$\frac{1}{4}$, SE.$\frac{1}{4}$, SE.$\frac{1}{4}$, Sec.12, T.3N., R.3E.	50.5
74	SE.$\frac{1}{4}$, NE.$\frac{1}{4}$, SW.$\frac{1}{4}$, Sec.12, T.3N., R.3E.	49
75	SW.$\frac{1}{4}$, NW.$\frac{1}{4}$, SW.$\frac{1}{4}$, Sec.12, T.3N., R.3E.	49
76	SE.$\frac{1}{4}$, NE.$\frac{1}{4}$, SW.$\frac{1}{4}$, Sec.11, T.3N., R.3E.	50

Measurements taken May 12, 1939.

Field Station	Location	Intensity
77	SW.$\frac{1}{4}$, SW.$\frac{1}{4}$, SE.$\frac{1}{4}$, Sec. 2, T.3N., R.2E.	45
78	NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, Sec.12, T.3N., R.2E.	46
79	NW.$\frac{1}{4}$, SW.$\frac{1}{4}$, NW.$\frac{1}{4}$, Sec.12, T.3N., R.2E.	46
80	NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, Sec.13, T.3N., R.2E.	48
81	SW.$\frac{1}{4}$, SE.$\frac{1}{4}$, NE.$\frac{1}{4}$, Sec.14, T.3N., R.2E.	48
82	SW.$\frac{1}{4}$, SW.$\frac{1}{4}$, NW.$\frac{1}{4}$, Sec.24, T.3N., R.2E.	47
83	NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, SW.$\frac{1}{4}$, Sec.19, T.3N., R.3E.	44
84	NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, SW.$\frac{1}{4}$, Sec.18, T.3N., R.3E.	48

Table II - Continued.

Field Station	Location	Intensity
85	SW.$\frac{1}{4}$, SW.$\frac{1}{4}$, NW.$\frac{1}{4}$, Sec.18, T.3N., R.3E.	47
86	NW.$\frac{1}{4}$, SW.$\frac{1}{4}$, SW.$\frac{1}{4}$, Sec. 7, T.3N., R.3E.	46
87	NW.$\frac{1}{4}$, SW.$\frac{1}{4}$, NW.$\frac{1}{4}$, Sec.7, T.3N., R.3E.	46
88	NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, SW.$\frac{1}{4}$, Sec. 6, T.3N., R.3E.	44
89	NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, Sec. 1, T.3N., R.2E.	46
90	SE.$\frac{1}{4}$, SW.$\frac{1}{4}$, SW.$\frac{1}{4}$, Sec.31, T.4N., R.3E.	40
91	SE.$\frac{1}{4}$, SW.$\frac{1}{4}$, SW.$\frac{1}{4}$, Sec.31, T.4N., R.3E.	45
92	NE.$\frac{1}{4}$, NE.$\frac{1}{4}$, NW.$\frac{1}{4}$, Sec. 6, T.3N., R.3E.	44
93	NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, NE.$\frac{1}{4}$, Sec. 6, T.3N., R.3E.	48
94	SW.$\frac{1}{4}$, SW.$\frac{1}{4}$, SW.$\frac{1}{4}$, Sec.32, T.4N., R.3E.	49
95	NW.$\frac{1}{4}$, SW.$\frac{1}{4}$, NW.$\frac{1}{4}$, Sec. 5, T.3N., R.3E.	47
96	SW.$\frac{1}{4}$, NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, Sec. 8, T.3N., R.3E.	47.5
97	SW.$\frac{1}{4}$, NE.$\frac{1}{4}$, NE.$\frac{1}{4}$, Sec.18, T.3N., R.3E.	45
98	NW.$\frac{1}{4}$, SW.$\frac{1}{4}$, SW.$\frac{1}{4}$, Sec.17, T.3N., R.3E.	48.5
99	SW.$\frac{1}{4}$, SW.$\frac{1}{4}$, NW.$\frac{1}{4}$, Sec.20, T.3N., R.3E.	48
100	SW.$\frac{1}{4}$, SW.$\frac{1}{4}$, SW.$\frac{1}{4}$, Sec.20,T.3N., R.3E.	48.5
101	SW.$\frac{1}{4}$, SW.$\frac{1}{4}$, SW.$\frac{1}{4}$, Sec.21, T.3N., R.3E.	48
102	NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, Sec.21, T.3N., R.3E.	47.5
103	SW.$\frac{1}{4}$, NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, Sec.16, T.3N., R.3E.	47
104	SW.$\frac{1}{4}$, SW.$\frac{1}{4}$, NW.$\frac{1}{4}$, Sec. 9, T.3N., R.3E.	47
105	SW.$\frac{1}{4}$, SW.$\frac{1}{4}$, NW.$\frac{1}{4}$, Sec. 4, T.3N., R.3E.	50

TABLE II - Continued.

Field Station	Location	Intensity
106	NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, Sec. 4, T.3N., R.3E.	48
107	SE.$\frac{1}{4}$, SE.$\frac{1}{4}$, SE.$\frac{1}{4}$, Sec.33, T.4N., R.3E.	50
108	NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, SW.$\frac{1}{4}$, Sec. 3, T.3N., R.3E.	50
109	NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, SW.$\frac{1}{4}$, Sec.10, T.3N., R.3E.	50
110	SW.$\frac{1}{4}$, NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, Sec.15, T.3N., R.3E.	49.5
111	NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, Sec.22, T.3N., R.3E.	49.5
112	SW.$\frac{1}{4}$, SW.$\frac{1}{4}$, NW.$\frac{1}{4}$, Sec.27, T.3N., R.3E.	47
113	SW.$\frac{1}{4}$, SW.$\frac{1}{4}$, SW.$\frac{1}{4}$, Sec.27, T.3N., R.3E.	49
114	SW.$\frac{1}{4}$, SE.$\frac{1}{4}$, SE.$\frac{1}{4}$,Sec.27, T.3N., R.3E.	49
115	NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, Sec.26, T.3N., R.3E.	49.5
116	SW.$\frac{1}{4}$, SW.$\frac{1}{4}$, NW.$\frac{1}{4}$, Sec.14, T.3N., R.3E.	50
117	NE.$\frac{1}{4}$, NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, Sec.11, T.3N., R.3E.	48
118	NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, Sec. 2, T.3N., R.3E.	49.5
119	SW.$\frac{1}{4}$, SW.$\frac{1}{4}$, SW.$\frac{1}{4}$, Sec.36, T.4N., R.3E.	49
120	NE.$\frac{1}{4}$, NE.$\frac{1}{4}$, NW.$\frac{1}{4}$, Sec. 1, T.3N., R.3E.	48
121	NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, NE.$\frac{1}{4}$, Sec.12, T.3N., R.3E.	52
122	SE.$\frac{1}{4}$, NE.$\frac{1}{4}$, SW.$\frac{1}{4}$, Sec.12, T.3N., R.3E.	50
123	NE.$\frac{1}{4}$, SE.$\frac{1}{4}$, SW.$\frac{1}{4}$, Sec.13, T.3N., R.3E.	53
124	SE.$\frac{1}{4}$, SE.$\frac{1}{4}$, SW.$\frac{1}{4}$, Sec.13, T.3N., R.3E.	53
125	NE.$\frac{1}{4}$, NE.$\frac{1}{4}$, NE.$\frac{1}{4}$, Sec.23, T.3N., R.3E.	51
126	SE.$\frac{1}{4}$, SE.$\frac{1}{4}$, NE.$\frac{1}{4}$, Sec.23, T.3N., R.3E.	50.5

TABLE II - Continued.

Field Station	Location	Intensity
127	SE.$\frac{1}{4}$, SE.$\frac{1}{4}$, SE.$\frac{1}{4}$, Sec.23, T.3N., R.3E.	50.5
128	NE.$\frac{1}{4}$, NE.$\frac{1}{4}$, NE.$\frac{1}{4}$, Sec.35, T.3N., R.3E.	49
129	SE.$\frac{1}{4}$, NE.$\frac{1}{4}$, SE.$\frac{1}{4}$, Sec.35, T.3N., R.3E.	49
130	SW.$\frac{1}{4}$, SE.$\frac{1}{4}$, SW.$\frac{1}{4}$, Sec.31, T.3N., R.4E.	48
131	SE.$\frac{1}{4}$, SW.$\frac{1}{4}$, SE.$\frac{1}{4}$, Sec.31, T.3N., R.4E.	49
132	NE.$\frac{1}{4}$, SW.$\frac{1}{4}$, NE.$\frac{1}{4}$, Sec.31, T.3N., R.4E.	49
133	SW.$\frac{1}{4}$, NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, Sec.31, T.3N., R.4E.	51
134	SW.$\frac{1}{4}$, NW.$\frac{1}{4}$, SW.$\frac{1}{4}$, Sec.30, T.3N., R.4E.	50
135	NE.$\frac{1}{4}$, NE.$\frac{1}{4}$, SW.$\frac{1}{4}$, Sec.30, T.3N., R.4E.	52
136	NE.$\frac{1}{4}$, NW.$\frac{1}{4}$, SW.$\frac{1}{4}$, Sec.29, T.3N., R.4E.	53
137	NW.$\frac{1}{4}$, SW.$\frac{1}{4}$, NW.$\frac{1}{4}$, Sec.29, T.3N., R.4E.	53
138	NW.$\frac{1}{4}$, NE.$\frac{1}{4}$, NE.$\frac{1}{4}$, Sec.30, T.3N., R.4E.	52
139	NE.$\frac{1}{4}$, NW.$\frac{1}{4}$, SE.$\frac{1}{4}$, Sec.19, T.3N., R.4E.	53
140	SE.$\frac{1}{4}$, SW.$\frac{1}{4}$, NW.$\frac{1}{4}$, Sec.19, T.3N., R.4E.	51
141	SW.$\frac{1}{4}$, SW.$\frac{1}{4}$, NE.$\frac{1}{4}$, Sec.24, T.3N., R.3E.	52
142	NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, NE.$\frac{1}{4}$, Sec.19, T.3N., R.4E.	50
143	SW.$\frac{1}{4}$, SW.$\frac{1}{4}$, SW.$\frac{1}{4}$, Sec.17, T.3N., R.4E.	53
144	NE.$\frac{1}{4}$, NE.$\frac{1}{4}$, NE.$\frac{1}{4}$, Sec.18, T.3N. R.4E.	53
145	NW.$\frac{1}{4}$, SW.$\frac{1}{4}$, NW.$\frac{1}{4}$, Sec. 8, T.3N., R.4E.	53
146	NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, SW.$\frac{1}{4}$, Sec. 5, T.3N., R.4E.	52
147	NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, Sec. 5, T.3N., R.4E.	53

TABLE II - Continued.

Measurements taken May 13, 1939.

Field Station	Location	Intensity
148	NE.$\frac{1}{4}$, NE.$\frac{1}{4}$, SE.$\frac{1}{4}$, Sec. 8, T.3N., R.4E.	52
149	SE.$\frac{1}{4}$, NE.$\frac{1}{4}$, NE.$\frac{1}{4}$, Sec.17, T.3N., R.4E.	52
150	NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, Sec.21, T.3N., R.4E.	52
151	NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, SW.$\frac{1}{4}$, Sec.21, T.3N., R.4E.	54
152	NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, Sec.28, T.3N., R.4E.	53
153	SW.$\frac{1}{4}$, NW.$\frac{1}{4}$, SW.$\frac{1}{4}$, Sec.28, T.3N., R.4E.	53
154	NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, Sec.33, T.3N., R.4E.	53
155	Sw.$\frac{1}{4}$, SW.$\frac{1}{4}$, SW.$\frac{1}{4}$, Sec.33, T.3N., R.4E.	52
156	SW.$\frac{1}{4}$, SE$\frac{1}{4}$, SE.$\frac{1}{4}$, Sec.33, T.3N., R.4E.	54
157	SW.$\frac{1}{4}$, SW.$\frac{1}{4}$, SW.$\frac{1}{4}$, Sec.35, T.3N., R.4E.	52
158	NE.$\frac{1}{4}$, SW.$\frac{1}{4}$, NE.$\frac{1}{4}$, Sec.35, T.3N., R.4E.	55
159	NE.$\frac{1}{4}$, SE.$\frac{1}{4}$, SW.$\frac{1}{4}$, Sec.27, T.3N., R.4E.	52
160	SW.$\frac{1}{4}$, SW.$\frac{1}{4}$, NE.$\frac{1}{4}$, Sec.27, T.3N., R.4E.	55.5
161	SW.$\frac{1}{4}$, SW.$\frac{1}{4}$, NW.$\frac{1}{4}$, Sec.27, T.3N., R.4E.	54
162	NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, SW.$\frac{1}{4}$, Sec.22, T.3N., R.4E.	53
163	NE.$\frac{1}{4}$, NW.$\frac{1}{4}$, NE.$\frac{1}{4}$, Sec.21, T.3N., R.4E.	52
164	SE.$\frac{1}{4}$, SE.$\frac{1}{4}$, SW.$\frac{1}{4}$, Sec.16, T.3N., R.4E.	51
165	NE.$\frac{1}{4}$, NE.$\frac{1}{4}$, NW.$\frac{1}{4}$, Sec.16, T.3N., R.4E.	53
166	NW.$\frac{1}{4}$, SW.$\frac{1}{4}$, NE.$\frac{1}{4}$, Sec. 9, T.3N., R.4E.	50.5
167	NE.$\frac{1}{4}$, SE.$\frac{1}{4}$, SW.$\frac{1}{4}$, Sec. 4, T.3N., R.4E.	53

TABLE II - Continued.

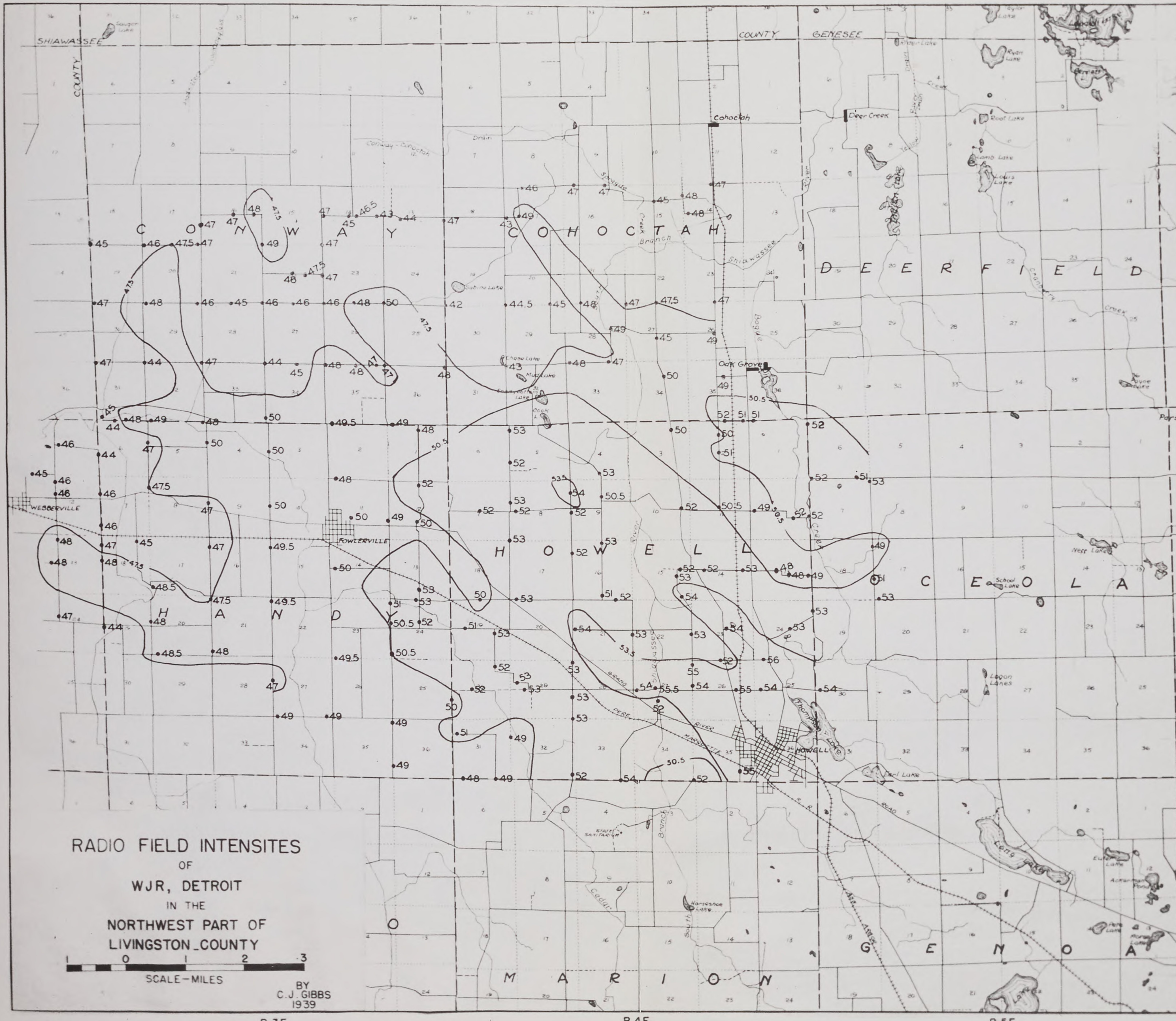
Field Station	Location	Intensity
166	NW.¼, SW.¼, NE.¼, Sec. 9, T.3N., R.4E.	50.5
167	NE.¼, SE.¼, SW.¼, Sec. 4, T.3N., R.4E.	53
168	SW.¼, NW.¼, N.W.¼, Sec.9, T.3N., R.4E.	54
169	SW.¼, NW.¼, SW.¼, Sec. 4, T.3N., R.4E.	53
170	NW.¼, NW.¼, NW.¼, Sec.33, T.4N., R.4E.	49
171	NE.¼, NW.¼, NE.¼, Sec.33, T.4N., R.4E.	47
172	NE.¼, SW.¼, NE.¼, Sec.28, T.4N., R.4E.	53
173	SW.¼, NW.¼, SE.¼, Sec.27, T.4N., R.4E.	52
174	SW.¼, NW.¼, NE.¼, Sec.34, T.4N., R.4E.	50
175	SE.¼, NW.¼, NE.¼, Sec. 3, T.3N., R.4E.	50
176	SW.¼, SE.¼, NE.¼, Sec.10, T.3N., R.4E.	52
177	SW.¼, SE.¼, NE.¼, Sec.15. T.3N., R.4E.	52
178	NE.¼, NW.¼, SE.¼, Sec.15, T.3N., R.4E.	53
179	SW.¼, SE.¼, SE.¼, Sec.15, T.3N., R.4E.	54
180	NE.¼, NE.¼, SE.¼, Sec.22, T.3N., R.4E.	53
181	NE.¼, NE.¼, NE.¼, Sec.27, T.3N., R.4E.	55
182	SW.¼, SW.¼, NW.¼, Sec.26, T.3N., R.4E.	54
183	SE.¼, SW.¼, SW.¼, Sec.23, T.3N., R.4E.	52
184	SE.¼, SW.¼, NE.¼, Sec.26, T.3N., R.4E.	55
185	SW.¼, SW.¼, NW.¼, Sec.25, T.3N., R.4E.	54
186	NE.¼, NW.¼, NW.¼, Sec.25, T.3N., R.4E.	56
187	SW.¼, SW.¼, NE.¼, Sec.23, T.3n., R.4E.	54
188	SW.¼, SE.¼, NW.¼, Sec.14, T.3N., R.4E.	52

TABLE II - Continued.

Field Station	Location	Intensity
189	SW.$\frac{1}{4}$, SE.$\frac{1}{4}$, NE.$\frac{1}{4}$, Sec.14, T.3N., R.4E.	53
190	SE.$\frac{1}{4}$, SE.$\frac{1}{4}$, NW.$\frac{1}{4}$, Sec.13, T.3N., R.4E.	48
191	NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, SE.$\frac{1}{4}$, Sec.13, T.3N., R.4E.	48
192	NE.$\frac{1}{4}$, NE.$\frac{1}{4}$, Se.$\frac{1}{4}$, Sec.13, T.3N., R.4E.	49
193	SE.$\frac{1}{4}$, NE.$\frac{1}{4}$, NE.$\frac{1}{4}$, Sec.24, T.3N., R.4E.	53
194	SW.$\frac{1}{4}$, SW.$\frac{1}{4}$, NE.$\frac{1}{4}$, Sec.24, T.3N., R.4E.	53
195	NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, SW.$\frac{1}{4}$, Sec.12, T.3N., R.4E.	49
196	NE.$\frac{1}{4}$, NW.$\frac{1}{4}$, SE.$\frac{1}{4}$, Sec.12,T.3N., R.4E.	52
197	NE.$\frac{1}{4}$, NE.$\frac{1}{4}$, SE.$\frac{1}{4}$, Sec.12, T.3N., R.4E.	52
198	NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, Sec. 7, T.3N., R.5E.	52
199	NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, Sec. 6, T.3N., R.5E.	52
200	NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, Sec. 1, T.3N., R.4E.	52
201	NE.$\frac{1}{4}$, NE.$\frac{1}{4}$, NE.$\frac{1}{4}$, Sec. 2, T.3N., R.4E.	51
202	NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, NE.$\frac{1}{4}$, Sec. 2, T.3N., R.4E.	52
203	SW.$\frac{1}{4}$, NW.$\frac{1}{4}$, NE.$\frac{1}{4}$, Sec. 2, T.3N., R.4E.	50
204	SW.$\frac{1}{4}$, SW.$\frac{1}{4}$, NE.$\frac{1}{4}$, Sec. 2, T.3N., R.4E.	52
205	SW.$\frac{1}{4}$, SW.$\frac{1}{4}$, NE.$\frac{1}{4}$, Sec.11, T.3N., R.4E.	50.5
206	NE.$\frac{1}{4}$, NW.$\frac{1}{4}$, NE.$\frac{1}{4}$, Sec. 7, T. 3N., R. 5E.	51
207	NE.$\frac{1}{4}$, NE.$\frac{1}{4}$, NE.$\frac{1}{4}$, Sec. 7, T.3N., R.5E.	53
208	SE.$\frac{1}{4}$, NE.$\frac{1}{4}$, NE.$\frac{1}{4}$, Sec.18, T.3N., R.5E.	49

TABLE II - Continued

Field Station	Location	Intensity
209	NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, SW.$\frac{1}{4}$, Sec.17, T.3N., R.5E.	51
210	NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, Sec.20, T.3N., R.5E.	53
211	SW.$\frac{1}{4}$, SW.$\frac{1}{4}$, NW.$\frac{1}{4}$, Sec.30, T.3N., R.5E.	54
212	SW.$\frac{1}{4}$, SE.$\frac{1}{4}$, SW.$\frac{1}{4}$, Sec.31, T.3N., R.4E.	45
213	SE.$\frac{1}{4}$, SW.$\frac{1}{4}$, SE.$\frac{1}{4}$, Sec.31, T.3N., R.4E.	45.5
214	SW.$\frac{1}{4}$, SW.$\frac{1}{4}$, SW.$\frac{1}{4}$, Sec.33, T.3N., R.4E.	47
215	SW.$\frac{1}{4}$, SE.$\frac{1}{4}$, SE.$\frac{1}{4}$, Sec.33, T.3N., R.4E.	49
216	SW.$\frac{1}{4}$, SW.$\frac{1}{4}$, SW.$\frac{1}{4}$, Sec.35, T.3N., R.4E.	47
217	NE.$\frac{1}{4}$, SW.$\frac{1}{4}$, NE.$\frac{1}{4}$, Sec.35, T.3N., R.4E.	51
218	NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, Sec. 6, T.2N., R.5E.	52
219	SW.$\frac{1}{4}$, NW.$\frac{1}{4}$, SW.$\frac{1}{4}$, Sec. 6, T.2N., R.5E.	52
220	NE.$\frac{1}{4}$, NE.$\frac{1}{4}$, NE.$\frac{1}{4}$, Sec.12, T.2N., R.4E.	51
221	NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, NE.$\frac{1}{4}$, Sec.12, T.2N., R.4E.	51
222	SE.$\frac{1}{4}$, SE.$\frac{1}{4}$, SE.$\frac{1}{4}$, Sec.12, T.2N., R.4E.	51
223	SW.$\frac{1}{4}$, SW.$\frac{1}{4}$,SW.$\frac{1}{4}$, Sec.18, T.2N., R.5E.	51
224	NE.$\frac{1}{4}$, NE.$\frac{1}{4}$, NE.$\frac{1}{4}$, Sec.23, T.2N., R.4E.	47
225	NW.$\frac{1}{4}$, NW.$\frac{1}{4}$, SW.$\frac{1}{4}$, Sec.13, T.2N., R.4E.	49


RADIO FIELD INTENSITES
OF
WJR, DETROIT
IN THE
NORTHWEST PART OF
LIVINGSTON COUNTY
SCALE-MILES
BY
C.J. GIBBS
1939
SHIAWASSEE
COUNTY
GENESEE
CONWAY
COHOCTAH
DEERFIELD
HOWELL
OCEOLA
HANDY
MARION
GENOA
Cohoctah
Deer Creek
Oak Grove
FOWLERVILLE
WEBBERVILLE
HOWELL
Thompson Lake
Earl Lake
Long Lake
R.3E.
R.4E.
R.5E.
T.4N.
T.3N.
T.2N.

EXPERIMENT IN THE CRAPO MINE, SHIAWASSEE COUNTY

An interpretation of the results obtained in the field intensity survey in Livingston county is not possible without some idea of the depth penetrated by the radio waves. Although this can be worked out theoretically it is advantageous to have experimental verification. The only way to accomplish this is to take underground measurements in mines, caves or tunnels. The Crapo coal mine, located about 1 mile west and 2 miles south of New Lothrop, is one of the few places in central Michigan where such a situation is possible. The mine is approximately 190 feet in depth. The overburden consists of glacial drift, mostly boulder clay, and Pennsylvanian shales. All of the overlying material has a low electrical resistivity. On May 20, 1939 the field intensity meter was taken into a drift of the mine to a position approximately one half mile from the shaft. At this point the only metal present was a 2-inch iron pipe used as an air line. It was impossible, however, to pick up any radio signal although WJR gave a field strnegth of 41 at the surface.

If Eq. (9) is solved for the depth at which 99 per cent of the energy of the wave has been absorbed the resulting form is -

$$z = \frac{2.3}{\pi} (p/f)^{\frac{1}{2}} \qquad (12)$$

Placing $p = 9 \cdot 10^{12}$ abohm-cm., a good average for glacial drift.
$f = 750,000$ cycles per second (WJR)

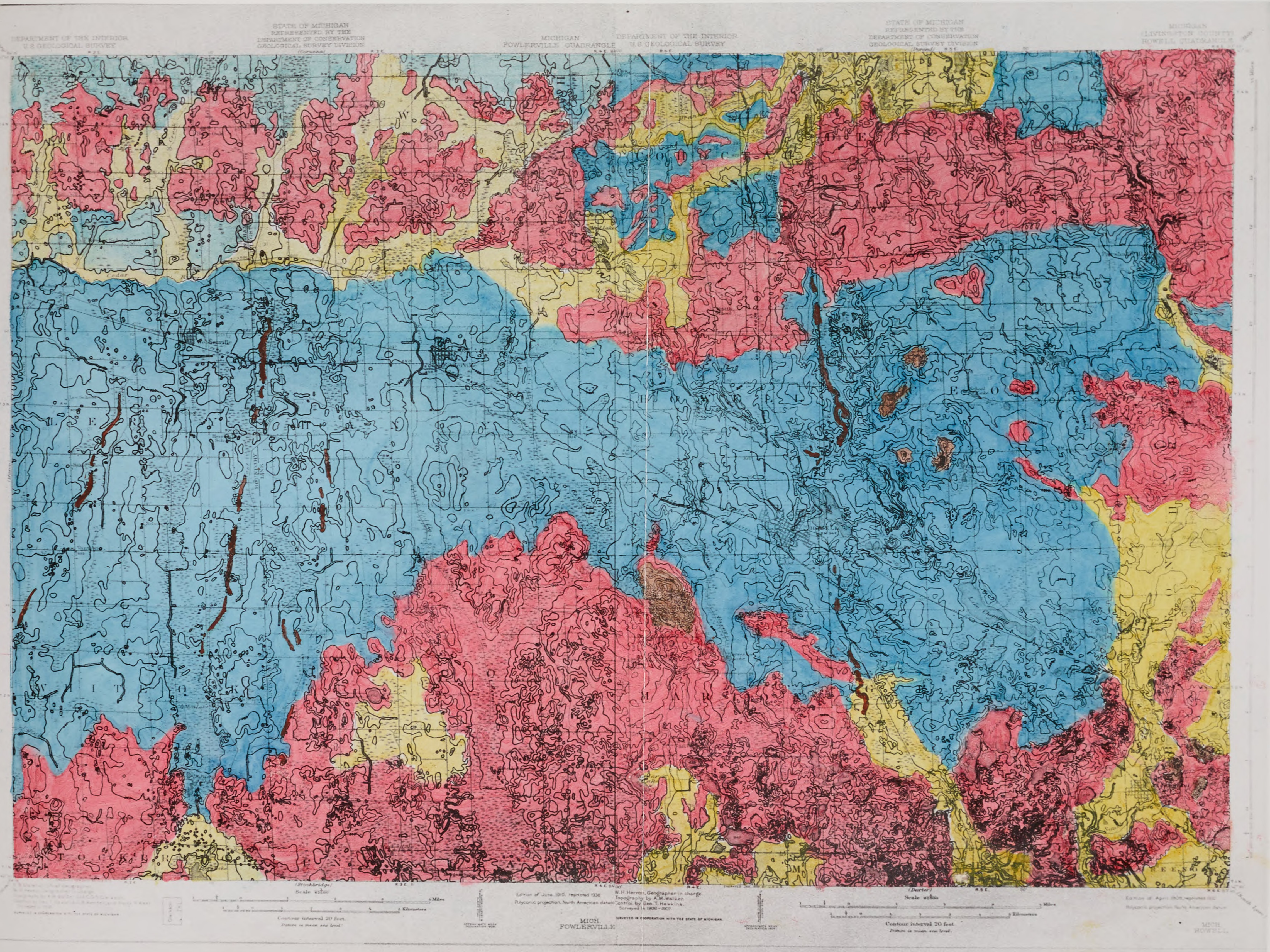
$$z = \frac{2.3}{\pi}\,(90.10^7/75)^{\frac{1}{2}} = 2530 \text{ cm.} = 25.3 \text{ m.}$$

In other words, 99 per cent of the energy of WJR's signal should be theoretically lost after penetrating only about 85 feet of glacial drift.

INTERPRETATION OF THE HOWELL SURVEY.

From the results of the preceeding experiment it may be concluded that variation of intensity must be influenced mainly by the presence of glacial drift and by the character of the topography. Fig. 8, following page 43, is a detailed map showing topographic and glacial features in Livingston County. In observing the contour map showing radio field intensities, (Fig. 7), the most striking feature is the fingering out of the contour lines in the direction of wave propagation. If the ground traversed by the wave were perfectly homogeneous the contours, or lines of equal intensity, would be a series of concentric circles. The center of curvature would be located at the transmitting station of WJR situated at Trenton, several miles south of Detroit. The result obtained shows a definite departure from ideal curvature due to shadow effects, produced at particular points where energy subtracted from the wave

Fig. 8.



MAP SHOWING GLACIAL FEATURES IN THE HOWELL AREA.

MORAINE   TILL PLAIN   OUTWASH PLAIN   KAME   ESKER causes the contours to be bent backwards. It will be noted that the 47.5 contour which extends through Cohoctah and Conway Townships shows a configuration similar to that of the 50.5 and 53.5 contours extending through Howell and parts of Handy and Oceola Townships. There is a wide belt of high intensity extending from southeast to northwest across Howell Township. Figure 8 shows that this belt is directly in line with a large strip of till plain situated southeast of the city of Howell. This till plain has a more gentle relief than the moraines flanking it and is beset with numerous lakes and swamps. Since till plain is largely boulder clay, which in this case is well saturated with water, the electrical resistivity will naturally be low. Theoretically the combined effect of low resistivity and level topography is conducive to good propagation, low absorption and high field strength.

The belt of high intensity is flanked on either side by zones of lower field strength. The readings recorded in section 13 of Howell Township and section 17 of Oceola Township, about three miles north of the city of Howell, show a marked drop in signal strength, suggesting that absorption has occurred near these points. Again referring to the glacial map it will be seen that this particular area lies directly behind a large esker and several kames in sections 17 and 18 of Oceola Township. Low intensities may be produced by eskers and kames in several ways. In the first place, these features are composed largely of stratified sand and gravel, materials of high electrical resistivity which causes electro-magnetic losses. On the other hand, eskers and kames have elevations higher than their surrounding areas and may act more or less as a shield. This latter property would be true of any marked elevation in the path of a radio wave.

Another belt of lower intensity extends from the southeast part of Handy Township in a direction about west-northwest. The glacial map shows an extensive area of moraine to the southeast of this zone, including a prominently large kame upon which the State Sanitarium is situated. These features produce a marked shadow effect similar to that associated with the esker and kames referred to above.

It may therefore be stated that the field intensity pattern obtained in the northwestern part of Livingston County is the result of glacial and topographic features and that the underlying bedrock produces no perceptable influence upon the field strength.

The absence of tilt which should theoretically exist in the electric vector is not easy to explain unless a high dielectric constant is assumed. This might be permissable on the basis that the water table is high in the area during the spring. However, since the assumption of a value for this constant without experimental verification is not justified no calculation involving EQ. (10) will be attempted. This inconsistancy of experiment with theory deserves further investigation.

Since the glacial drift in the Howell area averages about 100 feet in depth and no influence of underlying rock is apparent it would be of interest to run an intensity traverse across a formational boundary where the surficial material is very thin. Referring to Figs. 1, page 2, and 9, page 47, it will be noted that conditions of this nature occur in the region extending south and west through Jackson. On the basis of these considerations the following and final part of the experiment was conducted.

SURVEY IN THE JACKSON, MICHIGAN AREA.

On May 24, 1939, a radial traverse was run on WJIM (1210 kilocycles, 250 watts daytime), Lansing, starting in the southwest cor ner of section 28, Brookfield Township, Eaton County. On approaching the region of Marshall a fading and severe hum of the signal was noted. The hum was definitely associated with telephone wires, although the effect was not noted in other areas. A location was chosen where the noise level was no longer objectionable and the fading was found to be caused by an interferring station which could not be identified.

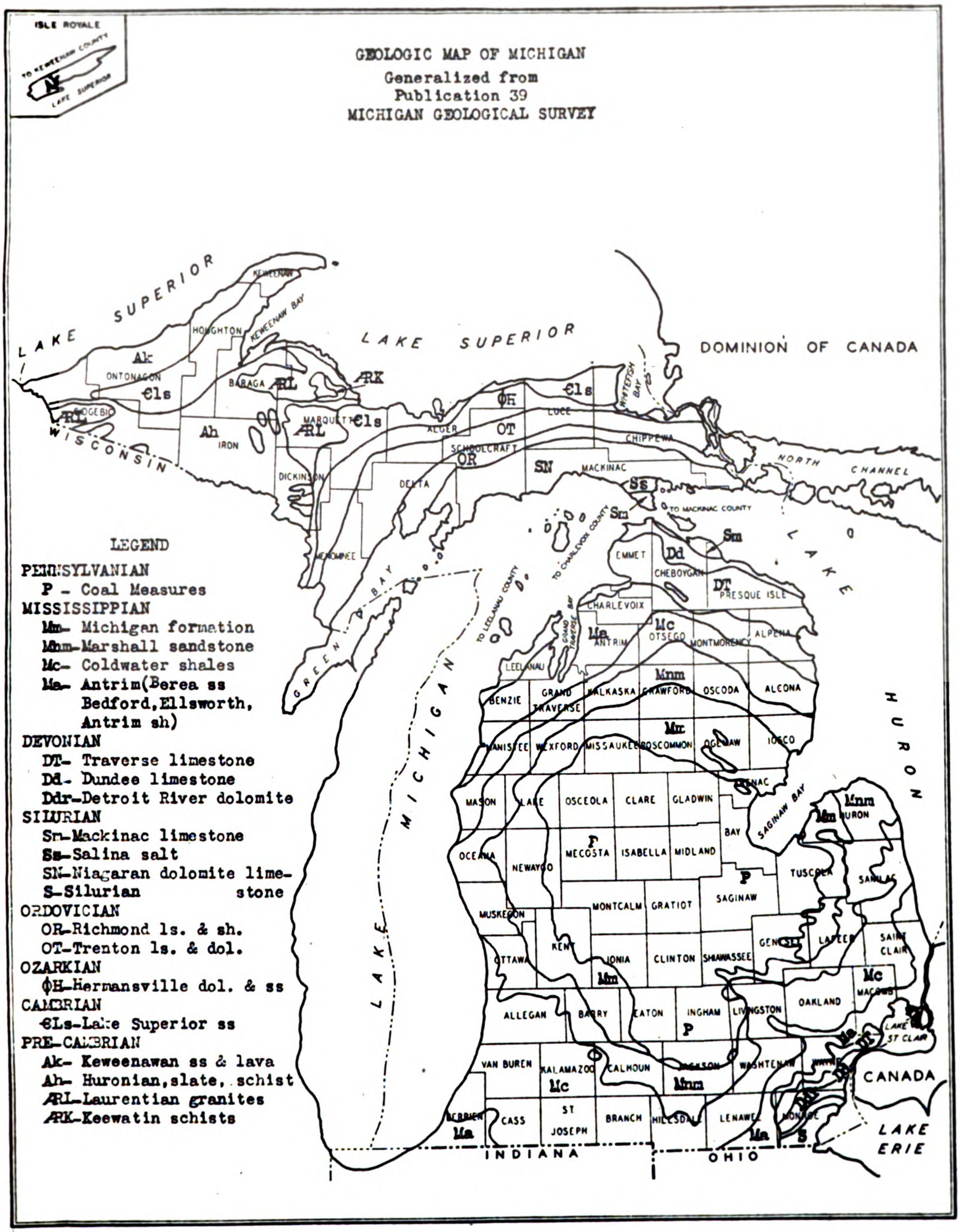


Figure 9.—Map showing the distribution of rock formations in Michigan.

Later in the day a similar traverse was attempted on WIBM (1370 kilocycles, 250 watts daytime), Jackson, starting at a point north of Burlington, Calhoun County, but again fading, due to an interferring station, necessitated abandoning the survey.

Finally on June 5, 1939, a radial traverse was made on WJR starting at a point one-fourth mile south of the corner of section 14, Butler Township, Branch County, and following a line through Litchfield and Moscow in Hillsdale County. The results of the survey are shown on the accompanying graph, (Fig. 10, page 49). It will be noted that a marked change in intensity occurs around Litchfield but that in the vicinity of the approximate location of the boundary between the Marshall and Coldwater formations the curve in particularly smooth. Therefore, it is concluded that the irregularities in the E-D curve are caused by the presence of the town itself and by topographic and glacial features rather than by the underlying bedrock. Inasmuch as no topographic map of the section is available no comparison between the relation of intensity changes and topographic expression can be definitely worked out. However, the character of the glacial material changes appreciably along the traverse and intensity variations may be accounted for in part by changes in the electrical properties of the ground. Another source of variation is the possibility of taking measurements slightly off the exact radial from the transmitter. In the latter case pronounced lateral

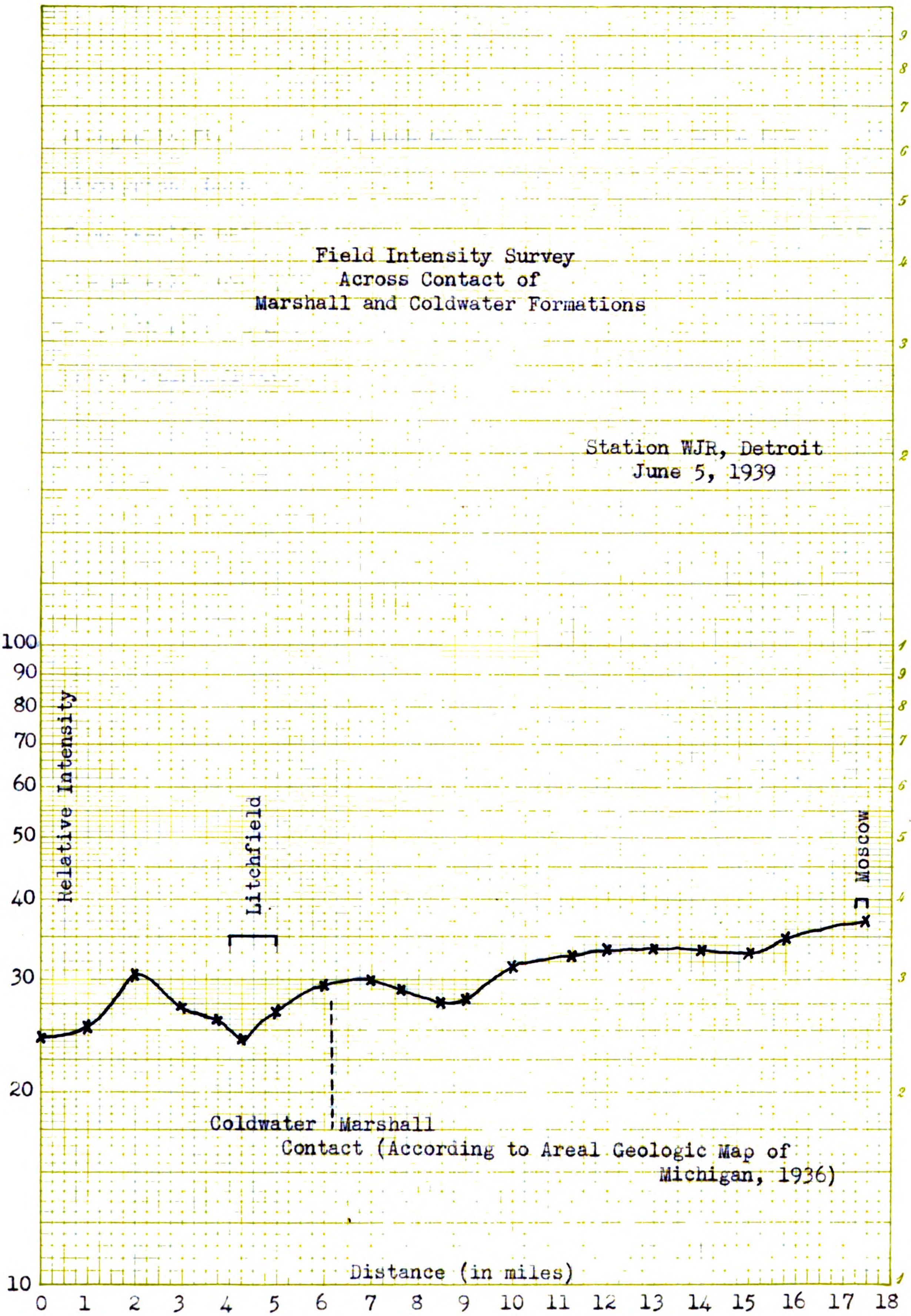


Fig. 10. Radio Field Intensity Traverse in the Jackson, Mich. Area.

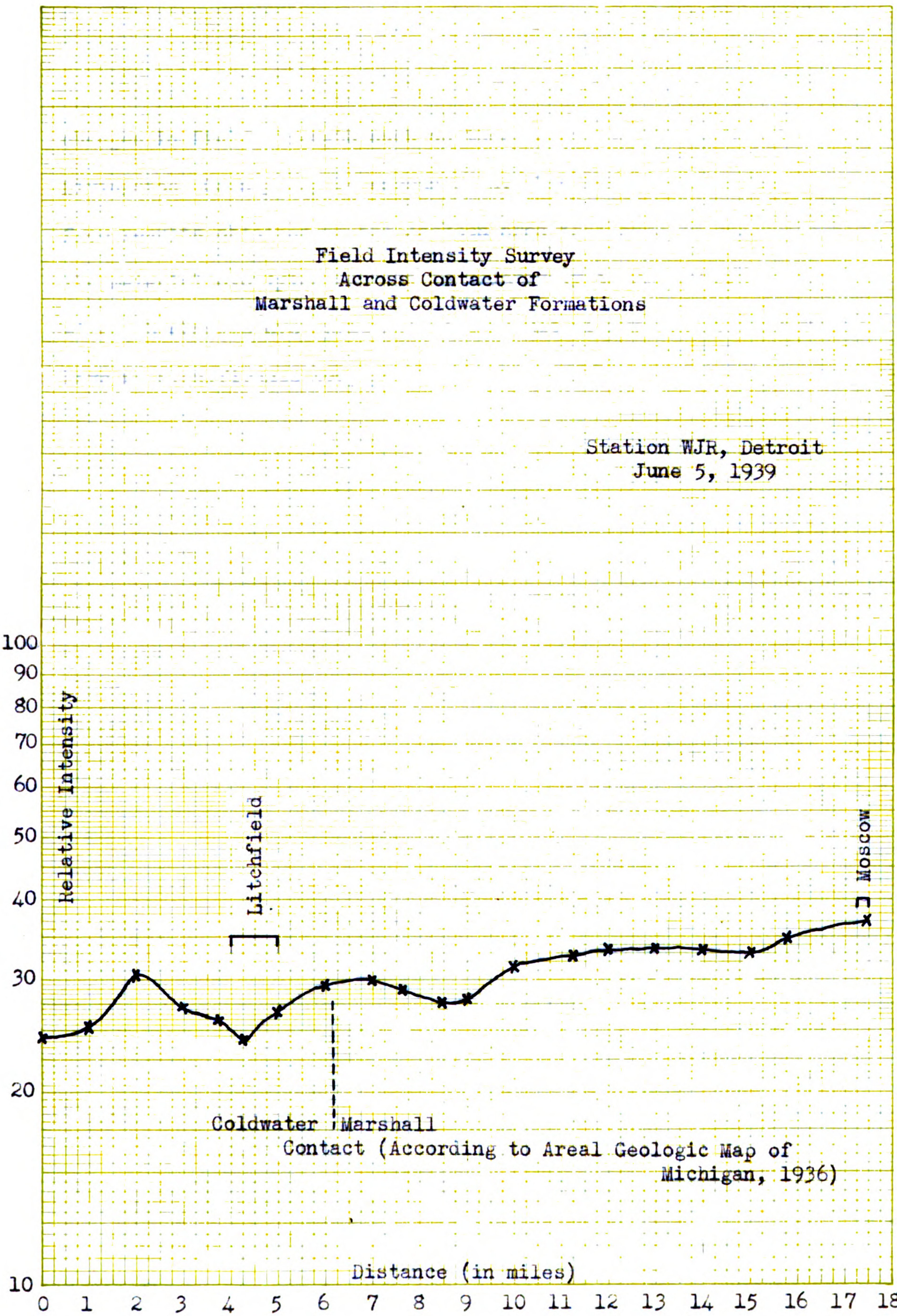


Fig. 10. Radio Field Intensity Traverse in the Jackson, Mich. Area.

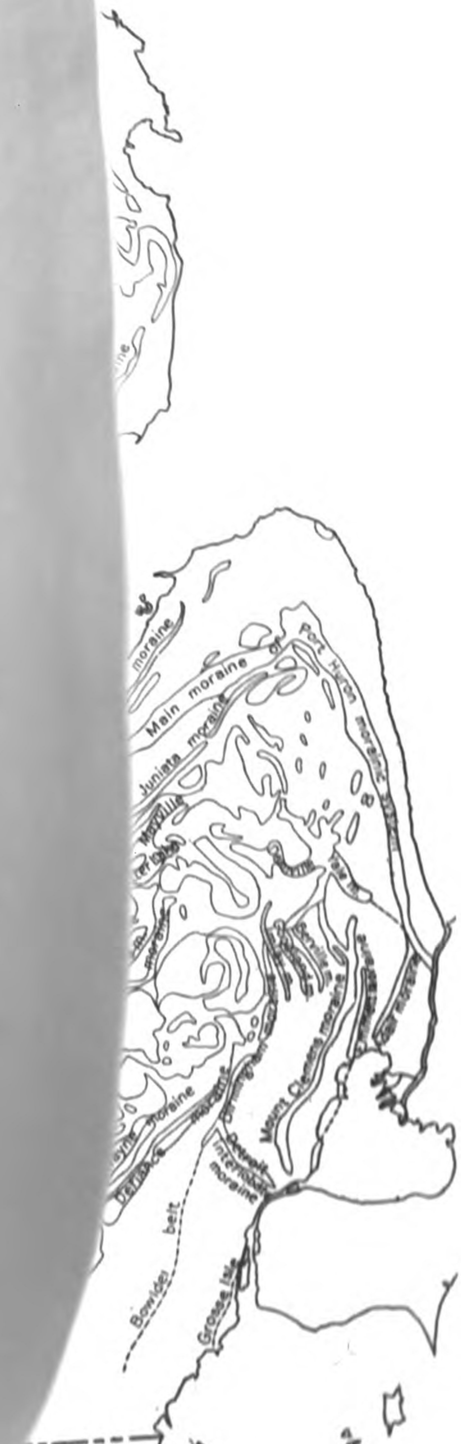
changes in field strength such as those shown on the areal map of Livingston County may be encountered. The conclusion is reached from results obtained in the Jackson area that even in regions where the material overlying bedrock is relatively thin that field strength changes are primarily the result of surface effects and have no significance geophysically.

TABLE III

FIELD INTENSITIES IN BRANCH AND HILLSDALE COUNTIES

Measurements taken June 5, 1939

Field Station	Location	Intensity
1	SE.$\frac{1}{4}$, NE.$\frac{1}{4}$, NE.$\frac{1}{4}$, Sec.14, T.5S., R.5W.	24.5
2	NE.$\frac{1}{4}$, NE.$\frac{1}{4}$, NE.$\frac{1}{4}$, Sec.13, T.5S., R.5W.	25.0
3	NE.$\frac{1}{4}$, NE.$\frac{1}{4}$, NE.$\frac{1}{4}$, Sec.18, T.5S., R.4W.	30.9
4	SW.$\frac{1}{4}$, SW.$\frac{1}{4}$, SW.$\frac{1}{4}$, Sec.9, T.5S., R.4W.	27.0
5	NE.$\frac{1}{4}$, NW.$\frac{1}{4}$, NE.$\frac{1}{4}$, Sec.16, T.5S., R.4W.	26.0
6	SW.$\frac{1}{4}$, SW.$\frac{1}{4}$, SW.$\frac{1}{4}$, Sec.10, T.5S., R.4W.	24.0
7	SE.$\frac{1}{4}$, SE.$\frac{1}{4}$, SE.$\frac{1}{4}$, Sec.10, T.5S., R.4W.	27.0
8	SE.$\frac{1}{4}$, NE.$\frac{1}{4}$, SE.$\frac{1}{4}$, Sec.11, T.5S., R.4W.	29.6
9	NE.$\frac{1}{4}$, SE.$\frac{1}{4}$, SE.$\frac{1}{4}$, Sec.12, T.5S., R.4W.	30.0
10	NE.$\frac{1}{4}$, SE.$\frac{1}{4}$, SW.$\frac{1}{4}$, Sec.7, T.5S., R.3W.	29.0
11	NE.$\frac{1}{4}$, SE.$\frac{1}{4}$, SW.$\frac{1}{4}$, Sec.8, T.5S., R.3W.	28.0
12	NE.$\frac{1}{4}$, SE.$\frac{1}{4}$, SE.$\frac{1}{4}$, Sec.8, T.5S., R.3W.	28.0
13	SE.$\frac{1}{4}$, NE.$\frac{1}{4}$, SE.$\frac{1}{4}$, Sec.9, T.5S., R.3W.	31.6
14	SW.$\frac{1}{4}$, NE.$\frac{1}{4}$, SW.$\frac{1}{4}$, Sec.11, T.5S., R.3W.	32.6
15	NE.$\frac{1}{4}$, NE.$\frac{1}{4}$, SE.$\frac{1}{4}$, Sec.11, T.5S., R.3W.	33.5
16	NE.$\frac{1}{4}$, NE.$\frac{1}{4}$, SE.$\frac{1}{4}$, Sec.11, T.5S., R.3W.	33.8
17	SE.$\frac{1}{4}$, SE.$\frac{1}{4}$, NE.$\frac{1}{4}$, Sec.7, T.5S., R.2W.	33.7
18	SE.$\frac{1}{4}$, SE.$\frac{1}{4}$, NE.$\frac{1}{4}$, Sec.8, T.5S., R.2W.	33.0
19	NE.$\frac{1}{4}$, SE.$\frac{1}{4}$, NE.$\frac{1}{4}$, Sec.9, T.5S., R.2W.	34.8
20	SW.$\frac{1}{4}$, NW.$\frac{1}{4}$, NE.$\frac{1}{4}$, Sec.11, T.5S., R.2W.	37.0
21	SE.$\frac{1}{4}$, NE.$\frac{1}{4}$, NE.$\frac{1}{4}$, Sec.11, T.5S., R.2W.	34.0
22	NE.$\frac{1}{4}$, NE.$\frac{1}{4}$, NE.$\frac{1}{4}$, Sec.12, T.5S., R.2W.	41.9



...e Lower Peninsula of Michigan.

(After Leverett)

CONCLUSIONS AND SUMMARY.

Weyl's formula (Eq. 8, page 13), for the attenuation of radio wave shows that the geologic factors influencing field intensity are conductivity and dielectric constant of the ground.

On Fig. 11 is shown the distribution of glacial moraines in Michigan. These features, composed largely of unstratified drift, are interspersed with till plains, consisting mainly of boulder clay, outwash plains, eskers and kames, made up principally of stratified sand and gravel. As a result the surficial material in Michigan varies considerably in its physical character and, therefore, in its electrical properties. This lateral variation in the ground constants is responsible in part for changes in radio field intensity.

In Summary, theoretical and experimental studies of radio reception which have been made in the areas of Michigan covered in this report prove definitely that the mantle of glacial drift together with topographic features are the controlling geologic elements affecting field strength of radio signals in the broadcast band. No influence of underlying bedrock was encountered since the penetration of the radio waves is apparently limited to a depth much less than the average thickness of the glacial drift in most areas.

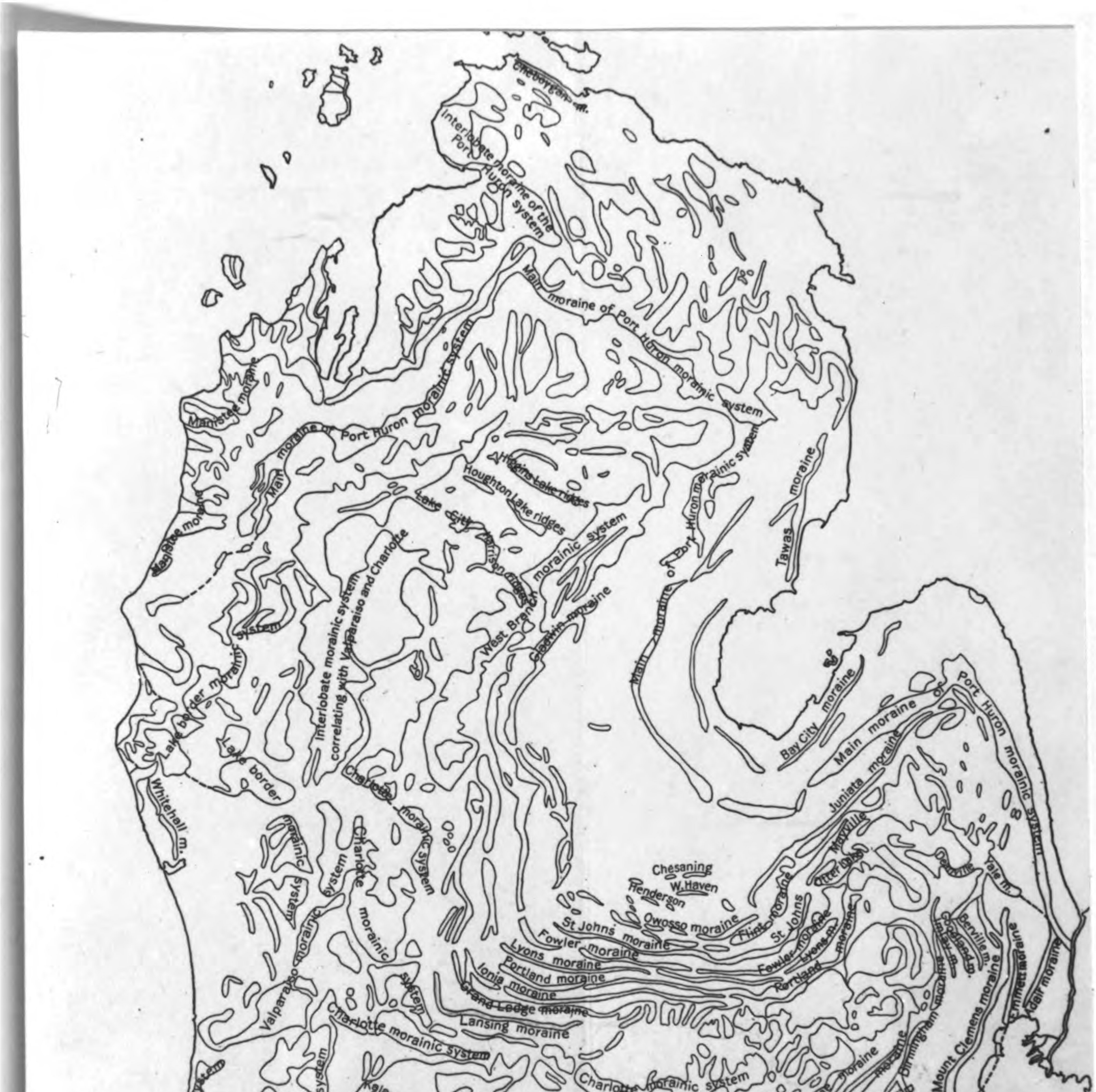


Fig. 11. Distribution of Glacial Moraines in the Lower Peninsula of Michigan.

(After Leverett)

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