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M. M. LEIGHTON, *Chief*
URBANA

REPORT OF INVESTIGATIONS—NO. 162

GEOLOGIC ASPECTS OF RADIO WAVE TRANSMISSION

BY

M. WILLIAM PULLEN

AUG. 26th 1818

PRINTED BY AUTHORITY OF THE STATE OF ILLINOIS

URBANA, ILLINOIS

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BY

M. WILLIAM PULLEN

CHAPTER 1 — INTRODUCTION

RADIO WAVES AND GEOLOGY

THE POPULAR AND SCIENTIFIC appeal of electronics has stimulated the use of radio methods of exploration in the search for natural resources in the earth's crust. Some of these methods seem to be impractical, but others show promise of success. It appears, from previous work and this study, that radio waves penetrate bedrock and other earth materials, and their depth of penetration depends on the power and frequency of the waves and on the effective conductivity of the earth materials.

Effective conductivity of earth materials to radio waves is controlled by the average value of conductivity and dielectric constant for the distance below the surface of the earth at which there are ground currents of appreciable amplitude.[1] Effective conductivity (ground conductivity) of earth materials to radio waves is determined by the resistance,[2] dielectric constant,[3] and magnetic permeability[4] of earth materials.[5] Dielectric hysteresis[6] (attenuation by a dielectric medium) may also be a factor in the attenuation of radio fields.

Radio wave propagation is a highly complex process dependent on many variables. One of the most important variables is the conductivity of earth materials, which changes from place to place within relatively short distances. This conductivity largely determines the strength of a radio field as measured in air at a distance from a transmitter.[7] It is the influence of earth materials on radio field intensity which is of interest to the geologist.

The present investigation is concerned with the relationship between radio fields and earth materials. If geologic features such as folding, faulting, and abrupt lithologic changes present electrical discontinuities (changes in effective conductivity and dielectric constant) which influence the behavior of radio fields measured in air at the earth's surface, recognition of such behavior through field strength measurements would provide a means of mapping these geologic features. If significant field strength anomalies are found in areas of known geologic features, and can be correlated with them, it would appear that unknown geologic features might be interpreted from measurements of field strength.

Because radio waves at broadcast frequencies (550-1600 kc.) are readily available and are known from previous work to be influenced by earth materials, they were employed throughout most of the investigation. They are propagated primarily by ground-wave and by sky-wave. Ground-wave intensity at a given distance from a transmitter, at these frequencies, is relatively constant and practically all daytime propagation is possible only by this means. Sky-wave fluctuates in intensity almost continuously. Sky-wave propagation, at broadcast frequencies, is operative only at night, such propagation during daytime being theoretically impossible.[8] Therefore, field intensity measurements were restricted to daytime ground-wave signals for the present study.

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[1] Terman, F. E., Radio engineer's handbook: New York, McGraw-Hill, 1st ed., p. 708, 1943.

[2] *Idem.*, p. 674.

[3] Standards of good engineering practice concerning standard broadcast stations 550-1600 kc: Federal Communications Commission, Washington, D.C., U. S. Govt. Printing Office, pp. 33-34, 1940.

[4] Smith, Woodrow, Antenna manual: Santa Barbara, Editors and Engineers, Ltd., p. 149, 1948.

[5] *See* Glossary of Radio Terms: Appendix B.

[6] Skilling, H. H., Fundamentals of electric waves: New York, John Wiley, 2nd ed., p. 149, 1948.

[7] Terman, *op. cit.*, pp. 708-709.

[8] Electronics Engineers of the Westinghouse Electric Corporation, Industrial electronics reference book: New York, John Wiley, p. 337, 1948.

Attenuation measurements on diamond drill cores were made in the laboratory, but laboratory conditions are so different from those of the field that the measurements were possibly only indicative of electromagnetic conductivities of rock cores. Early measurements in the field made with primitive equipment suggested that certain radio fields were influenced by specific geologic features; later more elaborate instrumentation indicated in much greater detail the influence of natural and cultural features as well as geologic conditions. Many influencing features other than geologic were therefore investigated, and it was found possible to recognize and to separate in some instances the influence of geologic features on radio field intensity.

OBJECTIVES

Striking similarity between a ground conductivity map of the United States (fig. 41), published by the Federal Communications Commission in 1938,[9] and the U. S. Geological Survey geologic map of the United States[10] was the impetus for this investigation. A search for the explanation of this similarity led to the study of irregular and unpredictable radio reception.

The major objectives were to collect data on field intensity of transmitted radio waves, and to determine what influence geologic conditions and earth materials have on field strength. To attain these objectives, it was necessary to develop suitable instrumentation and field techniques. Instruments were needed that would be compact and portable, yet rugged enough to withstand field operation, and that would give reliable continuous measurements. Field techniques had to be developed that would permit rapid and reliable field intensity measurements. Field intensity anomalies caused by specific geologic features needed to be examined to ascertain if there were optimum frequencies, powers, orientations, and distances that would provide the strongest or most readily identifiable signal anomaly.

Before the influence of earth materials on radio field strength could be determined, it was necessary to be able to recognize other factors that affect field strength. Therefore, a secondary objective of the work became the recognition of the other factors as hazards. The following features and factors were tentatively considered potential field hazards:

A. Cultural
   1. Wire fences
   2. Electric power, telephone, and other transmission lines
   3. Pipe lines
   4. Bridges
   5. Buildings and towers
   6. Road materials (concrete, blacktop, gravel, and dirt)
   7. Stability of power output at the radio transmitter

B. Natural
   1. Trees and other vegetation
   2. Bodies of water—lakes, ponds, and streams
   3. Topography

C. Meteorological
   1. Barometric pressure
   2. Wind velocity and direction
   3. Sunlight and cloudiness
   4. Temperature
   5. Humidity
   6. Magnetic storms
   7. Precipitation
   8. Natural electromagnetic phenomena

The following types of geologic conditions were selected for investigation:

1. Bedrock with faulting
2. Bedrock with folding
3. Cryptovolcanic structure
4. Variation in soil types
5. Variation in bedrock lithology
6. Variation in depth to uniform bedrock
7. Buried glacial drift-filled valleys
8. Ore deposits

This investigation was experimental, from a geological point of view. It is hoped that the data will contribute to a better practical understanding, and to the eventual theoretical understanding, of the phenomena involved in anomalous radio reception.

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[9] FCC, Standards of good engineering practice, *op. cit.*, pp. 33-34.

[10] Geologic map of the United States: U. S. Geol. Survey, 1932.

SCOPE

Measuring and recording equipment was tested experimentally to achieve satisfactory instrumentation. Various methods of analysis and presentation of the combined electromagnetic and geologic field data were tried before a satisfactory system was worked out.

Several hundred miles of traverses were selected along which radio field intensities were measured and recorded. The traverses were run mainly in Illinois, but to clarify the picture, some were run in Kentucky, Indiana, and Wisconsin.

A laboratory investigation of transmission of radio signals through, or along, diamond drill cores of different lithologies was made in an attempt to determine the transmission or attenuation behavior of the cores.

In the field, various man-made and natural features were examined for their influence on radio field intensity. The value and character of their influence depends on their orientation with respect to the direction of signal arrival and the point of measurement, and on the frequency, power, and distance to the radio station being monitored. With empirical data on the value and character of signal anomalies caused by these features, it became possible to investigate and evaluate the influence of geology on field intensity. Traverses could then be run measuring radio field intensities across areas of known geology, both in the presence and the absence of obvious natural and man-made field hazards.

The present work sets forth experimental data that illustrate many of the factors and features affecting radio field intensity at broadcast frequencies. The report evaluates the use of field intensity measurements as an aid in geologic exploration and offers a new concept of the methods of transmission of radio waves through earth materials.

ACKNOWLEDGMENTS

This work was part of a research investigation program of the Division of Groundwater Geology and Geophysical Exploration of the Illinois Geological Survey. The writer gratefully acknowledges the active interest and support of the investigation by M. M. Leighton, Chief of the Survey.

For encouragement to undertake the work, the writer is indebted to Carl A. Bays, formerly Geologist and Engineer and Head of the Division of Groundwater Geology and Geophysical Exploration of the Illinois Geological Survey; Ernest P. Du Bois, Geologist in the Coal Division, Illinois Survey; Stewart Folk, former Associate Geologist in the Oil and Gas Division of the Illinois Survey; to Harold R. Wanless, Professor of Geology at the University of Illinois; to A. James Ebel, former Assistant Professor of Electrical Engineering at the University of Illinois; and to R. D. Carmichael, Dean Emeritus of the Graduate School of the University of Illinois.

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Appreciation is also extended to M. B. Buhle, R. D. Knodle, Jack Wolf, and Ben Ellis, of the Illinois Geological Survey, who drove many hundreds of miles on field intensity traverses and assisted in instrument maintenance and field operations.

CHAPTER 2 — THEORETICAL CONCEPTS OF PROPAGATION

RADIO WAVES

Radio waves (electromagnetic waves) are subject to the same laws as light waves in regard to reflection, refraction, diffraction, polarization, interference, and speed of propagation. A radio wave transmitted from a nondirectional antenna at approximately 186,000 miles per second spreads out and travels in all directions. There appear to be two boundaries for this spreading wave, the surface of the earth and some ionized layers that are about 30 to 250 miles above the earth's surface.

The behavior of the wave depends upon its frequency. If the frequency is higher than approximately 30 mc, the wave may pass through the ionosphere and travel into space beyond, while in the vicinity of the antenna at the earth's surface, much of it will be rapidly absorbed and attenuated by earth materials. If the frequency of the wave is lower than approximately 30 mc, it may be reflected earthward by the ionosphere, while in the vicinity of the antenna it will follow the earth's surface for some distance before becoming absorbed or attenuated by earth materials.

The part of the wave that follows the earth's surface is called surface or ground-wave. The remainder of the wave is called the sky-wave or space-wave. According to Brainerd *et al.*:[1]

> The ground wave is usually further subdivided into a direct wave, a wave reflected from the ground (of importance when the receiving antenna is well above the ground) and a surface or guided wave. The ground wave is usually refracted in passing through the lower atmosphere, and this combined with the guiding effect which exists (the earth may act as a wave guide somewhat as one wire of a transmission line does) tends to cause the ground wave to follow the curvature of the earth when the frequency is not too great. But the ground wave often suffers severe attenuation, so that it cannot account for long-distance transmission except at relatively low frequencies.

According to Laport:[2]

> In free space devoid of all substance, including air or gases, an electromagnetic wave is propagated without any dissipation of its energy. The inverse relationship between field strength and distance is due to the expansion of the wave in three dimensions and the distribution of radiant energy over a larger and larger volume of space, so that the power flow follows the inverse-squares law with respect to distance.

However, ground-wave signal strength measured in microvolts per meter at a distance from the antenna commonly differs from that calculated from the inverse proportion relationship. This is because the earth's surface, or ground, is not a perfect conductor but has resistance, or a finite conductivity, so that some of the field strength is absorbed or attenuated.

INFLUENCE OF EARTH MATERIALS

The influence of earth materials on radio wave propagation and reception has been recognized for many years. Theories have been formulated to account for the kind and amount of influence by earth materials, and field observations have been conducted to test these theories. Sommerfeld[3] considered ground-wave propagation and arrived at an empirical equation which expresses signal intensity as a function of power, distance, frequency, and earth conductivity. Byrne,[4] and later Higgy and Shipley,[5] made radio transmission surveys in Ohio and found that their measured field strengths agreed reasonably well with field strengths predicted from Sommerfeld's equation.

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[1] Brainerd, J. G., ed., Ultra-high-frequency techniques: New York, D. Van Nostrand, pp. 436-437, 1946.

[2] Laport, Edmund A., Radio antenna engineering: New York, McGraw-Hill, p. 9, 1952.

[3] Sommerfeld, A., The propagation of waves in wireless telegraphy: Annual of Physik, vol. 4, no. 28, p. 665, March 1909.

[4] Byrne, J. F., Radio transmission characteristics of Ohio at broadcast frequencies: Ohio State Univ. Eng. Expt. Sta. Bull. 71, July 1932.

[5] Higgy, R. C., and Shipley, E. D., Radio transmission survey of Ohio: Ohio State Univ. Eng. Expt. Sta. Bull. 92, May 1936.

GROUND-WAVE AT BROADCAST FREQUENCIES

Broadcast frequencies range from 550 to 1600 kc. Sky-wave reception from broadcast stations is not usually possible in the daytime, and as all measurements were taken in the daytime, they were necessarily measurements of the ground-wave. The normal range of ground-wave reception is from approximately 50 miles, at the higher frequencies, to more than 400 miles at lower frequencies.

Terman[6] cites the work of Howe, who, assuming an average value for ground conductivity, concludes that radio waves penetrate the earth's surface at least 20 feet at 10 mc and 45 feet at 1 mc. Therefore, ground-wave signals at broadcast frequencies and lower were used in the present investigation.

WAVE-GUIDE TRANSMISSION AND PROPAGATION

In addition to the ground-wave theory, another method of propagation, not yet generally recognized as being particularly applicable at broadcast frequencies, is by wave-guide. This theory is a generally accepted explanation for transmission through hollow metal tubes at microwave frequencies. Wave-guide transmission may be thought of as transmission of electromagnetic waves in a dielectric medium bounded by one or more conducting planes.[7] Wave-guides, manufactured for use in ultra-high frequency transmission, are usually rectangular or circular in section. Propagation can also take place in the Z direction (transverse) between two roughly parallel planes having finite conductivity.

The wave lengths of an electromagnetic field that can be transmitted through a wave-guide are limited by the physical dimensions of the wave-guide itself. When wave lengths exceed the cut-off frequency dimension of the wave-guide, the waves are not transmitted along the guide. When the wave lengths are smaller than the cut-off frequency dimension of the wave-guide, the waves may be transmitted by one of several possible modes. Although much is known about the behavior and mechanics of guided waves at higher frequencies, there are not enough data to permit a description of the behavior of guided waves at all frequencies.

Ramo and Whinnery[8] state:

> For any given set of planes with arbitrary fixed spacing, there should be some frequencies and some angles of reflection for which boundary conditions could be satisfied by a wave having a component of propagation in the Z direction.

The wave-guide theory is applicable not only at very high frequencies but also at lower frequencies. At frequencies below a few hundred kilocycles the ionosphere can act as a good reflector of radio waves.[9] Since at these frequencies the earth is also a good reflector, one can consider the surface of the earth and the ionosphere as boundary conductors of a large parallel-plane wave-guide having an air dielectric. Transmission of low-frequency waves over large distances (thousands of miles) is possible by this mode of propagation. If the earth is considered as the floor of a wave-guide, the variable electrical conductivity of the floor will cause some energy to be attenuated, thereby causing a change in field intensity. Theoretically, as the floor of the guide becomes lower in conductivity or as the frequency decreases, the wave penetrates deeper into the floor.

GEOLOGIC WAVE-GUIDES

Wave-guide propagation in bedrock strata may take place under certain geologic conditions. A wave-guiding system may be thought of as a dielectric region between two parallel conducting planes. In rocks, a dry, poorly conducting rock stratum may be considered as the more-or-less dielectric region. If the rock strata above and below this dielectric region are porous and saturated with electrolyte, or have low electrical re-

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[6] Terman, F. E., Radio engineers handbook: New York, McGraw-Hill, 1st ed., p. 698, 1943.

[7] Sarbacher, R. I., and Edson, W. A., Hyper and ultra-high frequency engineering: New York, John Wiley, 1947.
Skilling, H. H., Fundamentals of electric waves: New York, John Wiley, 2nd ed., 1948.
Brainerd, *op. cit.*, pp. 455-494.
Ramo, Simon, and Whinnery, J. R., Fields and waves in modern radio: New York, John Wiley, pp. 292-295, 1947.

[8] Ramo and Whinnery, *op cit.*, p. 294.

[9] Jordan, E. C., Electromagnetic waves and radiating systems: New York, Prentice-Hall, p. 662, 1950.

sistivities, as shales and clays, they could be considered as parallel conducting planes. Theoretically, in a wave-guide with the parallel planes perfect conductors and with an air dielectric, a uniform plane wave should propagate between the planes in a Z direction with a phase velocity equal to the velocity of light and with no attenuation.[10] In a geologic wave-guide, with poorly conducting strata as the dielectric and good conducting strata as the roughly parallel planes, similar wave propagation may be possible, but the waves would be subject to much attenuation (from losses in the conductors and dielectric), and the wave velocities would be lower.

Regardless of the concept of propagation, whether by guided wave or the so-called ground-wave, it is known that signal intensity is affected measurably by the earth materials along the signal path.

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[10] Ramo and Whinnery, *op. cit.*, p. 292.

CHAPTER 3 — PREVIOUS WORK

There is only a limited amount of literature that deals directly with the relationship between transmitted radio fields and geologic conditions. However, there is considerable collateral literature, dealing more or less indirectly with the subject, in the fields of radio, electronics, communication and propagation engineering, and physics.

Bailey *et al.*[1] experimented with radio wave propagation using a frequency of 60 kc. Horizontal antenna lengths ranged from 14,000 to 17,000 feet. The effects of different earth materials beneath the antennas on directional characteristics were recognized. To the authors, variations in reception (and propagation) characteristics, at least in part, correlated with geologic formations, which they illustrated with cross sections of the rocks beneath their antennas.

Eve *et al.*[2] attempted to demonstrate penetration of rocks by radio waves in the Mount Royal tunnel. Because the tunnel was open at both ends and traversed by railroad tracks, their results were not considered conclusive. However, their data suggested that penetration is a function of frequency and that the higher frequencies were attenuated more than the lower frequencies. Signals at broadcast frequencies and lower were detectable throughout the entire tunnel.

Eve *et al.*[3] experimented with radio wave penetration of rocks in Mammoth Cave, Kentucky. This site was selected as the testing place because of its miles of underground passageways and rooms which contained no railroad tracks, wires, or other metallic conductors. Using various types of receiving antennas, signals from the surface at broadcast frequencies and lower were detected 150-350 feet below the surface. The overburden is composed of limestone and sandstone. Using an audio frequency of 500 cycles, signals were detected through 900 feet of rocks, suggesting again the increase in depth of penetration with decrease in frequency.

Volker Fritsch[4] has written extensively on the influence of underground geology on transmitted radio fields. He has described and illustrated numerous geologic conditions that improve signal reception and others that weaken or prevent it entirely. He demonstrated that radio signals at various frequencies can be detected in tunnels and mines, and cites experiments by Lowy, who detected 700 meter signals at a depth of 1000 meters. Underground in mines at Kotterbach, using frequencies of 300 meters (1000 kc) or greater, Fritsch correlated signal strength values with fractures, dip and strike of formations, and ore bodies.

In a coal mine at Grunbach, situated in a synclinal structure, Fritsch found reception very poor. In a mine at Ostrau (Moravia), reception from surface stations was possible at depths of 400-500 meters because of the presence of a good geologic conductor which dips steeply (or vertically). Fractures, ore bodies, or other geologic structures (conductors) favor reception if they

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[1] Bailey, A., Dean, S. W., and Wintringham, W. T., The receiving system for long-wave transatlantic radio telephony: Proc. Inst. Radio Eng., vol. 16, no. 12, pp. 1645-1705, December 1928.

[2] Eve, A. S., Steel, W. A., Olive, G. W., McEwan, A. R., and Thompson, J. H., Reception experiments in Mount Royal tunnel: Proc. Inst. Radio Eng., vol. 17, no. 2, pp. 347-376, February 1929.

[3] Eve, A. S., Keys, D. A., and Lee, F. W., The penetration of rock by electromagnetic waves and audio frequencies: Proc. Inst. Radio Eng., vol. 17, no. 11, pp. 2072-2074, November 1929. *Also,* U. S. Bureau of Mines Tech. Paper 434, pp. 37-40, 1928.

[4] These articles by Volker Fritsch were translated and abstracted by Professor Ernst Cloos from inaccessible German papers for the Geological Society of America:

Eineges über die Grundlagen der Funkmutung: Montan. Rundschau. Jahrg. 26, no. 4, pp. 1-6, 1934.

Beiträge zur Radiogeologie: Beitr. angew. Geophysik., Bd. 5, H. 3, pp. 315-364, 1935.

Beiträge zu den Beziehungen swischen Ausbreitung Hertz'scher Wellen und geologischer Beschaffenheit des Untergrundes (Funkgeologie). Grundlagen und Anwendung der Kapazitätsmethode: Beitr. angew. Geophysik. Bd. 5, H. 4, pp. 375-379, 1936; Bd. 6, H. 1, pp. 100-119, 1936.

Beiträge zur Funkgeologie, III. Einiges über die Ausbreitung Hertz'scher Felder in Gebirgen: Beitr. angew. Geophysik., Bd. 6, H. 3, pp. 277-306, 1937.

Beiträge zur Funkgeologie, IV. Darstellung der Eingenschaften geologischer Leiter: Beitr. angew. Geophysik., Bd. 6, H. 4, pp. 407-412, 1937.

Beiträge zur Funkgeologie, VII. Einiges über die Ausbreitung elektromagnetischer Wellen in Bergwerkschäcten und Stollen: Beitr. angew. Geophysik., Bd. 7, H. 4, pp. 449-461, 1939.

Die funkgeologische Untersuchung des Zinnobervorkommens von Schönbach bei Eger (Sudetenland): Neues Jahrb. f. Geol. B., Vol. 84, H. 1, pp. 90-116, 1940.

Messverfahren der Funkmutung: Munich, R. Oldenbourg, 1943.

connect the receiver with the surface. Fritsch believes that changes in field intensities can be predicted over an area of known geologic conditions and, also, that observed changes in field intensities may lead to the discovery of unknown geologic conditions.

Felegy and Coggeshall,[5] investigating the applicability of radio for emergency mine communications, successfully transmitted and received radio signals to and from the surface through intervening rocks. Amplitude-modulated radio transmission with voice modulation was used at frequencies from 33 to 220 kc running from 2-3 watts transmitter output power. Continuous two-way communication via rock strata (400 feet of sandstone, 150 feet of conglomerate, 30 feet of slate and clay, and a thin layer of surface soil) was maintained at the Reliance Colliery, Mt. Carmel, Pennsylvania, at distances up to 1050 feet, and intermittent communication was possible up to 2040 feet.

The above authors refer to the work of Wadley,[6] who claims to have transmitted signals through 5000-6000 feet of quartzite, using 500-foot linear antennas that touched nothing but air, both underground and at the surface. He used code signals from a 10 watt transmitter on frequencies between 100 and 300 kc.

Ernst Cloos[7] published what is probably the first geological report in this country which recognizes definite geologic influence on behavior of field strength. Using crude equipment, he was able to map faults and steeply dipping contacts between different kinds of rocks in the Baltimore area by an audible decrease in signal strength or complete absence of signal near or over these features. Best results were obtained when using a 250-watt broadcast station on a frequency of 600 kc. He concluded that in an area of known geologic conditions, with recognition of intensity disturbances caused by overhead wires, railroad tracks, road cuts, and the like, if the remaining intensity anomalies could be repeated over a period of days, months, and years, they could be definitely correlated with the geologic conditions.

Spieker[8] recognized a strong correlation between a radio transmission map of Ohio[9] and the geologic map. The radio transmission investigation was made to determine the most economical and efficient communications system that could be set up for use by the Ohio State Highway Patrol. On the radio transmission map the state was divided into zones classified as to effectiveness of transmission. Spieker observed that the area of best transmission was underlain generally by Ordovician, Silurian, and Devonian limestones; the second best area by Devonian and Mississippian shales; the third by Pennsylvanian and Permian rocks of varied lithology but with considerable sandstone; the fourth and poorest area by thick Pleistocene deposits.

From these observations Spieker concludes:[10]

> The generalization is obvious that radio transmission is affected by the texture of the rock immediately beneath the surface; tight, solid rock affords the best conditions and loose, open-textured materials the worst. This is supported by the fact that the values fall off notably as existing river channels are crossed, due perhaps in part to the topographic deflection, but probably also to the alluvium in the valleys.

Barret[11] was granted a United States patent wherein he claims the ability to make use of electromagnetic waves for acquiring useful subsurface geologic information. He describes suitable apparatus and techniques for determining the location and character of hidden geologic faults, for locating and defining buried masses such as salt domes and igneous plugs, and for locating and defining electrical discontinuities in buried strata.

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[5] Felegy, E. W., and Coggeshall, E. J., Applicability of radio to emergency mine communications: U. S. Bureau of Mines Rept. Inv. 4294, May 1948.

[6] Wadley, T. L. (Underground communication by radio in gold mines on the Witwatersrand). Suid-Afrikaanse Wetenskaplike En Nywerheidnavorsingsraad: Telekommunikasies Navorsinglaboratorium, Johannesburg, South Africa, T.R.L. 3, Nov. 1946.

[7] Cloos, Ernst, Auto-radio—an aid in geologic mapping: Am. Jour. Sci., ser. 5, vol. 28, pp. 255-268. 1934.

[8] Spieker, F. M., Radio transmission and geology: Bull. Am. Assoc. Petr. Geol., vol. 20, no. 8, pp. 1123-1124, August 1936.

[9] Higgy, R. C., and Shipley, E. D., Radio transmission survey of Ohio: Ohio State Univ. Eng. Expt. Sta. Bull. 92, May 1936.

[10] Spieker, *op. cit.*, p 1124.

[11] Barret, W. M., Electrical apparatus and method for geological studies: U. S. Patent 2,172,688, 1939.

More recently, Barret[12] conducted a demonstration before a group of geophysicists, geologists, and other technical men to prove that radio waves may be transmitted to depth in the earth. The site was at the Morton Salt Company's Kleer mine at Grand Saline, Texas, where signals were received underground on a frequency of 1602 kc from a transmitter on the surface 1200 feet away. Electric and telephone lines were cut and grounded at the top and bottom of the shaft, and pipes and the like were also grounded. The receiver was located in an abandoned part of the mine which was free from metal and separated from the shaft by 1800 feet of circuitous tunnels. Code signals from the portable transmitter at the surface apparently traveled through some 700 feet of sedimentary rocks before they were picked up by the receiver.

Howell[13] conducted field intensity investigations in faulted areas of California and New Jersey. He found that a decrease in intensity occurred above some faults in addition to a possible change in the direction of the field. He observed, like Cloos, that relatively weak electromagnetic fields seem to be more strongly influenced by geologic conditions than strong fields.

Blackburn[14] investigated field intensity variations in areas of known geologic conditions and concluded that field variations reflect geologic conditions. He claims to have used his "radiographic" method in commercial work in the United States and Canada. He ran continuous traverses and recorded field measurements on a graphic recorder of the Esterline-Angus type.

Kerwin,[15] at Massachusetts Institute of Technology, reviewed the literature and concluded that geologic mapping based on observation of field intensity variations should be practical. Supported by a grant from the Geological Society of America, he designed suitable field equipment and conducted several successful preliminary investigations of known geologic situations. He made continuous surveys and recorded the measurements graphically. He found that field intensity decreased over a basic dike with an electrical resistivity lower than that of the surrounding conglomerate, but increased over a dike with a resistivity higher than that of the surrounding rocks.

McIlwain and Wheeler[16] presented a paper at the technical session of the 1948 National Convention of the Institute of Radio Engineers which is available only in abstract form.

> A theoretical and experimental study of the propagation of radio waves through ground has resolved certain inconsistencies in prior work. Tests covered depths to several hundred feet and frequencies from 0.6 to 1.000 mc. As expected, dry ground is better than wet. At lower frequencies, ground behaves as a homogeneous, poorly conducting medium; at the higher, the rate of attenuation increases much more rapidly, indicating pockets of moisture separated by dry ground. A special technique has been used to test the horizontal propagation through substrata, which is especially useful to detect and trace dry layers, sandwiched between wet layers. The results show the limitations of radio waves for deep geophysical prospecting, though they may be useful for related exploration.

Haycock, Madsen, and Hurst[17] investigated propagation characteristics of electromagnetic waves in earth and through rocks, to evaluate the possibility of using radar methods and techniques to determine geologic discontinuities within the earth. Velocity, attenuation, and frequency of electromagnetic waves in earth materials were measured experimentally in the field. From standing wave measurements, the wave length and velocity of propagation in the earth materials used were calculated to be about one-tenth of that in the air. Attenuation measurements made with transmission lines and antennas buried in soil indicated 7.5 db per 100 feet at 350 kc, 11.7 db per 100 feet at 600 kc, and about 62 db per 100 feet at 5 mc. The authors success-

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[12] Barret, W. M., Salt mine test proves earth penetration by radio waves: World Petroleum, vol. 20, no. 3, pp. 62-63, March 1949.

[13] Howell, B. F., Jr., Some effects of geologic structure on radio reception: Geophysics, vol. 8, no. 2, pp. 165-176, April 1943.

[14] Blackburn, M. S., Radiographic method of geophysical exploration: World Oil, vol. 126, no. 11, August 11, 1947.

[15] Kerwin, Larkin, Use of the broadcast band in geologic mapping: Jour. Applied Physics, vol. 18, no. 4, pp. 407-413, April 1947.

[16] McIlwain, Knox, and Wheeler, H. A., The propagation of radio waves through the ground: Proc. Inst. Radio Eng., vol. 36, no. 3, p. 377, March 1948.

[17] Haycock, O. C., Madsen, E. C., and Hurst, S. R., Propagation of electromagnetic waves in earth: Geophysics, vol. 14, no. 2, pp. 162-171, April 1949.

fully demonstrated penetration of 400 feet of overburden by radio waves in mine-tunnel tests; frequencies between 300 and 1000 kc are apparently best suited for such through-the-earth propagation.

The authors conclude that, because of the apparent short propagation distances possible in earth materials as compared with the far greater distances possible in radar work, and because of directional antenna limitations at frequencies between 300 and 1000 kc, radar techniques for location of underground discontinuities appear to be inadequate.

It seems apparent, from a review of previous work, that there is some relationship between observed variation in field intensity and surface and subsurface geologic conditions. There is, however, a wide divergence of opinion as to the exact nature of the relationship and of the mechanics and phenomena involved. And there has been no systematic investigation described, and no extensive treatment of the subject, from the geological point of view.

CHAPTER 4—EQUIPMENT FOR RADIO FIELD INTENSITY MEASUREMENTS

PREVIOUS WORK

Instrumentation for measurement of signal intensity progressed from the simple scheme of Cloos,[1] who used a 1933 Majestic automobile radio and loud speaker, to the more elaborate equipment of Kerwin,[2] who used a radio direction finder with a shielded loop antenna. Kerwin measured signal strength in the intermediate frequency (I.F.) stage of his receiver with a Vomax vacuum-tube volt-meter and recorded it on an Esterline-Angus continuous recording milliammeter.

Felegy and Coggeshall[3] used conventional 6-tube amplitude modulation superheterodyne receivers with a frequency coverage from 80-175 kc in one band. Their transmitters had two stages (oscillator and amplifier), were amplitude-modulated, and had a power output of 2-4 watts, depending upon the impedance match obtained between the transmitters and the radiating material.

Howell[4] operated at broadcast frequencies using a portable direction finder with loop antennas for determining direction of signal arrival, and a portable field strength meter (a tuned radio-frequency receiver with a nondirectional antenna) for determining variations in field intensity.

Blackburn[5] used a small Hallicrafter communications receiver at broadcast frequencies and recorded signal strength continuously with an Esterline-Angus recorder actuated by a speedometer cable drive.

PRESENT WORK

Several systems of measuring signal strength were used early in the present work. These included equipment loaned by the University of Illinois broadcast station, WILL, and field intensity meters constructed in the Illinois Geological Survey laboratory.

INSTRUMENTATION FOR RECONNAISSANCE INVESTIGATION

The field intensity contour map (fig. 1) was made from measurements taken with an Illinois Survey laboratory-constructed field intensity meter designed for use in conjunction with automobile and battery-portable radio receivers (fig. 2). The Dixmoor water well (see fig. 1), owned by the village of Homewood, Illinois, produces water from porous Niagaran reef rock at depths from 92-104 feet and a crevice zone from 195-201 feet, as indicated by a geophysical log of the hole. The village needed a larger water supply and started a test hole approximately one mile west of the Dixmoor well hoping to encounter water-bearing reef rock. The field intensity traverse was run as the well was being drilled, to ascertain if such a survey, in advance of drilling, might not indicate the areal extent of the reef. Intensity values in the vicinity of the Dixmoor well are between 20 and 30 microamperes. It is possible that the area with values of 40 microamperes and less indicates part of the areal extent of the reef because reef rock was encountered in the test hole. The areas to the south and west have vastly different intensity values, perhaps indicative of strata other than reef rock. The entire area was resurveyed two weeks after the initial survey, using different equipment, but of the same type, and signal values were essentially duplicated.

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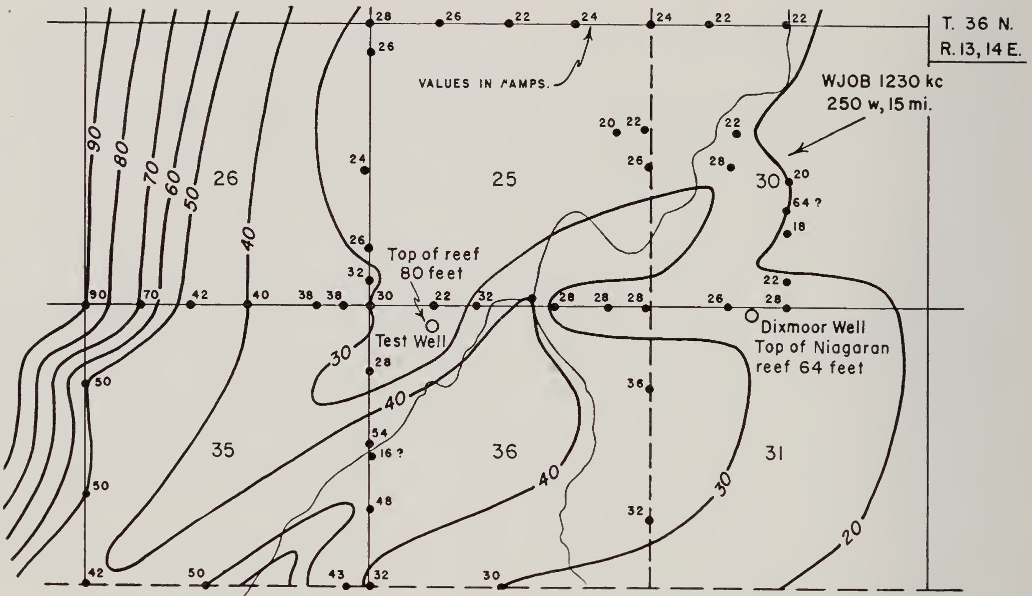
[1] Cloos, Ernst, Auto-radio—an aid in geologic mapping: Am. Jour. Sci., ser. 5, vol. 28, pp. 255-268, 1934.

[2] Kerwin, Larkin, Use of the broadcast band in geologic mapping: Jour. Applied Physics, vol. 18, no. 4, pp. 407-413, April 1947.

[3] Felegy, E. W., and Coggeshall, E. J., Applicability of radio to emergency mine communications: U. S. Bureau of Mines Rept. Inv. 4294, May 1948.

[4] Howell, B. F., Jr., Some effects of geologic structure on radio reception: Geophysics, vol. 8, no. 2, pp. 165-176, April 1943.

[5] Blackburn, M. S., Radiographic method of geophysical exploration: World Oil, vol. 126, no. 11, August 11, 1947.



ILLINOIS STATE GEOLOGICAL SURVEY

FIG. 1.—Field intensity contour map near Homewood, Illinois (based on spot readings with auto-radio intensity meter).

The validity of intensity measurements made with this type of equipment is conditioned by spot readings, field hazards, the personal element in tuning in a signal for maximum intensity, reading and recording the value, and the height of the receiving antenna above the earth's surface. However, in spite of the opportunity for error, intensity measurements with this equipment showed anomalies where they might be expected, many of which were supported later through rechecks employing more elaborate instruments.

INSTRUMENTATION FOR DETAILED INVESTIGATION

The chief component of the ultimate instrumentation used in the present work is the commercial field intensity meter, type 308-B, built by the Radio Corporation of America. This instrument is shock-mounted on aircraft-type Lord mounts on a small table fastened to the wooden floor of a wooden-bodied station wagon (figs. 3 and 4). The 308-B is a compact, fairly rugged precision instrument, easy to operate, and it covers a frequency range from 120 kc to 18 mc in six bands using three separate rotatable shielded loop antennas.

The power supply for the 308-B meter is an RCA-type 93-A vibrator unit with a nonspillable 6-volt storage battery, and a shielded cable for carrying voltage to the meter. This unit is fastened to the floor beneath the table. An auxiliary 6-volt storage battery is connected in parallel with that of the 93-A battery to prolong battery life and permit longer intervals of operation.

The recorder, an Esterline-Angus model A.W. with a 10-milliampere movement, is similarly shock-mounted on a small table fastened to the floor of the vehicle (fig. 4). A glass pen traces the field intensity record on a paper chart driven past it at a constant speed (one of several speeds available from a spring-drive mechanism). However, on traverses, the chart is actuated by a Clark recorder drive, model 102-A (fig. 4). The complete Clark recorder equipment includes a recorder drive, a speedometer tee for tying-in to the car speedometer, and interconnecting flexible drive cables. With this arrangement, the vertical scale of the chart is directly proportional to the mileage of the traverse as registered on the car speedometer. In addition to the signal intensity recording pen of the recorder, there are two side-marking chronograph pens.

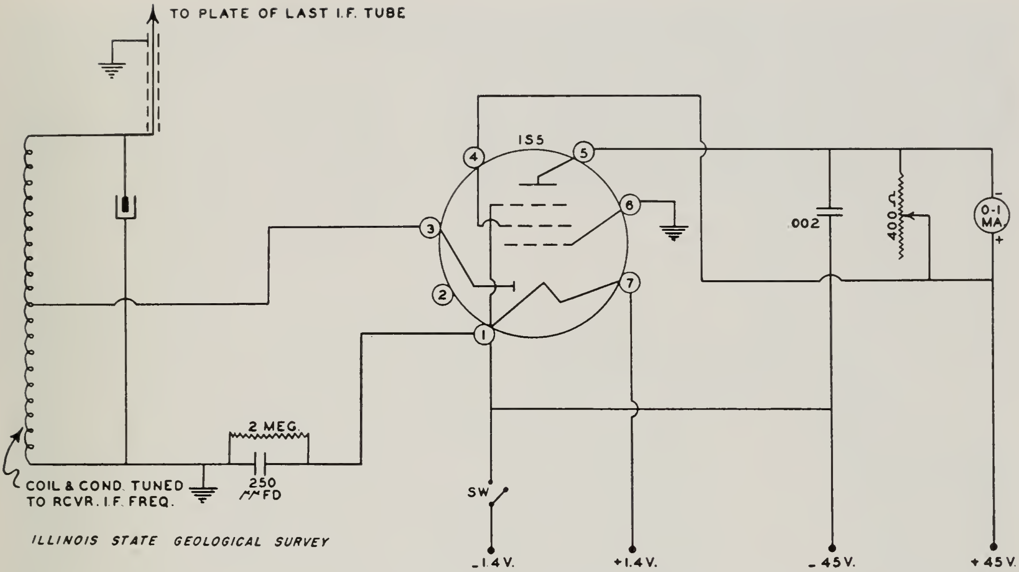


FIG. 2.—Circuit of field intensity meter designed for use with automobile and battery portable radios.

FIG. 3.—Wooden-bodied station wagon with permanently mounted radio field intensity measuring equipment.

Fig. 4.—Operator in working position. The 308-B field intensity meter (center); Esterline-Angus recorder and Clark speedometer drive (left).

Instrumentation for reliable continuous measurement of field intensity, automatically recorded, is essential in undertaking a comprehensive investigation of the influence of earth materials on radio wave transmission. These conditions are adequately met with the RCA 308-B field intensity meter, the Esterline-Angus recorder, and the Clark speedometer-actuated recorder drive.

Instrumentation in Mobile Operation

The instruments were permanently mounted in an International station wagon with a wooden body. This vehicle was chosen on the basis of tests in which measurements were taken from inside the vehicle, from the tailgate of the vehicle, and from 10 to 50 feet away from the vehicle. The measurements indicated differences insufficient to warrant their being taken from outside the vehicle. Dewitt and Omberg[6] investigated the accuracy of portable measuring equipment and found that radio frequency fields are distorted in the vicinity of metal-bodied cars due to a secondary field resulting from eddy currents. They found that the wooden-bodied station wagon is almost completely free from field distortion.

Instrumentation and Investigation in the Laboratory

There has been comparatively little laboratory investigation on the behavior of electromagnetic waves in rocks. This may be due in part to the apparent lack of economic application and to the difficulty of simulating field conditions. Wheeler[7] made some laboratory investigations on the dielectric constant and the A.C. and D.C. conductivity of oil sands. His instrumentation consisted of a radio frequency generator, a radio frequency bridge, and a communications-type receiver. Frequencies employed ranged from 1 to 30 mc. Although his results were

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[6] Dewitt, J. H., Jr., and Omberg, A. C., The relation of the carrying car to the accuracy of portable field intensity measuring equipment: Proc. Inst. Radio Eng., vol. 27, no. 1, pp. 1-4, January 1939.

[7] Wheeler, R. T., The dielectric properties of oil sands: Petr. Engineer, vol. 19, no. 9, pp. 141-154, June 1948.

far from complete, he concluded that the dielectric constant decreases rapidly with increase in frequency above 1 mc, and salt water in a sand is the chief factor in raising its dielectric constant.

At the Illinois Geological Survey laboratory, diamond drill cores were used in radio wave attenuation tests at frequencies ranging from 100 kc to 18 mc. Radio signals were transmitted through, or along, diamond drill cores of different lithologies to investigate the attenuation of signals transmitted through rocks.

The rock cores were used as transmission lines connecting a signal generator with a field intensity measuring receiver. Curves were drawn for the transmission ability of each core for frequencies between 100 kc and 18 mc. For control, transmission curves were drawn for air path and for direct coaxial connection between transmitter and receiver for the same range of frequencies. The results indicated that for certain frequencies all cores tested behaved as transmission lines yielding field intensities between those obtained with direct connection and with air path. Admittedly, laboratory conditions differ considerably from those in the field; thus the measurements, while possibly indicative of electromagnetic transmission in rocks, were not conclusive.

CHAPTER 5 — RADIO FIELD INTENSITY MEASUREMENT

FIELD INTENSITY AND LOOP ORIENTATION

Signal intensities were measured in the field. Relative field intensity was measured, rather than actual field intensity, in microvolts per meter. The chief interest is in significant changes of intensity; actual intensity values were rarely measured because they require considerable additional instrument calibration and manipulation which slows the speed of the surveys.

The shielded loop antenna of the 308-B meter is bidirectional. There are two places, 180 degrees apart through the complete 360 degrees of rotation, where signal intensity is at its maximum; also two places, 180 degrees apart, where signal intensity is at a null, at a minimum, or absent. Most of the several hundred miles of recorded traverses were run keeping the loop manually oriented in the direction of maximum signal intensity. This is not difficult to accomplish on straight roads following section or fractional section lines, but requires more attention on winding roads, especially in hilly terrain where a reference point on the horizon is difficult to maintain. Maximum signal intensity is indicated by the highest reading obtainable on the D.C. milliammeter of the 308-B meter. As the loop is rotated away from maximum signal orientation, there is a decrease in the D.C. milliampere readings.

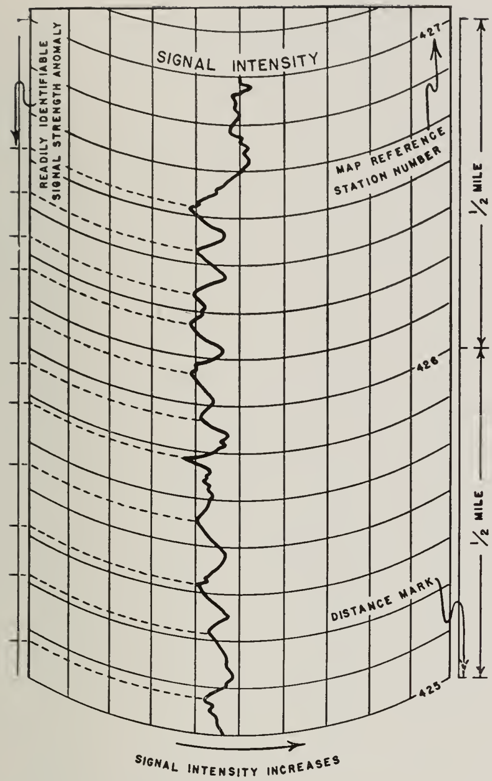
FIELD INTENSITY RECORDS

Field intensity values, indicated by the D.C. milliammeter of the 308-B, were automatically recorded on the paper chart of the Esterline-Angus graphic recorder (fig. 4). Signal intensity is recorded on the chart as the chart is driven past the main recording pen (figs. 5 and 6). In addition to the main recording pen, there are two chronograph or marking pens on the Esterline-Angus. They are located near the right and left margins of the chart, are 6-volt D.C. solenoid-actuated, and manually controlled from switches under the front edge of the recorder table (fig. 4). The pens trace vertical lines parallel to the chart margins, but, when actuated, they mark a short line normal to the vertical trace. The pen at the right was used to ink marks to correspond with map reference points along a traverse. In figure 5, these marks, labeled distance mark, bear the same number (map reference station number) as numbered points one-half mile apart on a geographic base map. The pen at the left was used to ink marks to correspond with field strength anomalies caused by a readily identifiable field hazard, such as an overhead wire, a railroad track, or a bridge. The dashed lines connect points on the curve (signal strength anomalies) with their respective solenoid pen marks.

When the marking pens are not used, the map reference points are indicated on the chart by the main recording pen in the form of an arc (fig. 6), by momentarily turning the selector switch of the 308-B to a calibrate position. The readily identifiable signal strength anomalies are indicated on the chart with an X or a check mark, and labeled stream, bridge, *oh* for overhead wire, etc. (fig. 6). The telephone and electric wire conditions are noted on the left margin of the chart. This method of indicating identifiable signal strength anomalies, wire conditions, and map reference points on the chart is faster and possibly more accurate than the solenoid marking-pen method, and is now employed wherever roads are not too rough.

GROUND-WAVE VERSUS SKY-WAVE SIGNALS

The Federal Communications Commission specified that in the broadcast band (550 to 1600 kc), primary service area means the area in which the ground-wave is not sub-

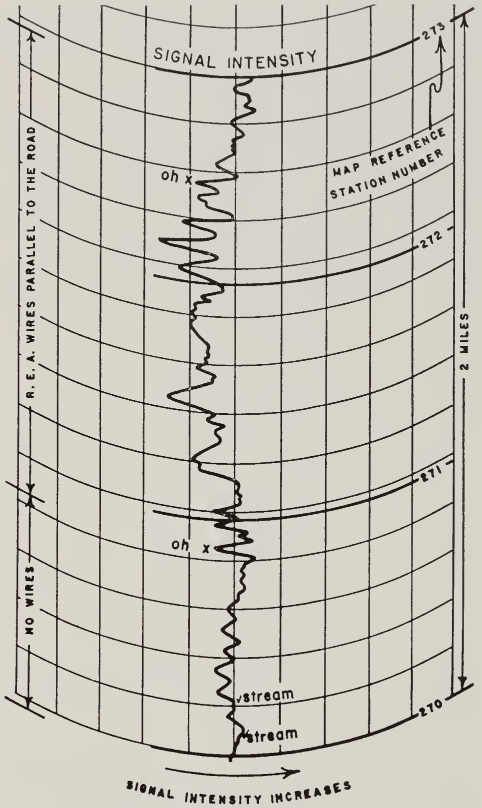


ILLINOIS STATE GEOLOGICAL SURVEY

FIG. 5.—Signal intensity record (taken from a chart recorded in the field) showing signal intensity curve, distance marks, map reference station numbers, and readily identifiable signal strength anomalies.

ject to objectionable interference or objectionable fading.[1] Westinghouse engineers[2] describe ground-wave as follows:

> In the broadcast band, there is virtually no sky-wave propagation in the daytime. Therefore, primary coverage is determined by power, frequency, and ground constants.
>
> At night the ionosphere contributes to sky-wave propagation. If the radiating system radiates an appreciable amount of energy at high angles measured from the ground, the sky-wave is reflected by the ionosphere into a region having appreciable ground-wave coverage. There it adds with its characteristic varying and uncertain phase position to the ground-wave producing fading. The sky-wave produces secondary coverage beyond the fading region, but it is relatively unreliable.
>
> Ground-wave propagation is good at the low-frequency end of the broadcast band but deteriorates near the high-frequency end of the band. . . .
>
> During the day coverage is completely by ground-wave. At night a region of ground-wave coverage is surrounded by a fading zone or at least a zone of inadequate signal. The fading zone is surrounded by a ring of sky-wave coverage.



ILLINOIS STATE GEOLOGICAL SURVEY

FIG. 6.—Signal intensity record (taken from a chart recorded in the field) showing signal intensity curve, distance, map reference station numbers, readily identifiable signal strength anomalies, and wire conditions. (*oh* stands for overhead wire, *x* indicates its position on the curve.)

Signal intensity records of sky-wave propagation illustrate the characteristic fading and variance of signal level. An illustrative record (fig. 7) was made with the 308-B equipment at a fixed location, between 9 P.M. and 1 A.M. local time. Signal intensity records were made in the daytime of ground-wave propagation with the 308-B equipment at a fixed location (fig. 8 is illustrative of ground-wave field strength).

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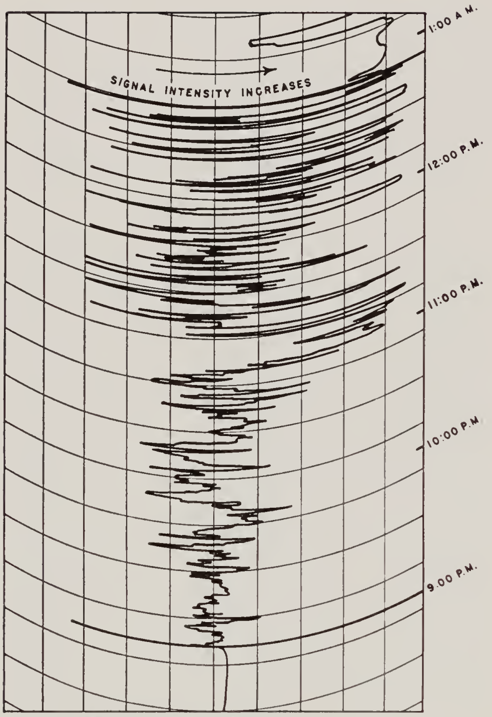
[1] F. C. C. Rules and Regulations, Rules governing standard broadcast stations: Section 3.11, Rules in force as of March 1, 1940: U. S. Govt. Printing Office, Washington, D.C., 1940.

[2] Electronics Engineers of the Westinghouse Electric Corporation, Industrial electronics reference book: New York, John Wiley, p. 337, 1948.



ILLINOIS STATE GEOLOGICAL SURVEY

Fig. 7.—Four-hour record of WLW (Cincinnati, Ohio) 700 kc, 50,000 watts—illustrating sky-wave signal intensity fluctuation, recorded at a fixed location in Urbana, Illinois, 200 miles from Cincinnati.

These curves illustrate the remarkably constant signal intensity usually encountered in ground-wave propagation within the primary coverage area.

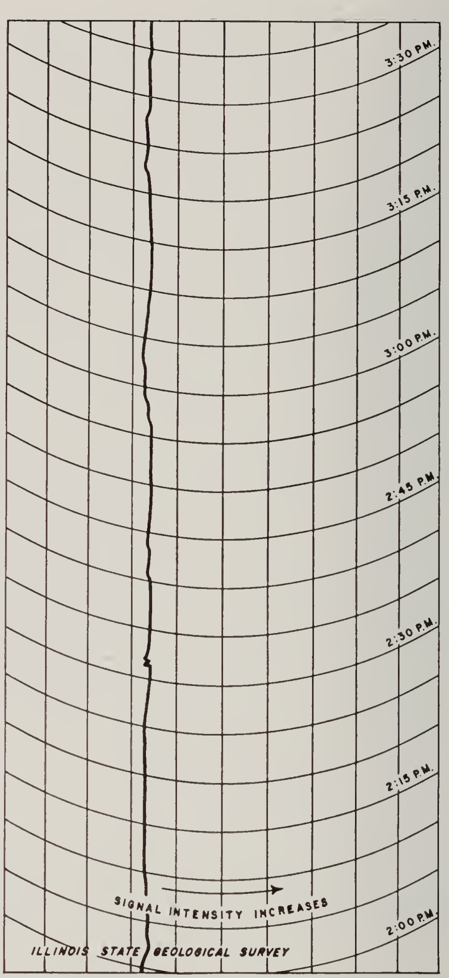


Fig. 8.—Record of WGN, 720 kc, 50,000 watts—illustrating ground-wave signal intensity, recorded at a fixed location in Urbana, Illinois, 130 miles from Chicago.

CONSTANCY OF GROUND-WAVE INTENSITY

The validity of the premise that influencing features cause varying signal intensity depends upon the assumption that the signal being measured is fluctuating very little in strength at its site of emanation. Federal Communications rules and regulations specify that each station shall be operated at all times as near to the authorized power as practicable. The operating power tolerance may be permitted to vary from 5 percent above to 10 percent below the authorized power for short periods.[3] The preceding assumption was verified by many signal intensity measurements. Signal intensity was recorded, from a fixed location, for time intervals ranging from 5 minutes to 12 hours. The ground-wave intensity curves show slight changes during short intervals and somewhat larger changes over longer intervals. The variations in signal intensity as transmitted, for the stations monitored, are negligible in comparison with variations caused by influencing factors in the field.

Thus it appears that an electromagnetic field radiating from a modern broadcasting station is sufficiently constant in intensity, in the ground-wave area, that significant

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[3] Standards of good engineering practice concerning standard broadcast stations 550-1600 kc.: Federal Communications Commission, U. S. Govt. Printing Office, Washington, D.C., p. 51, 1940.

changes can be attributed to factors other than fluctuation at the transmitter. This was borne out by repeated runs over the same traverse, the field chart record being essentially duplicated on runs made weeks, months, and years apart. If the signal strength varied significantly at the transmitter, measured intensity curves over a traverse at various time intervals would not be reproducible.

Modulation Effect

With some types of field intensity meters, signal intensity fluctuates with the modulation of the carrier signal. Modulation varies with the type of program being transmitted. A symphony orchestra or singer running the gamut of tone, pitch, and volume causes more irregular modulation levels than do the more quiet programs. The modulation effect is commonly most evident when monitoring a station at a very short distance. In such instances a signal with little modulation effect should be selected.

The modulation effect appeared occasionally using the reconnaissance-type field intensity meter (fig. 2) in conjunction with battery-portable and automobile radios. Kerwin describes modulation effect in connection with field intensity surveys in Massachusetts.[4]

> One of the disadvantages of using the broadcast band with the present equipment here became apparent. The modulating voltage had some effect on the instantaneous readings, although not the average. Therefore readings extending over some period of time were necessary to obtain accurate values. The type of program being broadcast also has an effect as the modulation of musical programs is much smoother than those of the "soap-opera" type, and gave records which were much easier to interpret.

Fortunately, the RCA 308-B field intensity meter is essentially free from the modulation effect. All recorded signal intensity curves made with the 308-B can be examined and interpreted without consideration of a modulation effect.

OUTLINE OF FIELD PROCEDURE

The procedure developed for field intensity surveying is as follows:—

1. Select an area for running traverse.
2. Locate area on geographic base map.
3. Assign map reference station numbers at one quarter mile, one half mile, or other selected intervals.
4. Move measuring equipment to the area for a daytime (ground-wave) traverse.
5. Choose a standard broadcast station the primary service area of which includes the area to be surveyed, and with preferred direction orientation to the area.
6. Select a broadcast signal that shows no modulation effect.
7. Calibrate the signal being measured so that the needle of the signal intensity meter points to the middle of the scale. This helps keep the needle on scale with signal intensity increases and decreases.
8. Connect (Esterline-Angus) recording meter to the field intensity meter (308-B).
9. Connect speedometer drive (Clark) to the recording meter. This provides a vertical scale in miles, or fractions thereof, for the chart.
10. Start running the traverse and keep the shielded loop antenna oriented for maximum signal intensity at all times.
11. Keep running field notes on the chart, noting streams, bridges, wires, etc.
12. Mark points on the signal intensity curve that correspond to map reference stations. This facilitates geographic orientation of the chart.
13. Run the same traverse several times using different broadcast stations with different frequencies, powers, distances, and directions of signal arrival.

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[4] Kerwin, Larkin, Use of the broadcast band in geologic mapping: Jour. Applied Physics, vol. 18, no. 4, pp. 407-413, April 1947.

CHAPTER 6—EFFECTS OF CULTURAL AND NATURAL FEATURES

The following are selected examples of features, primarily other than geologic, which affect signal intensity. They are specific features, representative of many observed in three years of field intensity surveying.

WIRES AND STEEL BRIDGE

Wires, because of their widespread distribution in Illinois, are the single greatest hazard influencing radio field strength. From hundreds of miles of observation, it has been found that the closer the wires are to the ground, the smaller their influence upon signal strength. Fences influence measurements of signal intensity less than telephone or electric wires strung on poles above the road. This condition may perhaps best be interpreted by the height relationship of the wires to the shielded loop antenna of the 308-B field intensity meter. The loop antenna in operating position is six feet above the ground; if the height of the wires is the same or greater than that of the loop, their effect on field intensity may be large, but if below the height of the loop, their effect is usually smaller. The kind and amount of effect wires have on field intensity depend upon their orientation with respect to the direction of arrival of the signal and to the geographic point of measurement.

Three miles south of Gibson City, Illinois (Area I), a series of traverses was run between stations 61a and 62, to determine the effects of telephone wires and a steel bridge on broadcast signal intensity, with signals varying in power, frequency, direction of arrival, and distance traveled (figs. 9 and 10). The power of the broadcast transmitters ranges from 250 to 50,000 watts, the frequencies 550 to 1580 kc, the distance 21 to 160 miles, and directions of arrival are widely separated (fig. 9). The 1980-foot traverses were run from south to north on a two-lane concrete highway (Illinois 47) which runs across an essentially flat plain; both electric and telephone wires parallel the highway, which crosses a steel bridge (fig. 10).

Description of Area I

The topography is essentially that of a flat ground moraine. Approximately 200 feet of glacial drift overlies several hundred feet of Devonian and Silurian limestone and dolomite. Because the bedrock is just west of the local crest of the LaSalle anticline it probably dips slightly to the west and south. Because of the more or less uniform geologic structure of the area investigated and the readily apparent field hazards (wires and bridge), recorded signal strength anomalies may be attributed chiefly to those field hazards rather than to any geologic component.

In all the recorded curves the effect of the steel bridge greatly reduces or eliminates the signals (figs. 11-14). Signals arriving from the south decrease in intensity beneath the overhead telephone wire (fig. 10), but increase immediately in front (south) of the bridge (figs. 12 and 13). The steel bridge appears to act as a transmitting element and reradiates the signal in the direction of travel. This may be the source of the intensity peaks north of the bridge (figs. 12 and 13). A greater number of peaks occur at high frequencies than at low frequencies. Station KSD at 550 kc (fig. 13A) shows one intensity peak north of the bridge; WDZ at 1050 kc (fig. 12B) shows three peaks; WKID at 1580 kc (fig. 12D) shows four intensity peaks.

Signals measured arriving from the north increase in strength at the north end of the bridge and beneath the overhead telephone wire (fig. 11). The intensity increase under the telephone wire may be caused by reradiation from the metal bridge.

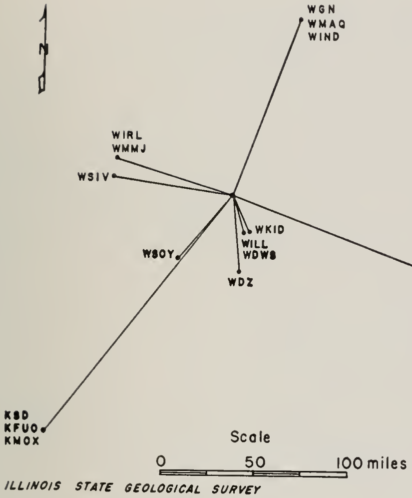


FIG. 9.—Location of broadcast transmitters—distance from area of traverse (Area I, 3 miles south of Gibson City, Illinois) and directions of signal arrival.

Signals arriving from the west do not increase in intensity at either the north or south end of the bridge. They decrease under the telephone wire and near a steel guy wire on an REA electric pole west of the road (fig. 14 A, C). The curves of signals arriving from the west are smoother and have fewer peaks north and south of the bridge than the curves of signals arriving from the north or south. The bridge structure is probably reradiating signals arriving from the west along the direction in which they are traveling (east) so that they are not in evidence north or south of the bridge along the line of traverse.

One signal from the southeast (fig. 14D) has enough southerly component to make the curve resemble the other signals from the south. However, it increases slightly under the telephone wire, thus behaving more like the signals from the north.

Summary.—Interpretation of signal intensity curves recorded between stations 61a and 62 suggests the following conclusions:—

Signals arriving from a southerly direction show:

1. Reduced intensity under the telephone wire crossing the road.
2. Increased intensity just south of the metal bridge structure.
3. Intensity greatly reduced or absent on the bridge.
4. One, two, three, or four intensity peaks north of the bridge, depending upon frequency. The lower the frequency the fewer the peaks, and the higher the frequency the greater the number of peaks.

Signals arriving from a northerly direction show:

1. Increased intensity just north of the metal bridge structure.
2. Increased intensity under the telephone wire crossing the road.
3. Intensity greatly reduced or absent on the bridge.

Signals arriving from a westerly direction show:

1. Intensity greatly reduced or absent on the bridge.
2. Reduced intensity under the telephone wire crossing the road.
3. Reduced intensity near a steel guy wire on an REA electric pole west of the road.

In addition to the influence of wires and the steel bridge on signal intensities, the influence of other cultural and natural features was investigated in other areas. Their effects on radio fields were carefully analyzed in a manner similar to that described in the foregoing section. The following sections summarize the effects of these other features but detailed analyses are omitted. The features described are supported by observations of similar features along many hundreds of miles of traverses.

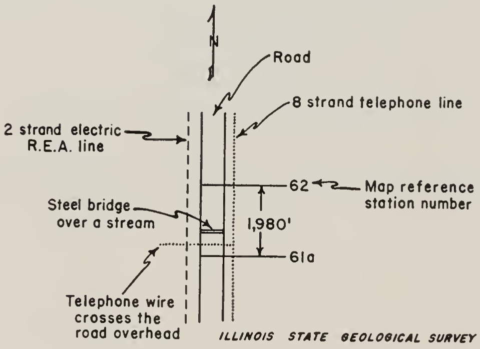
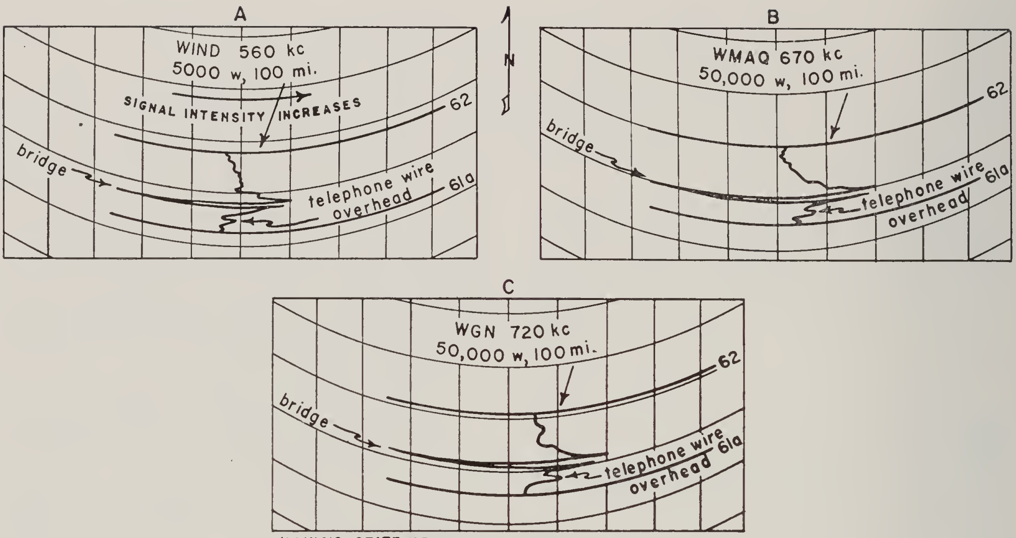
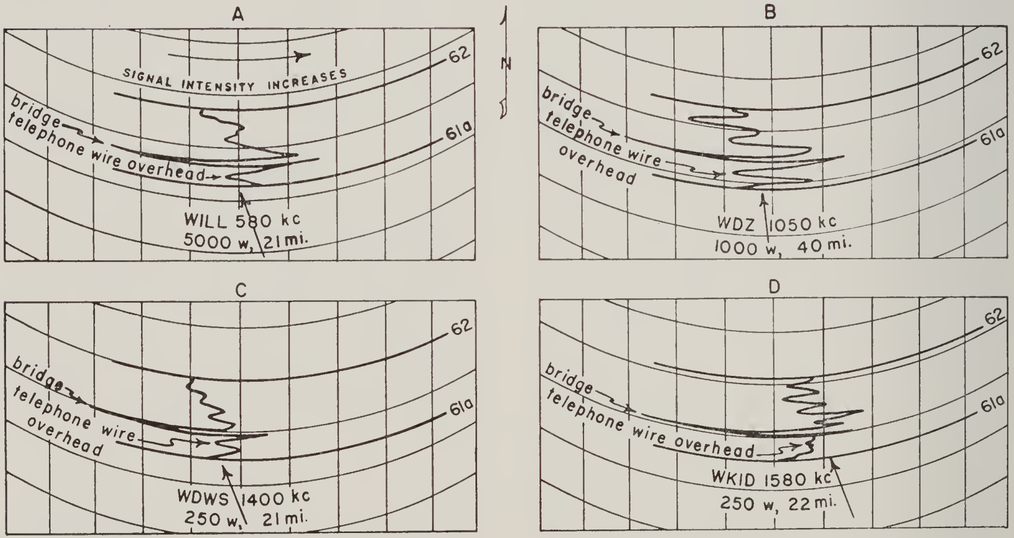


FIG. 10.—Natural and cultural features along line of traverse (Area I, 3 miles south of Gibson City, Illinois).



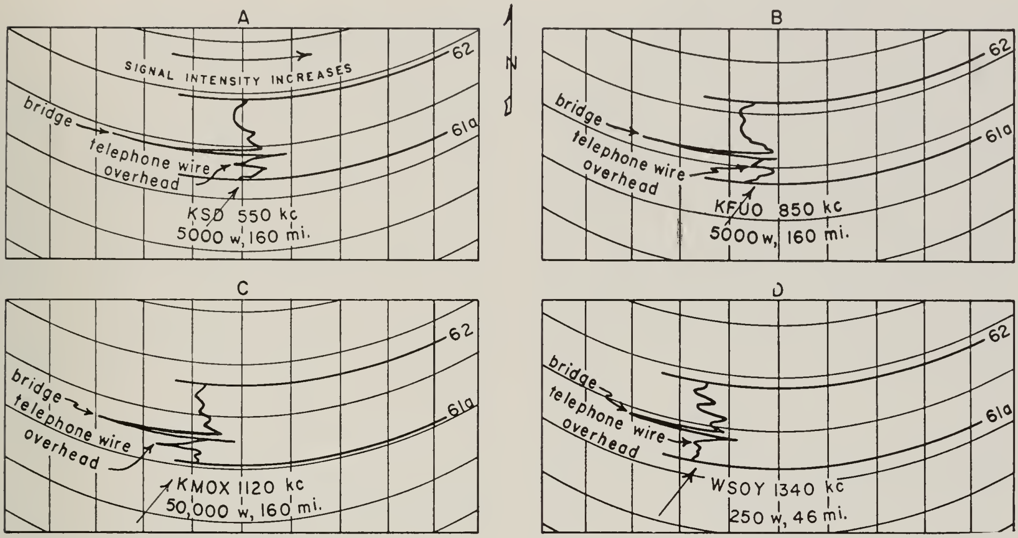
ILLINOIS STATE GEOLOGICAL SURVEY

FIG. 11.—Signal intensity curves, recorded along traverse (Area I, 3 miles south of Gibson City, Illinois), of signals arriving from the northeast.



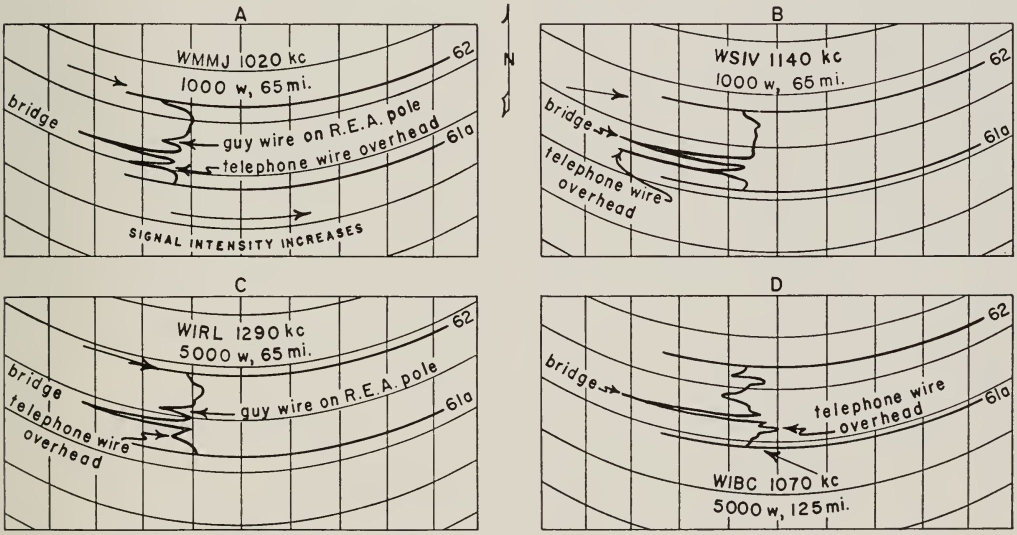
ILLINOIS STATE GEOLOGICAL SURVEY

FIG. 12.—Signal intensity curves, recorded along traverse (Area I, 3 miles south of Gibson City, Illinois), of signals arriving from the southeast.



ILLINOIS STATE GEOLOGICAL SURVEY

FIG. 13.—Signal intensity curves, recorded along traverse (Area I, 3 miles south of Gibson City, Illinois), of signals arriving from the southwest.



ILLINOIS STATE GEOLOGICAL SURVEY

FIG. 14.—Signal intensity curves, recorded along traverse (Area I, 3 miles south of Gibson City, Illinois), of signals arriving from the northwest and southeast.

WIRE FENCES

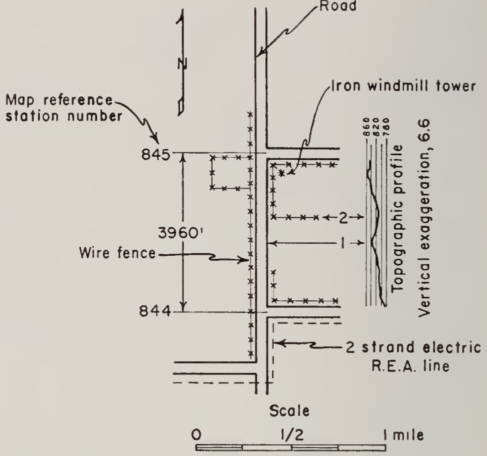
Description of Area II

In Area II, five miles west of Gibson City, Illinois (fig. 15), the topographic relief is approximately 80 feet. Signals from seven broadcast stations were measured while traverses were run across the area. Signal arrival directions were roughly north, east, south, and west. Signal frequencies ranged from 580 to 1580 kc, distances from 24 to 160 miles, and powers from 250 to 50,000 watts.

The line of traverse (4000 feet) is on the south slope of the Normal recessional moraine.[1] Thickness of the glacial drift ranges from 260 to about 320 feet, depending on surface elevation. The underlying Pennsylvanian bedrock surface is of low relief and lies at approximately 540 feet above sea level.[2] The beds are Lower McLeansboro in age, and probably of uniform sedimentary cyclic lithology. Here they lie about six miles west of the local crest of the LaSalle anticline and probably dip gently westward.

The seven runs along this traverse were all made from south to north along a secondary gravel road. A wire fence paralleled the road on the west side for the entire length of the traverse (fig. 15). At the north end of the traverse (on the west side) a farmyard was completely enclosed by a wire fence. A wire fence ran a short distance north from the south end of the traverse (on the east side of the road), and from the north end of the traverse a wire fence ran a short distance to the south. These fences on the east were joined at right angles by several east-west running wire fences. The fences were of two- and three-strand barbed wire, on both wooden and metal poles, and one fence was of coarsely woven rectangular wire net.

The effects (if any) of the fence paralleling the traverse on the west are unknown because it was a constant factor throughout the entire traverse. A slight decrease in intensity was observed at the north end of the traverse at the fenced-in farmyard. The decrease may have been caused by the additional fence or by a metal windmill tower at the east side of the road.



ILLINOIS STATE GEOLOGICAL SURVEY

FIG. 15.—Natural and cultural features along line of traverse (Area II, 5 miles west of Gibson City, Illinois).

The effects of the fences on the east are slight. A fairly consistent, but small, decrease in intensity was recorded near a fence on the east where another fence (oriented east-west) met it at right angles. It is possible that these decreases may have resulted from reradiation by the fences in some out-of-phase relationship, or that the wire fence configuration was such that it absorbed or otherwise attenuated part of the radiated field.

Description of Area III

In Area III, five miles southwest of Champaign-Urbana, Illinois (fig. 16), a one-mile traverse was run across 45 feet of topographic relief. Signals from 11 broadcast stations were measured while running the traverse across the area. Signal arrival directions were roughly north, east, south, and west. Signal frequencies ranged from 580 to 1580 kc, distances from 4 to 140 miles, and powers from 250 to 50,000 watts.

The line of traverse followed a secondary gravel road across the ground moraine about four miles west of the Champaign reces-

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[1] Leighton, M. M., Ekblaw, G. E., and Horberg, Leland, Physiographic divisions of Illinois: Jour. Geol., vol. 56, no. 1, fig. 4, p. 22, January 1948; reprinted as Illinois Geol. Survey Rept. Inv. 129, 1948.

[2] Horberg, Leland, Bedrock topography of Illinois: Illinois Geol. Survey Bull. 73, pl. 2, 1950.

sional moraine.[3] Drift thickness ranges from approximately 230 to 280 feet depending upon ground elevation. The underlying bedrock surface is fairly uniform and lies approximately 475 to 500 feet above sea level.[4] The beds are Tradewater in age and probably of uniform sedimentary cyclic lithology. Here they lie about two miles west of the local crest of the LaSalle anticline and probably dip gently to the west.

The eleven runs along this traverse were made from west to east along a secondary gravel road. Twelve different fence systems were encountered along the traverse. No one fence ran the entire length of the traverse. There were short east-west fences parallel to the traverse; some north-south fences joined the east-west fences; some north-south fences ended at the line of traverse without meeting or joining any of those oriented east-west. The fences were two-, three-, and four-strand barbed wire on both metal and wooden poles.

Wire fence effects on field intensity were either slight or nonexistent for the eleven traverse runs. The slight effects were not consistent for the various signals measured. For all practical purposes of radio field intensity investigation, except in rare and special instances, effects of wire fence can generally be ignored in Illinois.

OVERHEAD WIRES

The effects of an overhead telephone wire were reported in the discussion of Area I and the effects of both telephone and electric wires were observed in field measurements in Area III (fig. 16). These wires in Area III crossed the line of traverse at right angles at both the east and west ends. The field strengths of the eleven signals measured decreased beneath the north-south electric and telephone wires. Signals arriving from the north and south underwent the greatest attenuation; signals from the east and west the least.

GROUNDED ELECTRIC SERVICE POLES

A special type of signal intensity anomaly is illustrated by figure 17. The traverse was run from west to east, starting 2½ miles east of Harrisburg, Illinois, along State Highway 13. REA electric service wires on poles parallel the road along the west half of the traverse; along the east half there were no wires of any kind. The series of peaks (intensity increase and decrease) which make up the curve for the west half is caused by the grounding of every other or every third REA pole. Grounding of certain poles is a common practice. The maximum intensity peaks occur opposite the ungrounded poles, the minimum peaks opposite the grounded poles.

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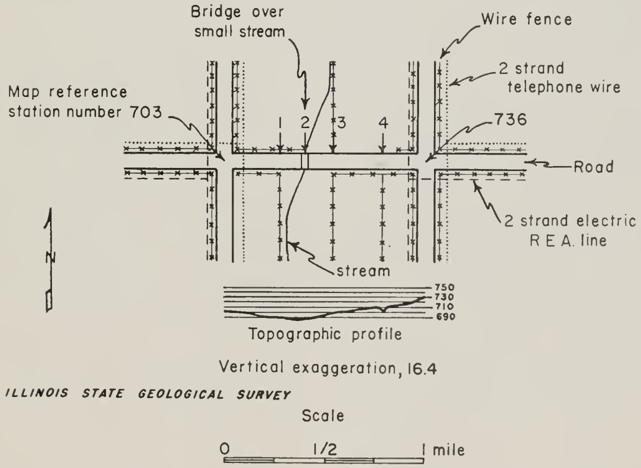
[3] Leighton, Ekblaw, and Horberg, *op. cit.*
[4] Horberg, Leland, *op. cit.*, pl. 2.



ILLINOIS STATE GEOLOGICAL SURVEY

Fig. 16.—Natural and cultural features along line of traverse (Area III, 5 miles southwest of Champaign-Urbana, Illinois).

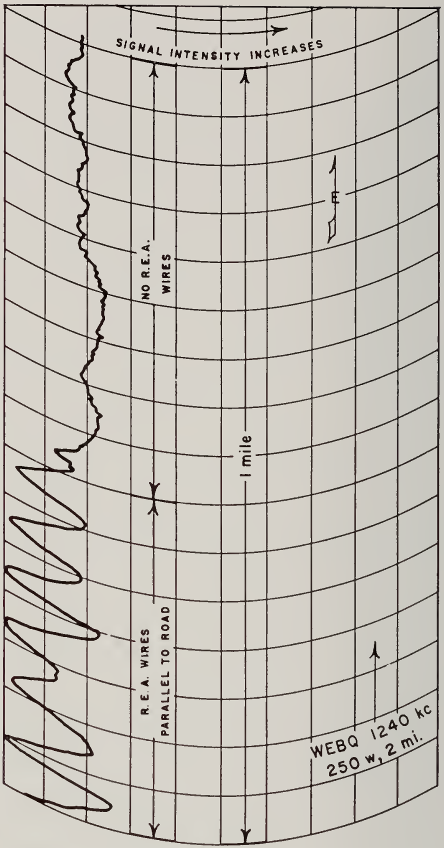
TOPOGRAPHY

In trying to determine the effect of topography on signal intensity it is difficult to eliminate the effects of geologic conditions involved in the control of the topography. In drift-covered areas, topographic variation may correspond to variation in drift thickness above the bedrock, or the relief may be the result of bedrock topography; thus signal intensity anomalies could be the result of drift thickness and/or topographic variation, or changes in subsurface geologic conditions.

In areas of moderate relief, with little or no glacial drift cover, it is difficult to lay out a traverse that will not cross lithologic boundaries in the bedrock. Areas of great relief, with or without glacial drift cover, are commonly associated with numerous lithologic changes in the bedrock. Areas of small relief hardly offer fair tests of topographic influence on radio signal intensity. Thus, the problem of completely isolating a signal anomaly due solely to topographic influence is most difficult.

Area II (fig. 15), which has about 80 feet of topographic relief, was selected to study the possible effect of topographic relief on signal intensity because the only known change in geologic conditions is the 80-foot variation in thickness of drift cover. In all the recorded curves there is a slight increase in signal strength atop a small hill (fig. 15, point 1 along the traverse), which may be attributed to the topographic high and/or to the increase in drift thickness over the essentially flat bedrock surface. This slight increase in signal intensity is insignificant compared to the relief of the curves recorded along this 3960-foot traverse.

Area III (fig. 16) has about 45 feet of topographic relief, caused by variation in drift thickness. As in Area II, the bedrock relief is probably small. Eleven runs were made across the traverse using different stations, powers, frequencies, distances, and directions of signal arrival, and at no place was there even a small signal anomaly which appeared related in any way to the 45 feet of topographic relief.



ILLINOIS STATE GEOLOGICAL SURVEY

Fig. 17.—Signal intensity curve recorded along traverse near Harrisburg, Illinois. High amplitude of curve in west half of traverse is caused by grounded electric service (REA) poles. Maximum intensity peaks occur opposite ungrounded poles, minimum peaks opposite grounded poles.

Topographic Shadow Effect

The only significant signal anomaly caused by topography in Illinois can be called a topographic shadow effect. This shadow effect, resulting from a barrier to signal propagation, is well illustrated in figures 18, 19, and 20. The map (fig. 18) shows the Shawneetown Hills and station points along the traverses. Signal intensity was recorded continuously as a traverse was run from south to north (stations 600-601-602-603) around the east side of the hills. A control traverse (fig. 20) was run from north to south over the hills (fig. 18, stations 264-263-614-615). The signal measured, on both traverses, was

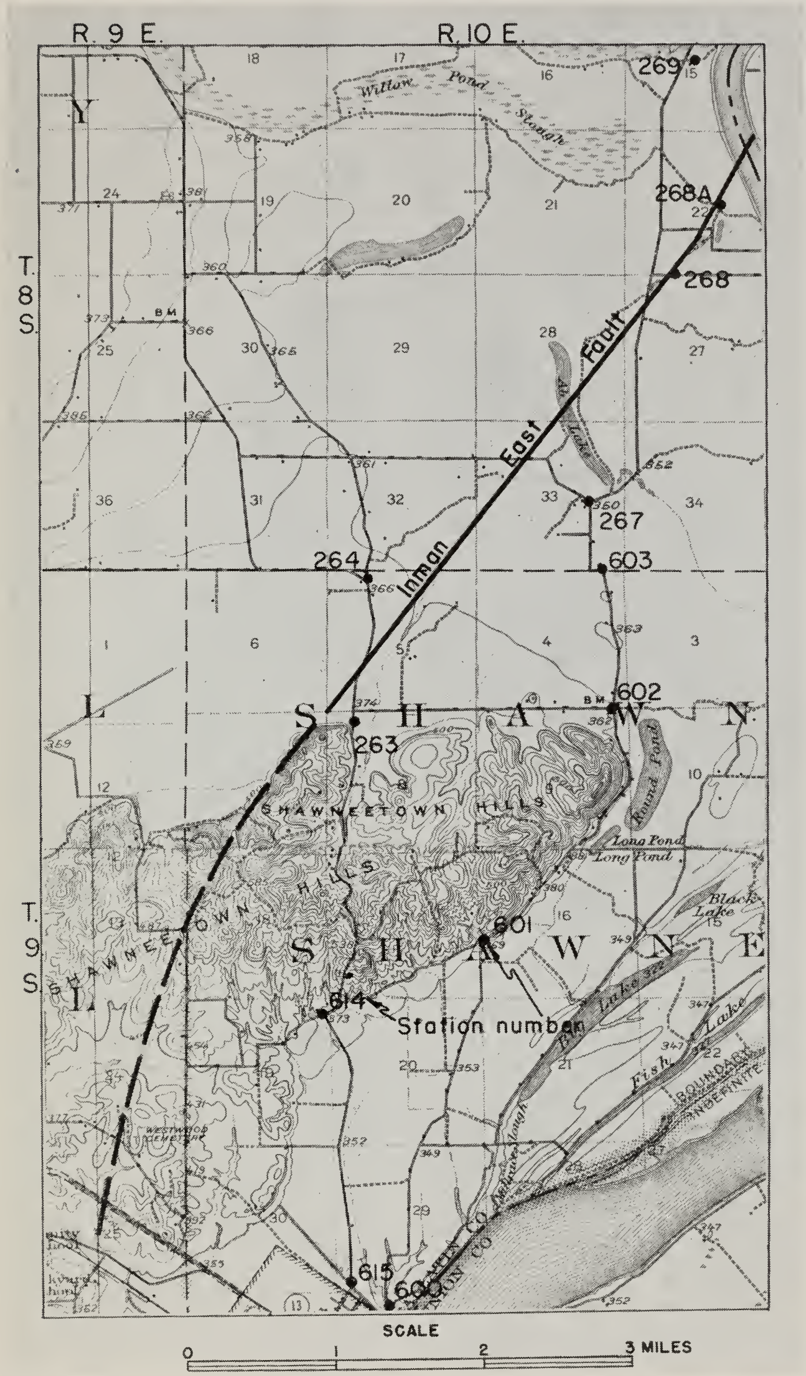


FIG. 18.—Topographic map of Shawneetown Hills area, Gallatin County, Illinois. Traverses were run along roads between the numbered points (map reference station numbers).

from WEBQ, Harrisburg, Illinois, 22 to 23 miles to the west.

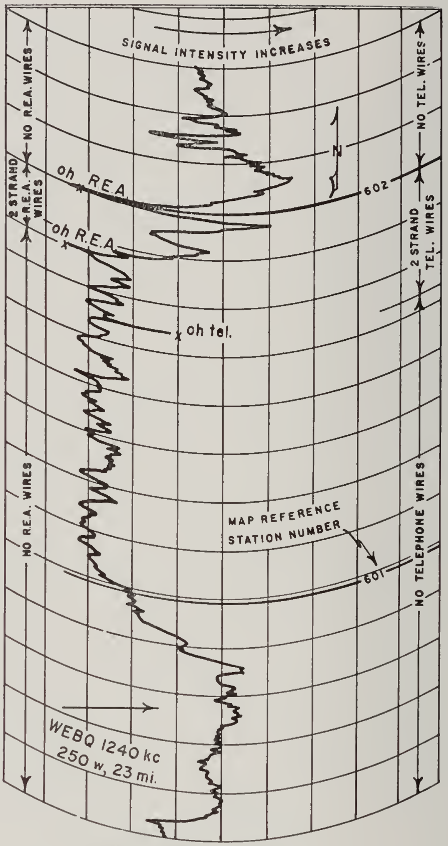
Signal intensity on the traverse around the hills (fig. 19) shows a decided decrease between station 601 and 602. Here the Shawneetown Hills come directly between the antenna of WEBQ and the measuring equipment along the traverse. North and south of the hills (out from behind them) signal intensity increases strongly.

In comparing the curves of the two traverses it should be remembered that the first was run from south to north and the second from north to south. Signal intensity along the control traverse is slightly higher north and south of the hills than it is on the hills. The intensity decrease on the hills may be due to either the geology, which differs from that of the Ohio River flood plain, or perhaps to attenuation by woods and vegetation on the hills. The significant feature of the curve is the apparent absence of any signal anomaly due to topographic influence. If topography exerted any great influence one might expect a strong signal increase on top of the hill, which rises about 200 feet above the surrounding Ohio River flood plain.

SUMMARY

Hundreds of miles of recorded field intensity measurements at broadcast frequencies in Illinois have shown that small topographic relief (20 to 60 feet) has little or no influence on signal strength. In areas of greater relief (60 to 400 feet), except for the topographic shadow effect, signal anomalies resulting from topographic influence appear, in general, to be insignificant. Where they are significant, it is difficult to assign the cause of the anomaly solely to topographic influence because in such areas geologic conditions sometimes change rapidly within short distances and may be the chief cause of an anomaly.

Concerning topographic influence, Kerwin concludes:[5]



ILLINOIS STATE GEOLOGICAL SURVEY

FIG. 19.—Signal intensity curve recorded in the Shawneetown Hills area, Gallatin County, Illinois. Intensity decrease between stations 601 and 602 caused by a shadow effect of the hills. Arrow above "WEBQ" indicates direction of signal arrival.

> It was also observed that topography appeared to have relatively little effect. In driving over stretches of country in Arlington where the geology was uniform, the field remained essentially constant except for manhole effects, etc., whether the receiver was passing over rolling hills, proceeding through cuttings, or on level ground. A notable exception was observed on top of Pine Hill, a prominence beside the Medford Dike and very close to the transmitting antenna of the broadcasting station being recorded. At the top of the hill the signal was extremely strong, but it weakened considerably as the bulk of the mountain was interposed sharply between the receiver and transmitter.

At broadcast frequencies and lower, the topographic effect on signal intensity in Illinois is not appreciable. Apparently, topographic effect increases with increase in frequency until at very high frequencies (30 to 300 mc), ultra-high frequencies (300

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[5] Kerwin, Larkin, Use of the broadcast band in geologic mapping: Jour. Applied Physics, vol. 18, no. 4, p. 413, April 1947.

to 3000 mc), and super-high frequencies (3000 to 30,000 mc) even a small knoll may produce a dead spot (area of no field strength) behind it.[6]

SHADOW EFFECT FROM WOODS

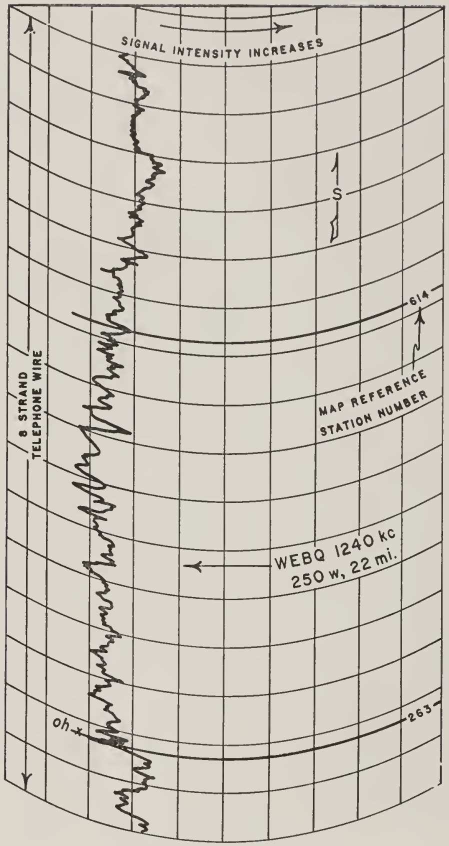
Description of Area IV

In Area IV, four miles west of Monticello, Illinois, a series of traverses was run between stations 346 and 347 (fig. 21) to investigate the influence of trees on signal intensity. The 10 broadcast transmitters ranged in power from 250 to 50,000 watts, in frequency from 550 to 1580 kc, in distance from 17 to 140 miles, and the signals had widely separated directions of arrival. The 3960-foot traverse was run from south to north on a secondary gravel road. The bedrock immediately underlying the traverse area is McLeansboro or Carbondale of the Pennsylvanian system, and the area is about 15 miles west of the axis of the LaSalle anticline. Here the bedrock is part of the south slope of a large buried valley, the Mahomet, which is considered preglacial.[7] The glacial drift thickens from about 300 feet (sta. 346 at the south) to approximately 400 feet (sta. 347 at the north), as the traverse crosses the south wall toward the center of the valley. The area investigated is covered by ground moraine, with 10 feet of topographic relief along the 3960-foot traverse, and lies about five miles west of the Cerro Gordo recessional moraine.[8]

Interpretation of the ten signal intensity curves recorded along this traverse show or suggest the following conclusions:—

Signals measured after they have come through the woods show:

1. Little or no attenuation for frequencies lower than 1000 kc.
2. Progressively greater attenuation for signals higher than 1000 kc.
3. Signals measured near the fringe edge of their primary coverage area are not a good test for attenuation by woods, as part of the arriving signal may be propagated by components other than ground-wave.



ILLINOIS STATE GEOLOGICAL SURVEY

FIG. 20.—Signal intensity curve recorded in the Shawneetown Hills area, Gallatin County, Illinois. Slight decrease in field intensity between stations 263 and 614 occurs on the hills.

Signals measured before they entered the woods show:

1. Decreased intensity along the margin of the woods, possibly the result of reflection or absorption at the boundary of the woods.

Signals measured arriving from all directions show:

1. Decreased intensity at margin of woods.
2. Individual trees along the roadside (fig. 21) cause no noticeable influence upon signal intensity.

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[6] Morecroft, J. H., Principles of radio communication: New York, John Wiley, 3rd ed., pp. 372-380, 1944.

[7] Horberg, Leland, A major buried valley in east-central Illinois and its regional relationships: Jour. Geol., vol. 53, no. 5, 1945; reprinted as Illinois Geol. Survey Rept. Inv. 106, p. 353, 1945.

[8] Leighton, Ekblaw, and Horberg, *op cit.*, p. 22.

The influence of the geologic component is uncertain and probably not significant. If bedrock and moraine conditions in the preglacial valley exert any influence on signal intensity it cannot be recognized as such in the recorded curves.

STREAMS

In Area III the line along which signal intensities were measured crosses a small stream nearly at right angles (fig. 16). Field intensity decrease over the stream was recorded for signals arriving from north-south directions (Chicago and St. Louis), 120 and 140 miles distant. Field intensity increase over the stream was recorded for all other signals (arriving from east-west directions), 4 to 80 miles distant. Signal arrival with respect to stream orientation and possibly distance appear to govern the type and magnitude of intensity variation over the stream rather than frequency or power of the signals.

Collateral observations indicate that stream-caused signal anomalies (either increase or decrease) are usually sharp but of relatively small magnitude.

BURIED PIPES

The influence of buried pipelines on signal intensity is not established. Along the traverses run in Illinois numerous pipelines were crossed, but in each instance the signal intensity anomalies caused by nearby electric, telephone, or transmission wires, overrode those of the pipelines. If signal intensity measurement across a pipeline could be made in the absence of overhead wires and other hazards, a small to medium anomaly might be expected. The anomaly would be either an intensity increase or decrease depending upon orientation of the long axis of the pipeline in the radio field being measured.

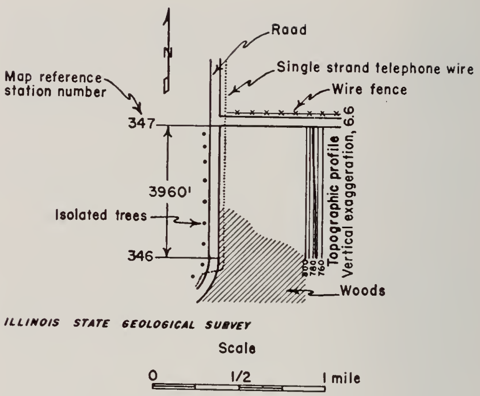

Fig. 21.—Natural and cultural features along line of traverse (Area IV, 4 miles west of Monticello, Illinois).

ROAD MATERIALS

Signal intensity is apparently not influenced by dirt, gravel, or tar roads. Numerous traverses along roads changing from dirt to gravel to tar showed little if any variation in signal intensity. Crossing a reinforced concrete highway would probably cause an intensity anomaly, but where such roads were crossed, associated wires seemed to override completely any anomaly caused by the differences in material surfacing the highways.

LAKES AND PONDS

The influence of lakes and ponds on signal intensity is not certain. Because of scarcity of lakes and ponds in the areas investigated, and the lack of good field conditions for measuring signal intensity around them, it was difficult to ascertain their influence. Bodies of water can be expected to influence signal intensity in varying degree, depending upon their size, shape, chemical composition, and orientation with respect to direction of arrival of the signal.

CHAPTER 7—EFFECTS OF METEOROLOGICAL CONDITIONS

Meteorological conditions appear to exert only a small influence on radio waves at broadcast frequencies, in primary ground-wave coverage areas, over short periods (fig. 8). However, they are known to influence radio waves of low frequency (long waves) over long time intervals, and waves of high frequency (short waves) over small time intervals. There are seasonal variations on long-wave signal intensity, the greatest signal strength usually being observed during the winter months.[1]

Morecroft,[2] describing a two-year field strength record of a long-wave transatlantic signal, reports no evident correlation between magnetic storms and field intensity. He does report an evident correlation between the number of sunspots and average field intensity, with field strength greater during solar activity.

Short waves have small ground-wave coverage areas. Their chief value in communications is their ability to travel great distances via sky-wave propagation paths. Short-wave signals are influenced greatly by cycles of solar activity, and may become severely attenuated during magnetic storms.

Gracely,[3] in his work on variations of ground-wave signal intensity at standard broadcast frequencies, attempted to correlate variations with temperature, precipitation, humidity, atmospheric pressure, dew point, and vapor pressure. He concludes there is closer and more continuous correlation with temperature than with any other meteorologic feature.

Most of Gracely's signal intensity measurements were spot readings, on six different paths, made at 1:30 P.M., E.S.T., daily or every fourth day, for periods of nine months to four years. He discovered that intensity variation was greater over long paths (up to 558 miles) than over short paths (down to 76 miles). Precipitation along the paths investigated frequently correlated with marked increases in signal intensity which remained for several days following periods of heavy rainfall. However, there were other periods of rainfall when no such signal intensity increase was observed. This led to investigation of ground moisture, along the various paths, taking into account the rates at which the ground gains moisture from precipitation and loses it by runoff and evaporation. The application of this analysis led only to another partial correlation. A few local coincidences between signal intensity and humidity were observed but also permitted only partial correlation.

In attempting to correlate signal intensity variation with temperature, the effects of vegetation along the paths, and effects of the gradient of the index of refraction of the lower troposphere were considered. Although some correlations between vegetation and signal intensity may be possible, vegetation alone is not responsible for the variations recorded. Similarly, it is difficult to explain the regular intensity-versus-temperature observations in terms of a lower tropospheric reflected wave component which is varying irregularly in height of reflection and length of path.

For ground-wave signal intensity at standard broadcast frequencies the following generalizations, according to Gracely, appear to be established with reasonable certainty: signal intensities decrease at higher temperatures; this decrease becomes greater with distance.

In field experimentation Kerwin[4] employed a stationary monitoring field intensity meter and obtained continuous field intensity

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[1] Morecroft, J. H., Principles of radio communication: New York, John Wiley, 3rd ed., p. 381, 1944.

[2] *Idem.*, pp. 383-385.

[3] Gracely, F. R., Temperature variations of ground-wave signal intensity at standard broadcast frequencies: Proc. Inst. Radio Eng., vol. 37, no. 4, pp. 360-363, April 1949.

[4] Kerwin, Larkin, Use of the broadcast band in geologic mapping: Jour. Applied Physics, vol. 18, no. 4, pp. 409-413, April 1947.

records on an Esterline-Angus recording milliammeter. He found that in general, the fields were stronger during rainy weather, and less affected by geology. He concluded that for periods of three to four hours, with constant weather and daylight conditions, the field remained steady.

Figure 8 is a typical curve recording variation in field intensity of ground-wave at a fixed location. These curves sometimes exhibit no more variation over a period of eight hours than they do for one hour. However, eight-hour curves occasionally exhibit minor variations, usually in the form of slow, gradual shifts in intensity.

Most of the traverses for the present work were run in periods five minutes to half an hour long. The longest traverses, run at speeds up to 45 miles per hour, took about one hour. Thus it appears that, with reasonably constant weather conditions for short periods of time, signal intensity is probably not significantly influenced by temperature or other meteorologic features.

One exception to the preceding generalization is the instantaneous intensity change caused by natural electromagnetic phenomena. These phenomena cause momentary bursts of high signal intensity. A common example is the burst of noise (static) which accompanies a lightning flash during a thunderstorm. This type of interference is common at broadcast frequencies, is especially evident at low frequencies (100 to 400 kc), but is less noticeable at high frequencies.

An intensity curve recorded from station WILL (580 kc) (fig. 23) fails to show static bursts (summertime fair-weather static) because they were not large enough to deflect the recording pen, although they were heard while monitoring the signal. A curve from radio range station AF (317 kc) (fig. 26), run along the same traverse 15 minutes later, shows the effect of almost continuous static bursts. Such intensity anomalies are not likely to be confused with those caused by field hazards or geologic conditions because the static-induced anomalies are characteristically instantaneous bursts of increased intensity. They are also readily identifiable when monitoring the signals with headphones.

Repeated runs over selected traverses, days, weeks, months, and years apart, under reasonably constant but different meteorological conditions, did not reveal any noticeable variations from the general character of the relative field intensity curves, as measured with the RCA 308-B field intensity meter.

CHAPTER 8—EFFECTS OF GEOLOGIC FEATURES

The experimentally obtained data on the influence of cultural, natural, and meteorological features on signal intensities provide a starting point for investigation of geologic influence. The problems of ascertaining geologic effects on signal intensities are, first, separating them from effects of field hazards and, second, making reasonable correlations with geology. Obviously, the effects of all field hazards have not been completely investigated, but it now appears possible to recognize and correlate some geologic effects.

Radio engineers have long held the concept that radio waves penetrate only shallowly into the earth's surface.[1] One of the methods of calculating the constants of the earth along a path consists of taking samples of the earth and measuring their conductivities and dielectric constants.[2] It would appear, as the result of tests with cave and mine communications, that radio waves do penetrate and are transmitted through some bedrock. Thus, it seems logical to postulate that abrupt changes in physical and structural characteristics of the rock strata may cause observable intensity and perhaps other changes in the radio field. If the electromagnetic field is partly in the air and partly in the ground, a change in the part of the field below the surface may be reflected in the air over the earth's surface and be measurable.

The following field examples have been selected from many hundreds of miles of traverse as representative of the effects of a variety of geologic situations upon field intensity. These examples demonstrate not only the geologic effects, but also limitations of the method.

FAULTING

Stratigraphic and lithologic discontinuity of the type usually presented by faulting might be expected to cause signal intensity anomalies. To appraise these effects, field hazards, if present, must be recognized and their influence accounted for.

Signal intensity was recorded across faults in Gallatin, White, Hardin, Pope, Johnson, Union, Jackson, Williamson, and Franklin counties, Illinois. Signal intensity associated with some of these faults was apparently unaffected, with some it may have been influenced slightly, while with others there appeared to be a strong influence. An intensity anomaly may be associated with a fault when lithologic discontinuity also offers electrical, chemical, or magnetic discontinuity to the field. Where fault structures were traversed, field intensity anomalies were most often associated with lithologic discontinuity. This is illustrated by the Shawneetown fault in Illinois (figs. 22-25), where signal intensity is commonly higher on the side of the fault nearest the transmitter.

SHAWNEETOWN FAULT IN ILLINOIS

A major fault zone, known as the Shawneetown in Illinois, trends from east to west across part of Illinois and Kentucky. This fault in southern Illinois was selected to test geologic influence on radio field intensity. According to Butts,[3] there is as much as 2,300 feet of displacement along the north side of Gold Hill (secs. 27 and 28, T. 9 S., R. 8 E.), Gallatin County, where Pennsylvanian beds of the Tradewater group to the north are in contact with Mississippian Ste. Genevieve limestone to the south. At Horseshoe Gap, three miles southwest of Equality, the relative displacement along the fault is not less than 3500 feet.

Numerous traverses, using signals from different stations, were run across the Shawneetown fault. Figure 22 shows the

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[1] Terman, F. E., Radio engineers handbook, New York, McGraw-Hill, 1st ed., p. 698, 1943.

[2] *Idem.*, p. 709.

[3] Butts, Charles, Geology and mineral resources of the Equality-Shawneetown area: Illinois Geol. Survey Bull. 47, pp. 58-59, 1925.

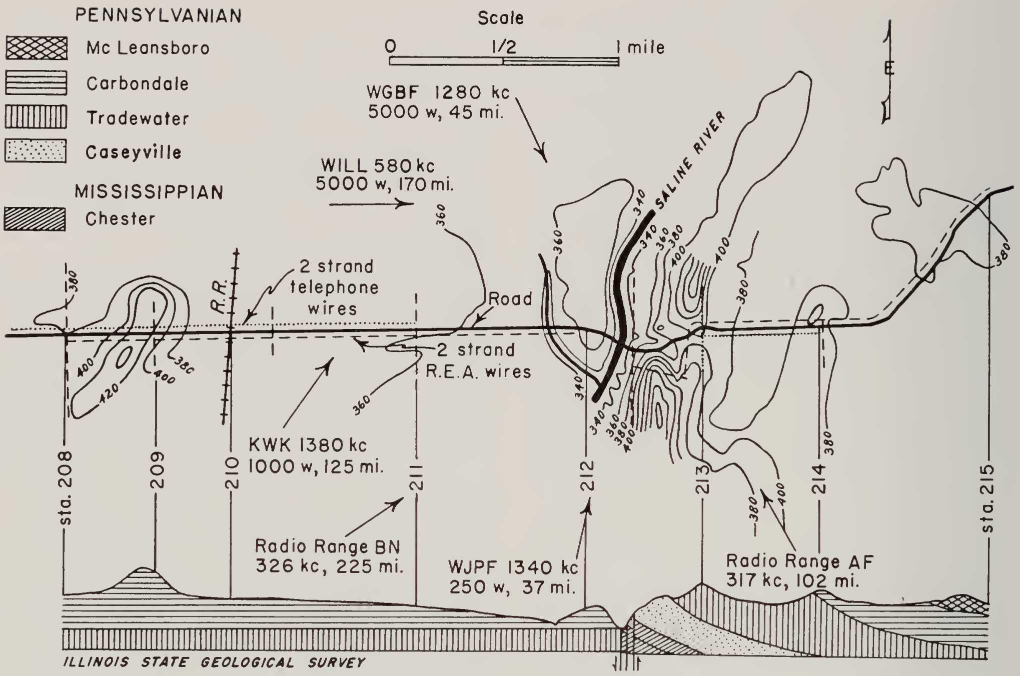


FIG. 22.—Route of traverse (along Illinois Highway 1) across the Shawneetown fault in Gallatin County, showing topographic contours, potential field hazards, and radio broadcast station data.

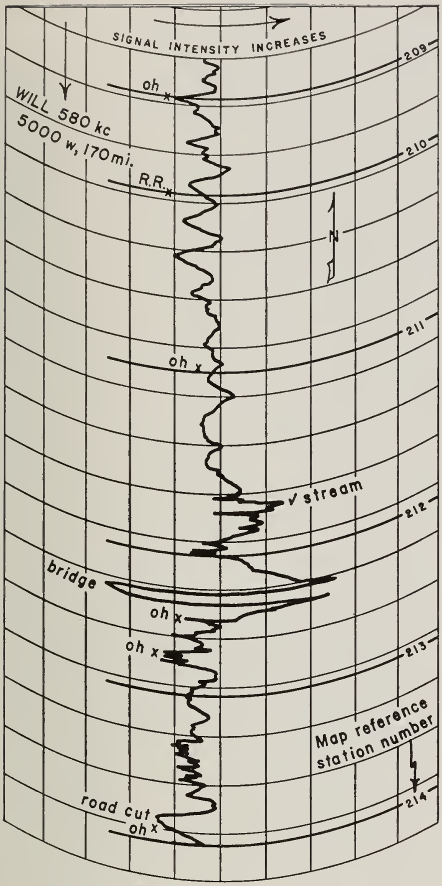
route of one of the traverses. Station 208 is at the junction of Illinois highways 13 and 1, about three miles east of Equality. Running south, station 210 is at the junction of Route 1 and the L & N railroad; station 212, just north of the Saline River; station 215, about two miles northwest of Gibsonia. The contour lines crossing the route along which the traverse was run (Illinois Highway 1) are topographic. The potential field hazards, electric and telephone wires, railroad tracks, streams, and bridges, are indicated. The geologic section has been generalized from Butts. The arrows beside the radio station data indicate the directions of signal arrival.

SIGNAL FROM BROADCAST STATION WILL

The signal from WILL, Urbana, Ill., 170 miles to the north (fig. 23), shows a fairly constant intensity level north of the fault, except for the influence of electric and telephone wires and the metal bridge approximately at the fault trace. South of potential field hazards, electric and telephone wires is still evident, but the general signal intensity drops off. The WILL transmitting antenna is on ground underlain by Pennsylvanian strata, and the 170-mile signal path from Urbana to the area of traverse is underlain by Pennsylvanian rocks. Crossing the fault, the radio field (above, along, and possibly carried by Pennsylvanian strata and glacial drift) encounters a geologic discontinuity as Pennsylvanian strata abut against Mississippian beds. The exact effect of the discontinuity on signal intensity cannot be differentiated from the influence of the metal bridge. However, the lower signal intensity level south of the fault is interpreted as influenced by the fault.

SIGNAL FROM BROADCAST STATION KWK

The signal from KWK, St. Louis, Mo., 125 miles northwest (fig. 24), shows (except for the influence of cultural features) fairly constant intensity levels in this area. The signal level north of the fault is noticeably higher than the level south of the fault. The influence of the fault on signal intensity is confused with the influence of



ILLINOIS STATE GEOLOGICAL SURVEY

FIG. 23.—Signal intensity curve of WILL recorded across the Shawneetown fault, Gallatin County, Illinois. Intensity decrease is evident south of the fault (see fig. 22).

the metal bridge, which is situated close to the fault trace. However, the lower signal intensity south of the fault suggests influence by the fault.

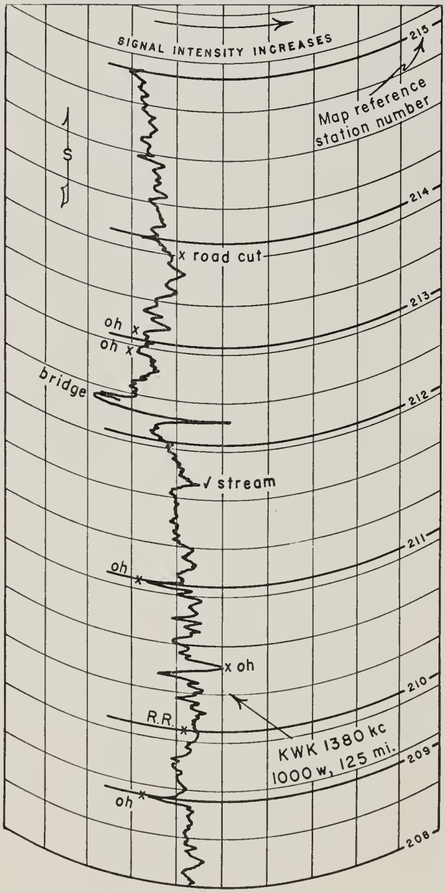
SIGNAL FROM BROADCAST STATION WJPF

The signal from WJPF, Herrin, Ill., 37 miles west and slightly north of the traverse (fig. 25), also shows fairly constant intensity levels, except for the influence of cultural features. The WJPF transmitter is northwest of the fault, on terrain underlain by Pennsylvanian strata. The signal level north of the fault is considerably higher than that to the south. The decrease in intensity at the bridge masks the influence of the fault, but the fault may cause lower intensity to the south.

SIGNAL FROM RADIO RANGE STATION AF

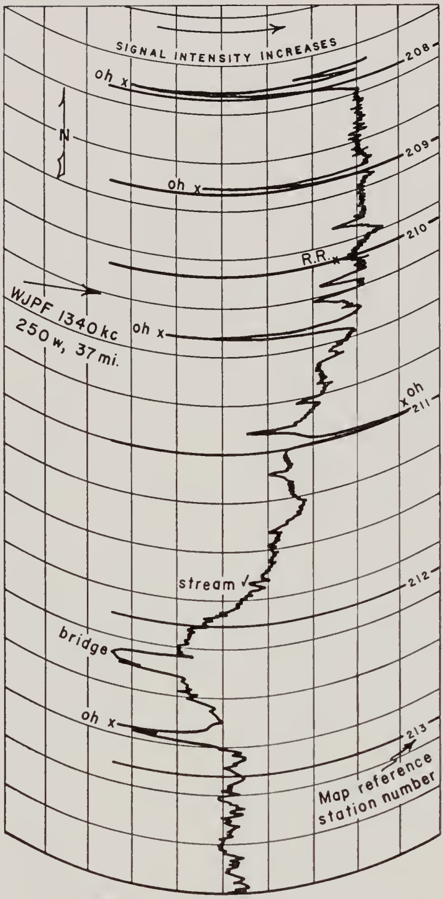
The signal from radio range station AF, Advance, Mo., 102 miles southwest, is transmitted at 317 kc. The numerous sharp intensity peaks (fig. 26, to the right) represent bursts of static and noise. An almost continuous crackling, popping, and rushing noise was heard in the headphones while monitoring the signal along the traverse. This is characteristic of reception of low frequencies with low signal intensities in summer weather.

Signal level decreases at the bridge and immediately to the south, and also in the vicinity of the railroad tracks. Influence on signal intensity by the fault is not readily apparent. The slight decrease of in-



ILLINOIS STATE GEOLOGICAL SURVEY

FIG. 24.—Signal intensity curve of KWK recorded across the Shawneetown fault, Gallatin County, Illinois. Intensity decrease is evident south of the fault (see fig. 22).



ILLINOIS STATE GEOLOGICAL SURVEY

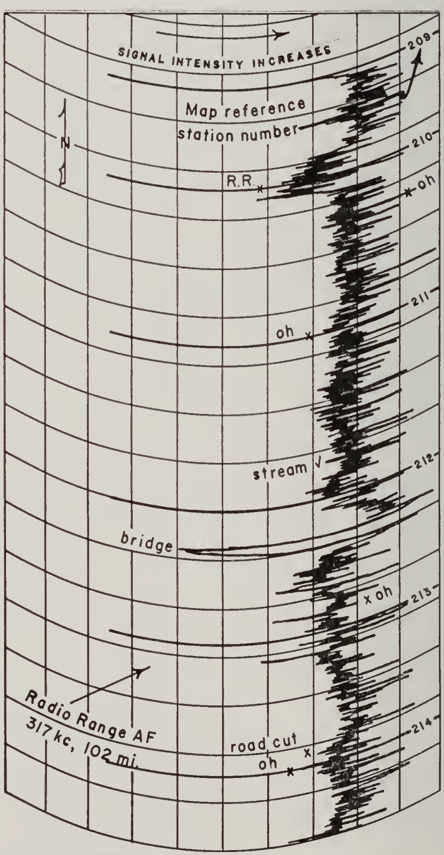
FIG. 25.—Signal intensity curve of WJPF recorded across the Shawneetown fault, Gallatin County, Illinois. Intensity decrease is evident south of the fault (see fig. 22).

tensity immediately south of the bridge is the only obvious anomaly on the curve that cannot be solely accounted for by either cultural or meteorological effects. If the fault trace was not close to the bridge, the decrease could possibly be assigned to the bridge influence alone, but under the circumstances the anomaly is assigned to both bridge and fault influence. It is possible that a signal at low frequency (317 kc) with this orientation is not as strongly influenced by this fault as signals at higher frequencies.

SHAWNEETOWN FAULT IN KENTUCKY

Before investigating the Shawneetown fault in Illinois, it was considered likely that this major structure would cause a major variation in signal strength. Preliminary field investigation across the Shawneetown fault, with reconnaissance-type equipment, and spot readings 330 feet apart, revealed large signal anomalies. Subsequent continuous traverses across the fault show that spot readings, unless removed from field hazards, can be misleading.

The comparatively small signal anomalies, recorded on continuous traverses across the fault, may be due to a general signal attenuation by field hazards. Electric and telephone wires parallel the road and pass overhead; railroad tracks, a stream, and a river cross the traverse, and the traverse itself winds over terrain with about 80 feet of topographic relief. Perhaps the lack of



ILLINOIS STATE GEOLOGICAL SURVEY

FIG. 26.—Signal intensity curve recorded across the Shawneetown fault, Gallatin County, Illinois. The intensity decrease immediately south of the bridge is the only obvious anomaly that may be due in part to the influence of the fault.

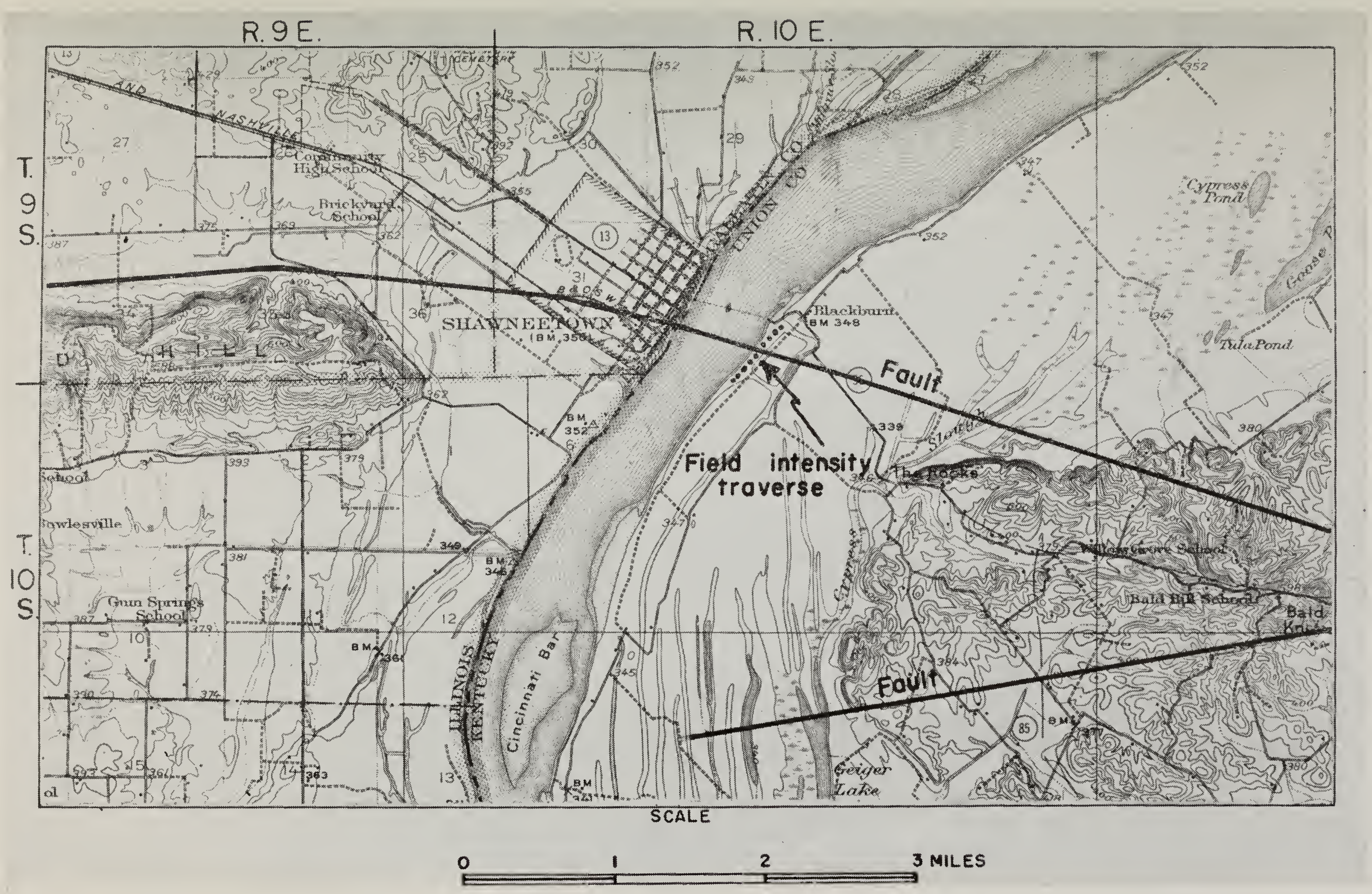
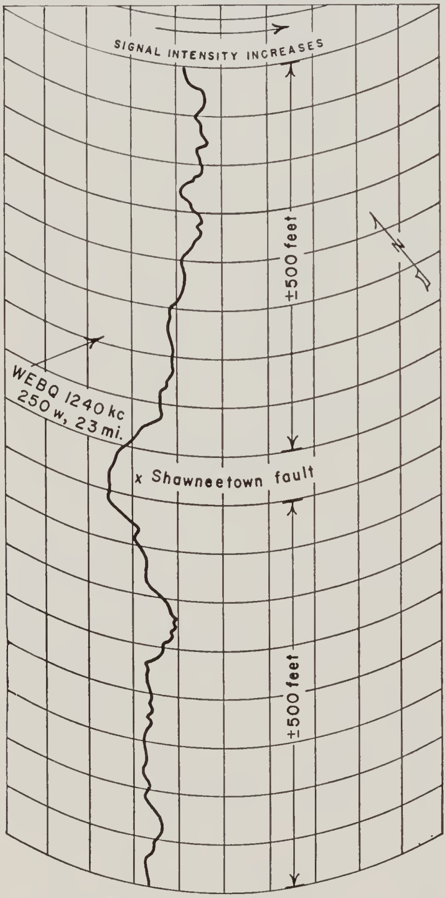


FIG. 27.—Location of field intensity traverse across the Shawneetown fault, on the Ohio River bottoms in Kentucky.

large signal strength anomalies across the fault should be no more surprising than the small anomalies that were recorded in the midst of field hazards. The anomalies (figs. 22-26), though smaller in magnitude than might be expected, appear to be the results of fault influence.

It was desirable to further substantiate the Shawneetown fault influence on signal strength by crossing it, if possible, where there were no associated field hazards. Accordingly a location was chosen on a level alluvial plain along the Ohio River bottoms in Kentucky (fig. 27). The plain was about car-roof height in corn at the time of the traverse. Thus, the factors of soil, topography, and vegetation were uniform. Figure 28 shows the curve recorded along this traverse. The signal was from WEBQ, Harrisburg, Ill., 23 miles west and slightly north. The transmitting antenna is north of the fault on terrain underlain by lower McLeansboro beds of the Pennsylvanian system.



ILLINOIS STATE GEOLOGICAL SURVEY

FIG. 28.—Field intensity curve recorded along traverse across the Shawneetown fault, on Ohio River bottoms in Kentucky.

The curve shows an intensity decrease near the fault, and general field intensity is higher north of the fault. In the entire length of the traverse (more than a mile) there is only the one major anomaly (fig. 28). The signal path from WEBQ partly parallels or coincides with the strike of the fault. If a signal from the north or south were used (with the signal path at a high angle to the strike of the fault), the effect of the geologic discontinuity on that signal might be greater and the signal strength anomaly stronger. This traverse (fig. 28) is interpreted as unquestionably demonstrating geologic influence on signal intensity.

INMAN EAST FAULT

Traverses across the Inman East fault, Gallatin County, Ill. (fig. 18), yielded the common type of signal anomaly with intensity higher on the side of the fault closer to the transmitter. They also yielded a special type of anomaly which may result from some of the electromagnetic field being transmittted by limestone beds.

The Inman East fault trends northeast-southwest across the Ohio River bottoms in Gallatin County (fig. 18). The stratigraphic throw ranges from approximately 200 to 400 feet. The downthrown strata are on the east side of the fault. Intersection of the major plane by drill holes in the Inman East oil pool (secs. 11, 14, T. 8 S., R. 10 E.) indicates a dip of about 60 degrees to the southeast.[4] In the area of the traverses, alluvial and outwash glacial debris is approximately 100 to 150 feet thick; the underlying lower McLeansboro rocks (Pennsylvanian) present a surface of gentle relief; the near-surface beds involved in faulting range from No. 6 coal bed to 50 feet above the West Franklin limestone (250 feet above No. 6 coal bed).

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[4] Pullen, M. W., Subsurface geology of Gallatin County north of the Shawneetown fault: *In* Illinois Geol. Survey Rept. Inv. 148, 1951.

Field intensity using the signal from WJPF (250 watts, 1340 kc), 46 miles west of the fault trace, was lower east of the fault than west. Field intensity from WGBF (5000 watts, 1280 kc), 30 miles northeast of the fault, was lower on the west than on the east side, but the intensity immediately east of the fault was considerably higher than elsewhere on the east side within a few miles of the fault. Two explanations of the anomaly are suggested: first, intensity is increased by reflection of part of the field at the structural discontinuity or by excitation of the structure; second, intensity is reinforced at the fault by that part of the field which is transmitted from the east to the fault plane by the West Franklin limestone. The first explanation is compatible with radio theory. If the second explanation is valid it may operate alone or in combination with the first.

The transmitting antenna of WGBF, at Evansville, Ind., is on or close to the outcrop of the West Franklin limestone. The limestone, with some faulting, extends southwest and abuts along the Inman East fault plane at depths of 150 to 300 feet on the east (downthrow) side. In Schlumberger electric logs the West Franklin limestone has high apparent resistivity as compared to strata above and below the limestone. Because of the thickness of the limestone in relation to the electrode configuration, it is probable that there is even greater resistivity contrast in true in-place resistivities. Electric logs of some holes that intersect the fault indicate that the material along the fault plane itself has higher electrical resistivity than adjacent shales, siltstones, and sandstones.

In several wells, the surface pipe is seated and cemented in the West Franklin limestone (Carter Oil Co., E. H. Busick C-87, sec. 11, T. 8 S., R. 10 E.), thus directly connecting the limestone strata with the surface of the ground.

The limestone offers the emitted radio field a comparatively high resistance path. Kerwin[5] demonstrated high field intensity associated with rocks of high electrical resistivity and low intensity with rocks of low resistivity. The increase in intensity close to the Inman East fault, as compared to intensity measured in the air path away from the fault, might be the result of bridging between the West Franklin limestone (carrying part of the field in the ground from Evansville) and the surface either by the cemented metal surface pipe in the drill holes or by high resistance material along the fault plane, or both.

If the intensity anomalies across the Inman East fault are valid expressions of geologic influence on field intensity, then bedrock structure influence is making itself felt through 100 to 150 feet of alluvium and glacial outwash.

CRYPTOVOLCANIC STRUCTURE NEAR KENTLAND, INDIANA

Geologic Setting

The Kentland cryptovolcanic structure lies between the towns of Kentland and Goodland, Newton County, in northwestern Indiana. Here, disturbed Ordovician rocks cropped out (before quarry operations) in a flat glacial plain. The largest of these quarries (McCray) lies about 200 feet south of U. S. Highway 24 in sec. 25, T. 27 N., R. 9 W. (fig. 30). The disturbed Ordovician rocks have been described by Shrock and Malott;[6] the history and evolution of geologic thinking has been summarized and the stratigraphy and structure have been described by Shrock;[7] and the paleontology of the rocks has been discussed by Shrock and Raasch.[8]

Field intensity surveys were run over this area to ascertain if disturbed Ordovician rocks (apparently pushed up through younger overlying strata) had any measurable influence on signal intensity.

The topography of the area is that of a level glacial drift plain. The drift thick-

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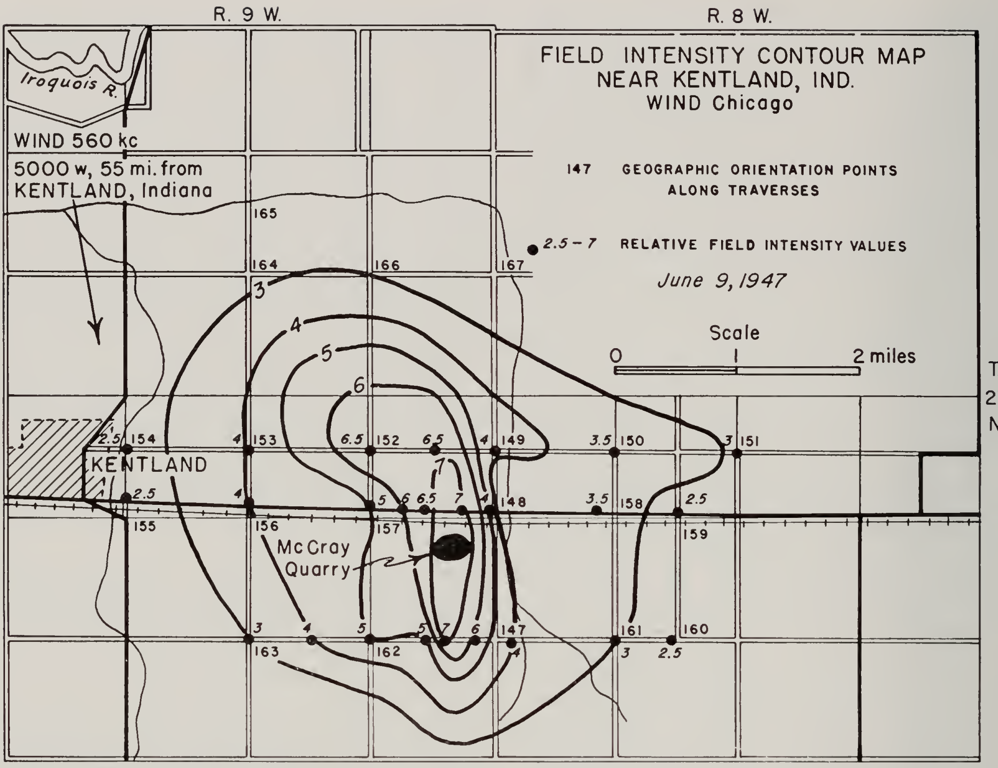
[5] Kerwin, Larkin, Use of the broadcast band in geologic mapping: Jour. Applied Physics, vol. 18, no. 4, p. 412, April 1947.

[6] Shrock, R. R., and Malott, C. A., The Kentland area of disturbed Ordovician rocks in northwestern Indiana: Jour. Geol., vol. 41, no. 4, pp. 337-370, 1933.

[7] Shrock, R. R., Stratigraphy and structure of the area of disturbed Ordovician rocks near Kentland, Indiana: Am. Midland Nat., vol. 18, no. 4, pp. 471-531, 1937.

[8] Shrock, R. R., and Raasch, G. O., Paleontology of the disturbed Ordovician rocks near Kentland, Indiana: Am. Midland Nat., vol. 18, no. 4, pp. 532-607, 1937.



ILLINOIS STATE GEOLOGICAL SURVEY

FIG. 29.—Field intensity contour map near Kentland, Indiana (Sta. WIND).

ens in all directions away from the quarries in the cryptovolcanic rocks. Drill-hole data indicate a maximum thickness of 160 feet locally.

The geological map of Indiana (1932)[9] shows the quarry area surrounded by Devonian (New Albany) strata, with Mississippian (Osage) immediately east and south. On the basis of fauna found in the quarries, Raasch and Bays[10] consider most of the exposed disturbed Ordovician strata Black River and Trenton in age.

Shrock[11] considers the disturbed Ordovician rocks an inlier surrounded by Silurian, Devonian, Mississippian, and possibly Pennsylvanian strata. He believes that most or all of the disturbed Ordovician strata exposed in the present quarries have been uplifted at least 1500 feet. The uplift caused faulting, fracturing, shattering, and brecciation of the strata. The Ordovician away from the quarries assumes its normal regional attitude.

Logan reported a well at Kentland[12] about three miles west of the quarry area that penetrated 100 feet of glacial drift, 145 feet of Devonian, 305 feet of Silurian, and 570 feet of Ordovician strata. If the present exposed upstanding mass of disturbed Ordovician rocks is the result of a post-Silurian or Devonian diastrophism, then it was forced up through the overlying Silurian or Silurian-Devonian strata. If the diastrophic incident was post-Ordovician–pre-Silurian, it is possible that part of the disturbed Ordovician mass may have been covered by younger sediments. Since the geologic relations at the margins of the disturbed mass are unknown, the age of the diastrophic event cannot be ascertained.

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[9] Logan, W. N., Geological map of Indiana: Indiana Conserv. Comm., Div. Geol. Pub. 112, 1932.

[10] Raasch, G. O., and Bays, C. A., personal communication, 1949.

[11] Shrock, *op. cit.*, p. 517.

[12] Logan, W. N., Economic geology of Indiana: Handbook of Indiana Geology, pt. 5, p. 950, 1922.

Regardless of whether Silurian beds were directly involved in the cryptovolcanic action or were later deposited around or partly over the Ordovician mass, they are probably in direct contact with the upthrown Ordovician mass, or at least not far from it.

FIELD HAZARDS

Field hazards in the area are numerous. Both telephone and electric wires are parallel to and cross the roads. A railroad track runs east and west through the middle of the area (figs. 29, 30). These field hazards cause diverse intensity anomalies, for the most part recognizable.

FIELD INTENSITY MEASUREMENTS

The field intensity curves from radio station WIND, 560 kc, 5000 watts, 55 miles northwest (transmitter at Gary, Ind.), are nearly constant and relatively flat. In general, field intensity decreases sharply beneath overhead wires and increases near and at the cryptovolcanic structure. The map, based on the intensity curves (fig. 29), shows a closed intensity high around the cryptovolcanic structure. The transmitting site of station WIND is on terrain underlain by Devonian and Silurian rocks.

Additional traverses were run over the area using station WDAN, Danville, Ill., 1490 kc, 250 watts, 45 miles south and slightly west of Kentland. Intensity does not change over the cryptovolcanic structure. The transmitter site at Danville is underlain by Carbondale strata of Pennsylvanian age.

The signal from station WDZ, Tuscola, Ill. (now relocated at Decatur), 1050 kc, 1000 watts, 80 miles, 35 degrees west of south, from Kentland, showed a small intensity increase over the cryptovolcanic structure. The WDZ transmitter site is underlain by the crest of the LaSalle anticline, and Devonian-Silurian dolomites are the first bedrock encountered (at depths from 30 to 50 feet). There may be some geologic relationship which causes the signal intensity from WDZ to increase over the cryptovolcanic structure while that of station WDAN remains constant. The frequencies of the two stations are close, the transmitting powers 1000 and 250 watts, but the stronger station is 80 miles away and the weaker only 45 miles. Signal intensity from station WDAN, on Pennsylvanian strata, is not influenced by the Ordovician strata exposed around Kentland. Some of the sedimentary layers between the Pennsylvanian and Ordovician have low electrical resistance, such as shale, and as comparatively good electrical conductors they may act as shields and prevent the radio fields from reaching the Ordovician, Silurian, or Devonian strata below.

Again, two explanations of the anomaly are suggested: first, intensity increases at the structure by reflection or excitation; second, intensity is reinforced at the structure by that part of the field which may be transmitted by the Devonian-Silurian rocks from Tuscola to Kentland where these beds are in contact with the disturbed Ordovician rocks.

FIELD INTENSITY CONTOUR MAPS

A regional survey of the area was made using the signal from station WAAF, Chicago, Ill. Radio station WAAF operates on a frequency of 950 kc, with a power of 1000 watts, and is 75 miles, 15 degrees west of north, from the town of Kentland.

The field intensity map (contours represent measured intensity values) gives a regional picture covering a considerable area around the cryptovolcanic disturbance (fig. 30). The transmitter site is underlain by Silurian strata. Signal intensity in the Kentland area is relatively weak (20 to 30 microvolts per meter) but increases in the vicinity of the cryptovolcanic structure. Field strength calculations for station WAAF in the Kentland area, using the Sommerfeld formula as modified by Van der Pol, indicate an expected field intensity of 20 microvolts per meter or less. This value is found in areas at some distance from the quarries, but at or near the quarries signal intensity reaches 50 microvolts per meter. This intensity anomaly may be explained by reflection and excitation, and/or signal reinforcement through Silurian rocks connecting Kentland and Chicago.

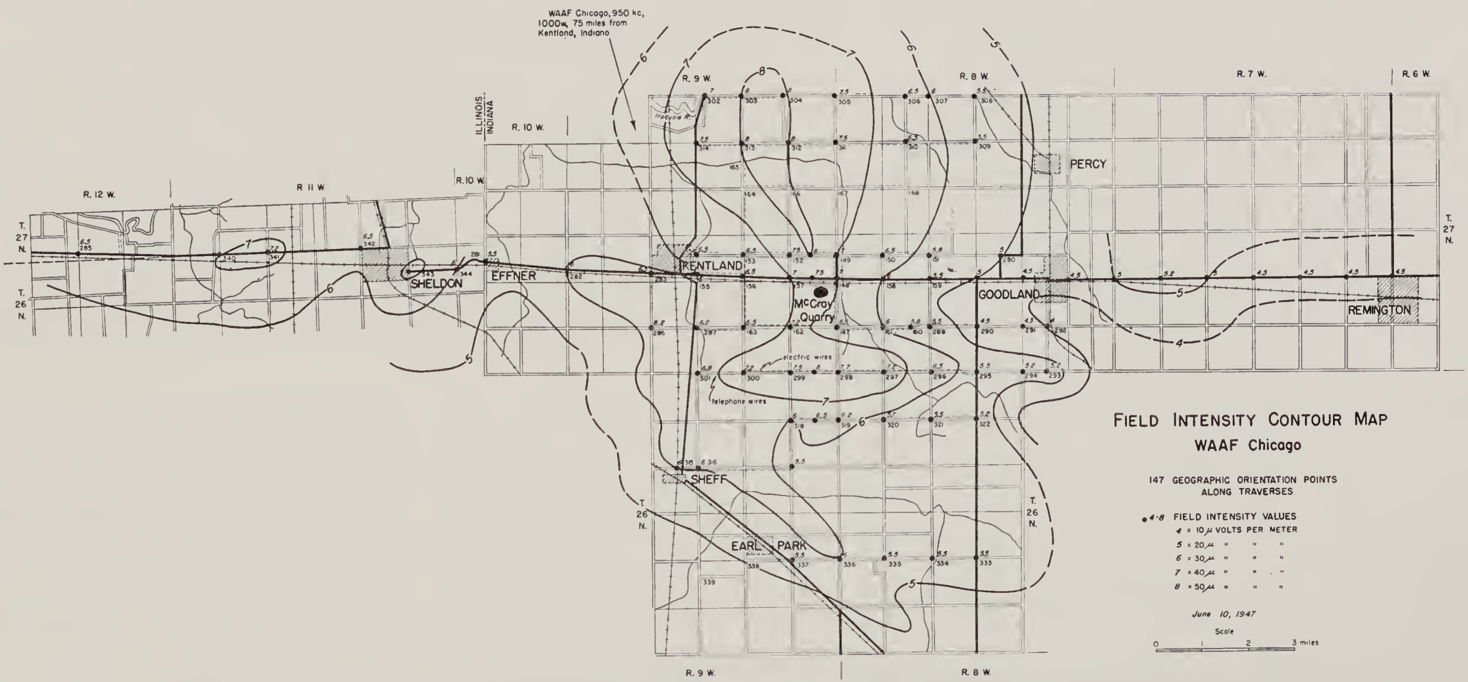

FIG. 30.—Field intensity contour map of Kentland, Indiana, area (Sta. WAAF).

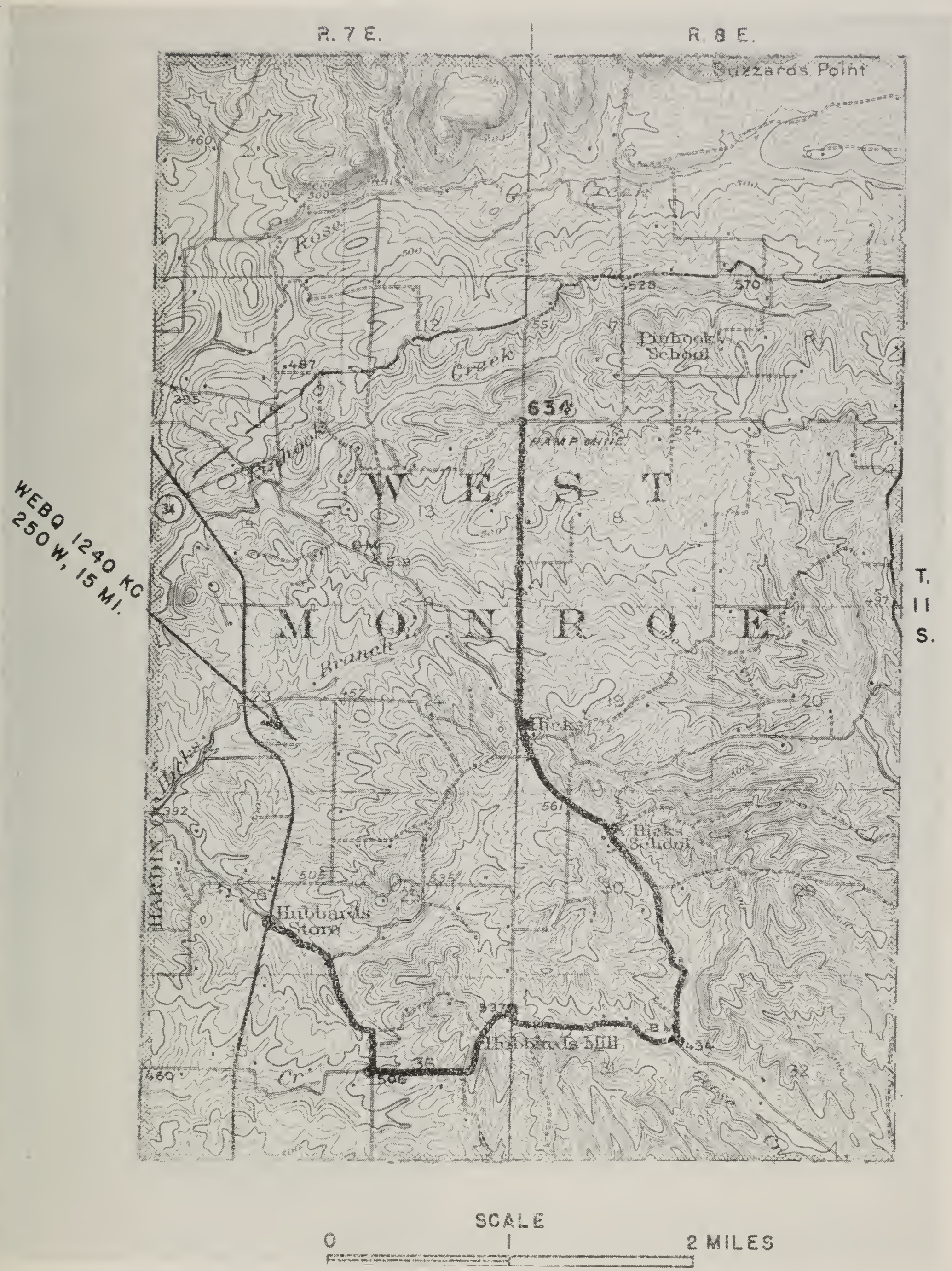

FIG. 31.—Location of field intensity traverse across Hicks dome, Hardin County, Illinois.

It is of interest that high intensity values are found in an area north and slightly west of the exposed cryptovolcanic structure (fig. 30). It is possible that future exploration will prove that this high-intensity area overlies an extension, if not a major part, of the cryptovolcanic structure.

SIGNAL INTENSITY VERSUS MAGNETIC INTENSITY

Shrock and Malott included a magnetic intensity variation map[13] made by Justin Zinn, who used a Hotchkiss superdip. A well-defined magnetic anomaly is shown in the area of the quarries and beyond them. This anomaly may be caused by locally raised pre-Cambrian basement or intrusive magnetic rock.

The radio field intensity anomaly extends north and west beyond the quarries whereas the magnetic anomaly extends east and northeast. If the signal intensity anomaly were caused by a magnetic component of the earth, the two anomaly patterns might be the same or similar. This is not the case; therefore it appears, at least around Kentland, that an anomaly in the magnetic field does not greatly influence the intensity of an electromagnetic field in the ground-wave area.

SIGNAL INTENSITY BEHAVIOR

Field hazard influence is easily recognizable on the map (fig. 30). The field intensity contour lines are pinched in toward the railroad track which cuts through the middle of the area. Signal intensity is apparently reduced considerably near the good metallic conductors (rails and associated wires), but the increased signal strength over the cryptovolcanic structure is strong enough to overcome this influence.

An interesting observation can be made by comparing the field intensity contour maps on stations WAAF and WIND (figs. 29, 30). The intensity anomaly for WIND over the cryptovolcanic structure is relatively small compared to the strong anomaly for WAAF.

The two stations are about equidistant from the surveyed area, the frequencies are roughly similar, the powers are 5000 and 1000 watts, yet the weaker station (WAAF) produces the greater intensity anomaly. This can possibly be explained by the geologic setting of the two transmitters. WAAF is on Silurian terrain; WIND is on Devonian-Silurian terrain. Or perhaps the weaker signal is more sensitive to geologic and other influences than the stronger one.

Cloos[14] observed a similar relationship near Baltimore, Md. Of the four broadcast stations then in the Baltimore area, only WCAO (600 kc, 250 watts) showed clearly what he called "dead spots." The other three stations, WBAL (1060 kc, 10,000 watts), WFBR (1270 kc, 500 watts), and WCBM (1370 kc, 250 watts), appeared clear and undisturbed within the region investigated. Cloos says that where the signals are strong, anomalies are rare, but the same signals at a greater distance from their transmitters, and consequently weaker, are useful for detecting intensity anomalies. He qualifies his use of the word "strong" as being simply descriptive, without implication as to frequency or power of the station.

DEPTH TO BEDROCK

It would appear possible that some strata propagate or transmit radio waves through or along themselves so that, where the strata come to or near the surface, they add to signal intensity propagated along the air path. Thus, the depth from the ground surface to underlying bedrock might be an influencing factor. The disturbed Ordovician rocks, which are now being quarried, formerly cropped out in the flat glacial till plain. Shrock[15] quotes Gorby who gives the thickness of drift as 100 feet in a drill hole at the town of Kentland three miles west; more than 100 feet two miles south; 150 feet one mile north; and 30 feet only 200 yards east of the quarry.

Radio waves appear to be more attenuated traveling in unconsolidated glacial drift

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[13] Shrock and Malott, *op. cit.*, p. 366.

[14] Cloos, Ernst, Auto-radio—an aid in geologic mapping: Am. Jour. Sci., ser. 5, vol. 28, pp. 256-261, 1934.

[15] Shrock, *op. cit.*, p. 472.

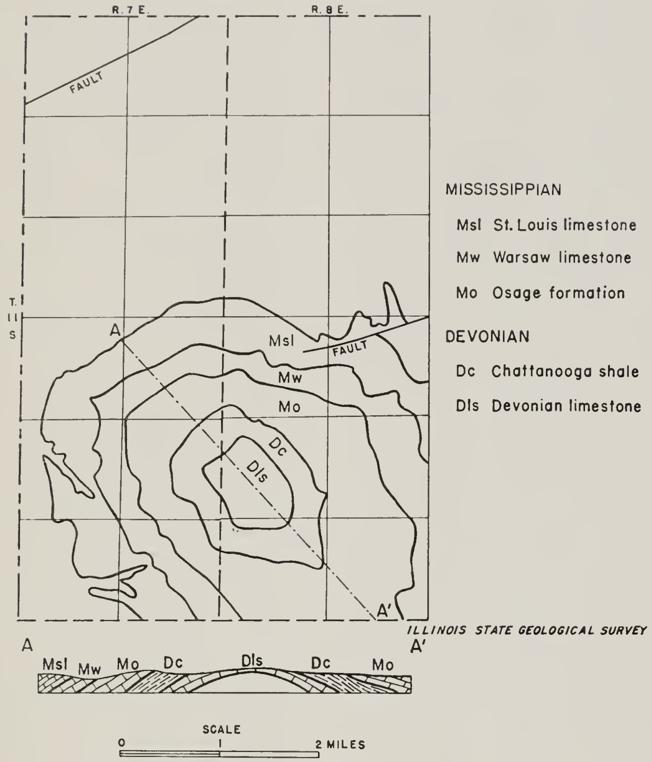

Fig. 32.—Geologic map and cross section of the center of Hicks dome, Hardin County, Illinois (*after* Weller, Stuart, The geology of Hardin County: Illinois Geol. Survey Bull. 41, 1920).

than in consolidated bedrock.[16] If this is true, increased intensity over the cryptovolcanic structure might be explained by the proximity of bedrock as the glacial till cover thins. However, depth to bedrock does not appear to be a major influence here because field intensity one mile north of the exposed cryptovolcanic structure, where the drift is 150 feet thick, is as strong as it is at the structure, where the drift is thin or absent.

DOME STRUCTURE WITH A SUSPECTED IGNEOUS ORIGIN

Geologic Setting

Hicks dome in Hardin County, Ill., a great doming of the rock strata, has been described by Weller.[17] At the center of the dome Devonian limestone (thought to be Onondaga in age) crops out, and is encircled by successively younger beds, the outermost of which are Pennsylvanian in age. Weller[18] postulated igneous intrusion as the cause of structural deformation. Although the dome is analogous in many ways to the Omaha dome in Gallatin County, Ill., which is known to be intruded,[19] surface examinations and drilling to date have failed to encounter any igneous material. Hicks dome is of interest for this type of study, in preference to the Omaha dome, because of the fewer hazards to radio fields and the more varied surface lithologic contrasts. The dome is cut in places by faults, and faulting is common in the surrounding area. Field strength surveys were made across the dome to explore the feasibility of geo-

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[16] Spieker, E. M., Radio transmission and geology: Bull. Am. Assoc. Petr. Geol., vol. 20, no. 8, pp. 1123-1124, Aug. 1936.

[17] Weller, Stuart, The geology of Hardin County: Illinois Geol. Survey Bull. 41, 1920.

[18] *Idem.*

[19] English, R. M., and Grogan, R. M., Omaha pool and mica-peridotite intrusives, Gallatin County, Illinois: Illinois Geol. Survey Rept. Inv. 130, 1948.

logic mapping by signal intensity measurements.

The area is part of the driftless section of southern Illinois, lying south of the margin of farthest Illinoian ice advance. Topographic relief along the traverse over the dome (fig. 31) is 225 feet.

The core of Hicks dome (Devonian) is in sec. 30, T. 11 S., R. 8 E. Successively younger beds are encountered in all directions away from the core of the dome. Pennsylvanian strata occur about five miles north of the core. In that distance, along the north flank of the dome, the stratigraphic section ranges from Devonian limestone to Caseyville sandstone (Pennsylvanian). A cable tool well was drilled to a depth of 2345 feet in the southeast corner of sec. 30, T. 11 S., R. 8 E., in 1935. The hole started in the Chattanooga-New Albany formation and penetrated 1675 feet of Devonian and Silurian strata and 570 feet of Ordovician beds. In 1944 the hole was deepened to a total depth of 3295 feet, penetrating Ordovician strata still farther. The geologic map and cross section (fig. 32) show the attitude of the formations near the core of the dome. This map covers the same area and is drawn to the same scale as the topographic map (fig. 30).

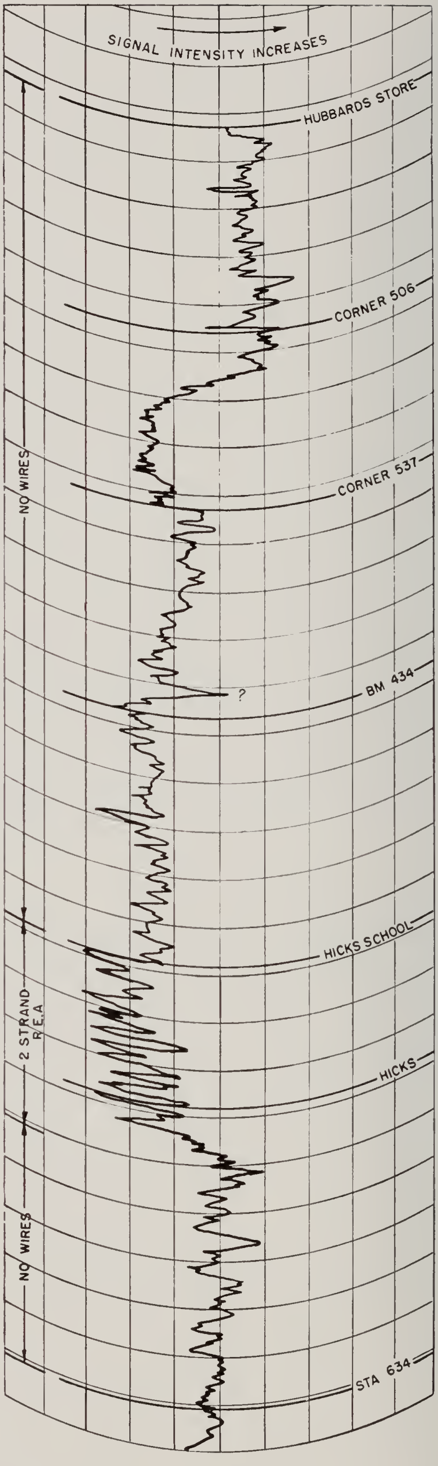

Fig. 33.—Signal intensity curve recorded across Hicks dome, Hardin County, Illinois. Intensity decrease (between Hicks and corner 506) is attributed to older strata at the center of the dome.

Field Hazards

The only wires along the traverse are two-strand REA service on poles running along the road between Hicks and Hicks school (fig. 33). There is considerable difference in the curve recorded alongside the wires and in the curve where there were no wires. Its amplitude is greatly increased by the effect of grounded REA poles (fig. 33). Also, signal intensity reaches its lowest level for the entire traverse near these wires, which have an attenuating effect.

Topographic relief of 225 feet may possibly influence signal intensity in some small way, but its effect is nowhere evident. Meteorologic conditions were constant for the 30 minutes it took to complete the traverse. A real field hazard was the opportunity for error in maintaining the shielded loop antenna of the RCA 308-B (field intensity meter) in a maximum signal orientation over the winding traverse. However, extra precaution was taken to assure proper loop orientation, and intensity anomalies because of misorientation are small and do not affect the overall intensity curve. This was demonstrated by repeating the traverse many times and essentially duplicating the recorded curve each time. The curve shown in figure 33 was selected as representative of approximately 30 curves recorded during three days of field investigation of Hicks dome.

Field Intensity Measurements

The signal from station WEBQ, Harrisburg, Ill. (1240 kc, 250 watts), 15 miles northwest, was used for the traverse. The traverse starts at station 634 (fig. 31), continues along the indicated route to Hicks, Hicks school, B.M. 434, corner 537, corner 506, and ends at Hubbards store. The geological map and cross section (fig. 32) show where successive formations were crossed to reach the Devonian core of the dome and where they were recrossed going down the flank of the dome.

The signal intensity curve (fig. 33) shows lower intensity associated with the older beds and higher with younger beds. The lowest signal intensity, between Hicks and corner 506, is found over Warsaw, Osage, and Devonian terrains. The highest occurs farther down the flanks of the dome (geologically, not topographically) over St. Louis and younger beds.

The irregular and step-like character of the curve over the north flank of the dome (station 634 to Hicks) is interpreted to correspond to the characteristic conductivities and dielectric constants of the Chester and lower Mississippian strata. Kerwin[20] demonstrated a relationship of high field intensity associated with high resistivities and lower intensities with lower resistivities of earth materials. A Schlumberger electric log of a nearby drill hole (Ashland, No. 1 Lackey, sec. 11, T. 11 S., R. 9 E.), which penetrates the strata from the Vienna limestone to the St. Louis limestone, shows that the apparent resistivities of the formations differ considerably. The limestones are generally high (200 to 1400 ohm meters), the sandstones lower (80 to 190 ohm meters), and the shales lowest of all (10 to 40 ohm meters). A detailed field intensity survey on a detailed chart scale, tied in to formation boundaries and widths along the traverse, would show the relationship between the step-like character of the curve and the various rock strata. There is a small unexplained signal anomaly near B.M. 434 (indicated on the chart with a question mark).

The transmitting site at WEBQ is underlain by Pennsylvanian strata. As Hicks dome is traversed and successive strata crossed (from younger to older beds), signal intensity decreases. This, again, would appear to indicate that part of the energy may be propagated through or along strata energized beneath the transmitting antenna, for as successively older beds are crossed (farther removed from Pennsylvanian strata), signal intensity becomes lower.

ORE BODIES

Several hundred miles of radio field intensity traverses were run during two successive field seasons in the Galena lead and zinc area of northwestern Illinois in order to investigate the possible influence of ore on signal strength.

Geologic Setting

The Galena area lies almost entirely within the driftless region of northwestern Illinois. Surface materials consist chiefly of stream deposits, dune sand, loess, and glacial outwash deposits.[21] Topographic relief in the area is about 500 feet. Outcropping strata are Silurian dolomites, and Ordovician Maquoketa shale, Galena dolomite, Decorah dolomite, limestone, and shale, and Platteville limestone, dolomite, and shale.[22] These strata are more or less horizontal and parallel. Structure contours on top of the

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[20] Kerwin, *op. cit.*, p. 412.

[21] Trowbridge, A. C., and Shaw, E. W., Geology and geography of the Galena and Elizabeth quadrangles: Illinois Geol. Survey Bull. 26, pl. IV, 1916.

[22] *Idem.*

Galena dolomite[23] indicate that the surface dips northeast at approximately 17 feet per mile. Structure contours on top of the Oilrock (Guttenberg member of the Decorah formation) show this surface folded in places forming gently dipping anticlines and synclines.[24]

ORE DEPOSITS[25]

The lead and zinc ore deposits of the Galena area are in the Galena, Decorah, and Platteville formations, in a zone about 140 feet thick. The mineralized zones range in depth from 100 to 650 feet but are commonly between 250 and 350 feet. The ore deposits may be curved (arcuate) or long and relatively straight. The minable deposits are usually 25 to 300 feet wide, thicknesses are commonly up to 40 feet with a maximum of 125 feet, and length may be several thousand feet. The major zinc-lead deposits (lower-run deposits) are in "flats" (nearly horizontal sheets between or parallel to bedding planes) and in "pitches" (sheets cutting across bedding planes).

The zinc mineral is largely sphalerite (zinc sulfide). Above water level the sulfide becomes partially or entirely oxidized to carbonate to form the zinc carbonate mineral smithsonite. The ore grade ranges from 3 to 20 percent zinc. The lower range of 3 to 5 percent is considered minable depending upon economic conditions. Pyrite and marcasite (iron sulfide) are associated with the sphalerite. Metallic iron ranges from 5 to 20 percent of the zinc ore. The mineral galena (lead sulfide) is usually less than 1 percent of the zinc ore but is found locally in rich pockets. The main gangue mineral is calcite (calcium carbonate).

Most top-run deposits are about 100 feet above the lower-run deposits in solution channels in the dolomite. The ore is usually entirely galena but grades laterally into zinc and iron. The ore deposits are usually less than 25 feet wide, from 5 to 20 feet thick, and up to several hundred feet long. Between the top-run and lower-run deposits there are middle-run deposits which combine features of both. The middle-run deposits are likely to be high in iron.

AREAS OF WORKING AND ABANDONED MINES

In areas of working and abandoned mines, field hazards are concentrated in the underground car tracks, machinery, electric motors and pumps, mine wires and cables, and electric and telephone service wires. Because of them, signal strength anomalies caused by ore deposits are nowhere clearly separable from those caused by field hazard influences. Field intensity surveys were run over the following mining areas: Bautsch, Gray, Pittsburg, Blewett, Ginte, Graham, Graham-Schneider, Vinegar Hill, North and South Unity, and Northwestern.

An interesting observation of possible significance was made on a traverse over the Bautsch ore body before mining was started. The traverse was run across the south end of the ore deposit at the time a shaft was being dug approximately 200 feet north. The only nearby wires were three strands of electric service coming in from the north. The recorded curves, run from southeast to northwest, decreased in signal strength near the ore body, and orientation of the maximum signal direction shifted south approximately 45 degrees. Similar changes in orientation were observed over other ore deposits, but because of the structure, machinery, cables, and guy wires associated with the shafts, no positive significance is attached to these observations. Various other changes in signal strength over operating or developed properties are not attributable solely to ore influence because of attendant field hazards.

PROSPECTIVE ORE-BEARING AREAS

Many miles of traverse were run, away from known ore deposits but within the boundaries of the principal mineralized areas,[26] and numerous changes in signal

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[23] *Idem.*

[24] Willman, H. B., and Reynolds, R. R., Geological structure of the zinc-lead district of northwestern Illinois: Illinois Geol. Survey Rept. Inv. 124, pl. 7, 1947.

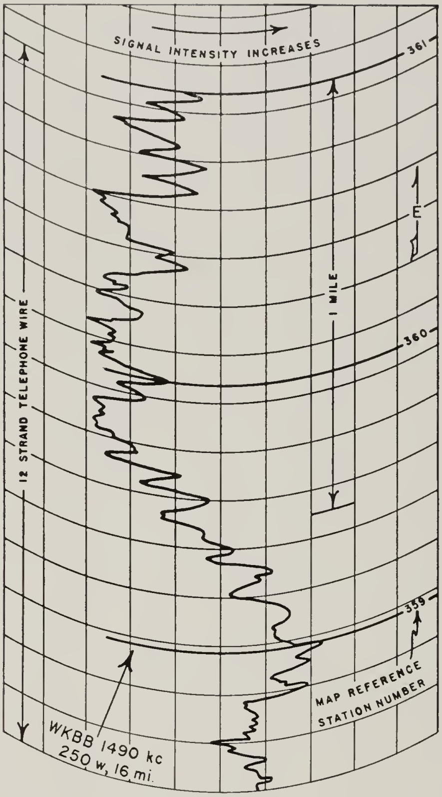
[25] The geology in the following paragraphs is based on: Willman, H. B., Reynolds, R. R., and Herbert, Paul, Jr., Geological aspects of prospecting and areas for prospecting in the zinc-lead district of northwestern Illinois: Illinois Geol. Survey Rept. Inv. 116, 1946.
Willman, H. B. and Reynolds, R. R., Geological structure of the zinc-lead district of northwestern Illinois: Illinois Geol. Survey Rept. Inv. 124, 1947.

[26] Willman, Reynolds, and Herbert, *op. cit.*, fig. 1.

strength were observed. However, most of these changes are relatively small or so near wires and other field hazards that correlation between them and ore-deposit influence is uncertain. Several exceptions, one a strong intensity anomaly, merit mention.

On an east-west traverse along the south edge of sec. 1, T. 28 N., R. 1 E., signal strength (station WKBB, Dubuque, Iowa, 16 miles northwest) decreases significantly and orientation of the maximum signal path shifts approximately 45 degrees near station 360 (fig. 34). Such a signal strength decrease is common in the presence of intermittent overhead wires; here, wire conditions (12 strands of telephone line) remain constant for the entire traverse, thus some other explanation for the anomaly is required. It seemed possible that the anomaly might be caused by deposits of conductive ore. The mining company owning the lease drilled a test hole near station 360 (Furlong lease) on the basis of the signal strength anomaly (fig. 34). Test drilling confirmed the presence of conductive minerals in the bedrock. Field examination of the well cuttings revealed abundant pyrite between 50 and 100 feet deep, some cuttings running as high as an estimated 50 percent iron content. Some zinc was encountered just below 100 feet, but only small amounts of ore minerals were found between the zinc level and the bottom of the hole. The test hole failed to find ore in commercial quantities, but the pyrite-rich strata above 100 feet were uncommonly thick and rich for the area. It is possible that this shallow iron deposit is the direct cause of the recorded attenuation of signal strength, or that associated ore deposits, as yet undiscovered, may exist in this vicinity.

A sharp decrease in signal intensity was observed in a north-south traverse along the east edge of sec. 6, T. 28 N., R. 2 E. The decrease occurs approximately ⅛ mile north of the southeast corner of sec. 6, and cannot definitely be accounted for by the associated field hazards. A similar sharp signal strength anomaly (increase) was observed in the NE ¼ sec. 24, T. 28 N., R. 1 E. This too cannot be definitely accounted for by associated field hazards.



ILLINOIS STATE GEOLOGICAL SURVEY

FIG. 34.—Signal intensity curve recorded in the Galena, Illinois, area. The signal decrease, centered at station number 360, is attributed to a rich concentration of iron sulphide from 50 to 100 feet deep.

AREAS OF NEWLY DISCOVERED ORE BODIES

To investigate further the relationship between signal intensity and ore deposits, traverses were made over proved ore reserves where there were few cultural field hazards in the Shullburg, Wis., area. Extensive traverses were made along secondary roads and in the fields and meadows away from obvious field hazards. Access to the land containing the ore deposits was facilitated and information on their location and geologic settings was kindly furnished by R. R. Reynolds,[27] who accompanied the field party and aided in making many of the traverses.

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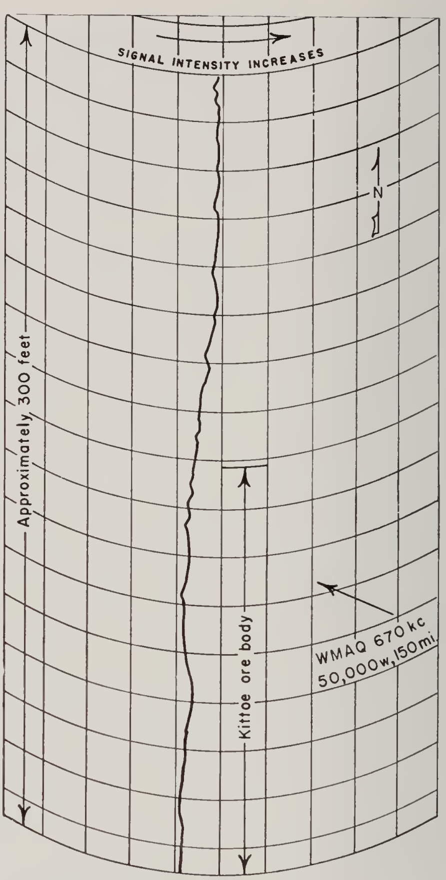
[27] Geologist, The Calumet and Hecla Company, Shullburg, Wis.

Most of the ore deposits traversed are in or near synclinal axes and trend generally east-west. Three of the six ore deposits crossed have up to 140 feet of Maquoketa shale cover, two have thin Maquoketa shale cover (10 to 40 feet), and one, the Kittoe deposit, has no Maquoketa shale cover.

The only clear signal strength anomaly was observed on the Kittoe property where signal strength decreases as the ore deposit is crossed (figs. 35, 36). A small stream, running approximately parallel to the trend of the ore, prevented crossing the ore deposit completely and might be the cause of the observed anomaly. The Kittoe ore deposit contains rich amounts of galena and pyrite associated with and above the sphalerite. The recorded signal anomaly over the ore may be at least partly caused by lead and iron minerals.

Other ore deposits, Hendrickson and Gensler, contain small to large percentages of lead and iron with zinc ore, but no changes in signal strength were observed in traverses across them. The Maquoketa shale has low electrical resistivity (where seen in electric logs of drill holes), is a relatively good conductor, and probably attenuates radio fields greatly. Perhaps the shale lowers the energy sufficiently so that it does not penetrate to the strata below. This factor might account for the anomaly on the Kittoe (with no Maquoketa shale cover) and the absence of anomalies on the other five ore deposits overlain by various thicknesses of the shale. Many detailed measurements were made over these ore deposits using stations with different frequencies, powers, distances and directions of signal path, but strength curves were essentially similar.



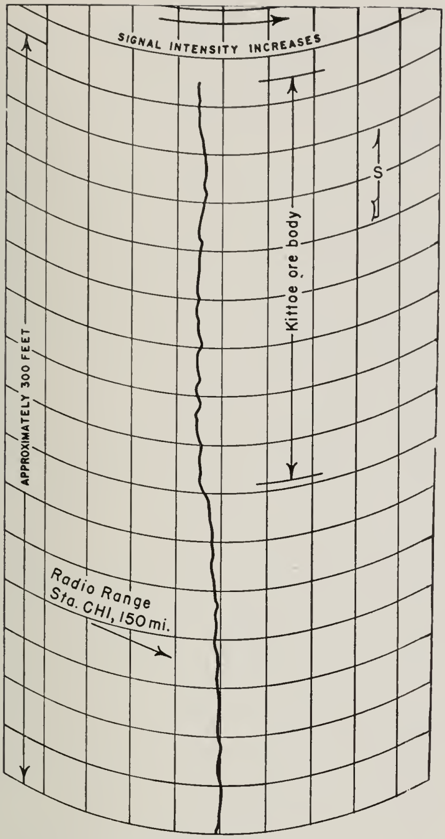
ILLINOIS STATE GEOLOGICAL SURVEY

Fig. 35.—Signal intensity curve of WMAQ recorded south of Shullberg, Wisconsin. Decrease in signal intensity may be due in part to the influence of the Kittoe ore deposit.

Summary

Field intensity measurements in the Galena area were made over ore deposits ranging from 100 to 600 feet in depth. Most of the known deposits traversed are chiefly sphalerite (poorly conductive zinc sulfide) with minor amounts of associated conductive ore in the form of lead and iron sulfides. No signal strength anomalies were observed which could be attributed solely to deposits of the ore mineral sphalerite. Signal strength anomalies recorded near working or abandoned mines were usually accompanied by cultural field hazards so that their significance is doubtful. In prospective ore-bearing areas away from known deposits several interesting anomalies were observed. One such anomaly appears to be accounted for, in part at least, by a rich concentration of conductive iron sulfide at shallow depths. On traverses over newly discovered and unmined ore deposits, only at Kittoe is there a signal anomaly.

From observations of signal strength behavior in air in the presence of linear metal conductors, such as wires and railroad tracks, it seems probable that linear or tab-



ILLINOIS STATE GEOLOGICAL SURVEY

FIG. 36.—Signal intensity curve of CHI recorded south of Shullberg, Wisconsin. Decrease in signal intensity may be due in part to influence of the Kittoe ore deposit.

ular conductive ore deposits underground might exert similar influence. Most metal conductors in a radio field reduce the signal strength considerably, but occasionally they increase it, possibly through reradiation. It appears that in the absence of field hazards, or with recognition of their effects if present, abnormally low signal strength (or more rarely abnormally high strength) might be indicative of conductive ore in the bedrock. This is assuming that the radio field penetrates to the ore deposit. In the Galena area, the low-resistant Maquoketa shale appears to act as an electrical shield preventing appreciable amounts of radio fields from reaching underlying conductive ore deposits. Apparently here ore detection by the field intensity method is only promising where there are shallow conductive ores not covered by Maquoketa shale.

On the basis of observations by Closs[28] in the Baltimore, Md., area, steeply dipping bedrock contacts greatly reduce signal strength or even eliminate it. Thus an essentially nonmetallic tabular ore body might be recognized through field intensity measurements if the ore was steeply dipping or in an almost vertical position. In the Galena area, steeply dipping, poorly conductive tabular ore bodies in pitches are usually associated with the lower- and sometimes with the middle-run ore deposits. No observed signal strength anomalies can be definitely attributed to such structures. However, it is possible that if the steeply dipping tabular ore deposits were of larger dimensions or came closer to the surface, field intensity measurements might reveal their presence.

UNDERGROUND MINED-OUT AREAS

Investigation of the influence of underground mined-out areas on signal strength was neither planned nor anticipated. It resulted from ordinary observation and coincidence. Traverses were run looking for signal anomalies from the southern exten-

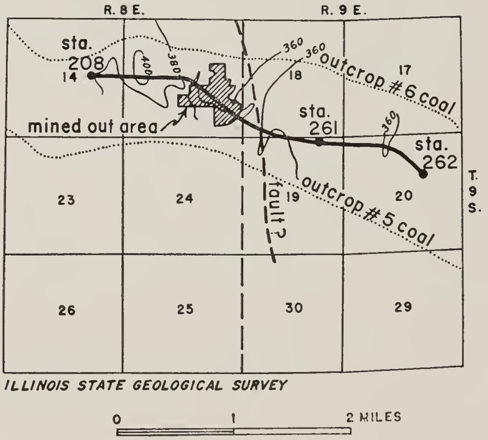


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FIG. 37.—Map showing route of traverse (sta. 208–261–262) over mined-out area along Illinois Highway 13, Gallatin County. Contours are topographic, fault is extension of Ridgeway fault, and outcrops are of No. 6 and No. 5 coal beds.

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[28] Cloos. *op. cit.*

sion of the Ridgeway fault in Gallatin County, Ill. Along Illinois Highway 13, between Equality and Shawneetown, a signal intensity high was repeated near the B. & W. coal mine, sec. 13, T. 9 S., R. 8 E. (fig. 37). The mine superintendent kindly permitted access to an up-to-date mine map which showed the extent of the mined-out area. This area corresponded almost precisely with the field-intensity high. The Ridgeway fault had not been encountered in the mine. Therefore, inference was made (erroneously) postulating a cause-and-effect relationship between the mined-out area and the signal anomaly.

GEOLOGIC SETTING OF THE B. & W. COAL MINE

The Harrisburg (No. 5) coal was being mined at a depth of 95 feet, 275 feet above sea level. Fifty-five to 65 feet of interbedded shale and siltstone and shaly siltstone lie above the coal bed, and 30 to 40 feet of cover overlies the bedrock surface. No. 6 coal crops out north of the mine and No. 5 crops out south (fig. 37). The mined-out area was "dry" and offered a geologic discontinuity, some 95 feet below the surface, between bedrock and the air-filled mined-out area. At that time, early in the field work (June 1947), it was postulated that because the air in the mine was probably a better medium for radio wave propagation and transmission than the surrounding rocks, signal strength increased. This led to investigation of other mined-out areas.

TRUAX-TRAER COAL MINES

Through the courtesy of Walter Roe, engineer for Truax-Traer Coal Company, field investigations were made over a large, abandoned, watered mine at Hollidayboro, Jackson County, Ill. The depth to the coal (No. 6) ranges from about 70 to 130 feet. A caprock (Herrin limestone) up to 6 feet thick overlies the coal bed. The limestone is not continuous because of solution along jointing planes. Traverses run over the area used signals differing in power, frequency, distance, and direction of signal path, but no significant intensity anomalies were obtained. Radio transmitters, constructed in the Illinois Geological Survey laboratory, were used first over the mined-out area, then off the mined-out area, but precise measurements showed no significant anomalies.

The Hollidayboro and the B. & W. mines differ chiefly in conditions within the mined-out areas and in the immediate caprock. The mined-out area at the B. & W. mine is "dry," the caprock is interbedded shale and siltstone; at Hollidayboro the mined-out area is filled with water, the caprock is limestone. The difference in effect on signal strength between the B. & W. mine and the Hollidayboro mine was tentatively explained by the differing conditions of the mined-out areas. It was thought that perhaps the electrical discontinuity between bedrock and Hollidayboro mine water (an electrolyte) was not as great as that between bedrock and air (assuming radio fields were penetrating to these depths). However, in electric logs of nearby drill holes, the shales above the coal have low electrical resistivities and therefore could be acting as a shield to prevent an appreciable amount of a radio field from reaching the mine-out area.

M. B. Buhle, Illinois State Geological Survey geologist, made collateral earth resistivity measurements in the Hollidayboro area. These measurements are made by inserting four metal stakes into the ground (at various spacings to achieve various depths of penetration) along a line of traverse. From 10 to 200 volts at 18 cycles per second, at 10 to 200 milliamperes, are applied to the two outer stakes. Potential difference is measured between the two inner stakes and, from these readings, apparent resistivity in ohm-centimeters is calculated using the Wenner formula.[29]

Measurements were taken for depths from 10 to 150 feet (maximum depth of coal 130 feet), at five- or ten-foot intervals. Resistivity values in ohm-centimeters at depths of 50 feet average about 4000, at 75 feet about 6000, at 100 feet about 7000, and at 150 feet about 5000. These values are relatively low and for the most part result from the high conductivities of the large

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[29] Wenner, Frank, A method of measuring earth resistivity: Bur. Standards Sci. Paper 258, July 15, 1914.

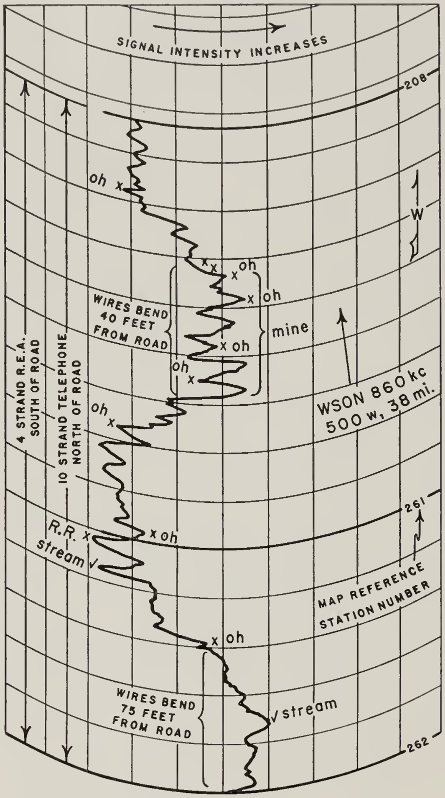
amount of shale in the geologic section. If these shales act as a shield to radio fields preventing them from penetrating to the geologic discontinuity below, then of course the discontinuity cannot affect signal strength measured at the surface.

Additional traverses were run over coal mines in Franklin and Williamson counties. No signal strength anomalies were recorded over these mines except in a few questionable instances where field hazards must be taken into consideration. Why a signal anomaly should be present over the B. & W. mined-out area and not over other mined-out areas needed to be explained. Therefore the B. & W. coal mine was re-examined.

RE-EXAMINATION OF B. & W. MINE

In the meantime, much had been learned about field hazards, and close examination of wire conditions along the traverse provided a reasonable explanation, other than geologic, for the intensity anomaly.

Examination of the field intensity chart recorded between stations 208 and 262 (figs. 37, 38) reveals a good intensity high over the mined-out area (labeled *mine*). Signal strength decreases to the west (toward station 208) and to the east (toward station 261), but increases farther east (toward station 262). Inspection of the wire conditions (noted to the left on the chart) reveals that four strands of REA wires south of the road and ten strands of telephone wires north of the road run along the entire traverse. Apparently the effect of the wires on the signal from WSON, Henderson, Ky., 38 miles east, is a general reduction in intensity, because at the two places where the wires bend away from the road, signal intensity increases noticeably. The wires, although they are constant for the entire length of the traverse, bend away from the road at the mine (increasing signal strength), and the significance of their temporary bending away from the road was not previously realized. The probable southern extension of the Ridgeway fault trends along the east edge of the mine (this is known from B. & W. mine test holes), but it could not be confirmed by field intensity measurements because of the strong influence of the wires.



ILLINOIS STATE GEOLOGICAL SURVEY

FIG. 38.—Signal intensity curve run over mined-out area along Illinois Highway 13, Gallatin County. Mined-out area labeled *mine,* and places where wires bend away from the road are indicated.

Because of the premature incorrect correlation between the mine and signal intensity, later anomalies of all types were carefully analyzed for influence of field hazards before the cause was attributed to geologic influence. At the B. & W. mine a comparatively small mined-out air-filled area, covered by 95 feet of bedrock and alluvium, has no recognizable influence on signal strength measured at the surface. It is conjecture whether the absence of a signal anomaly results from the mined-out area's insignificant influence or on insufficient depth penetration of the radio field.

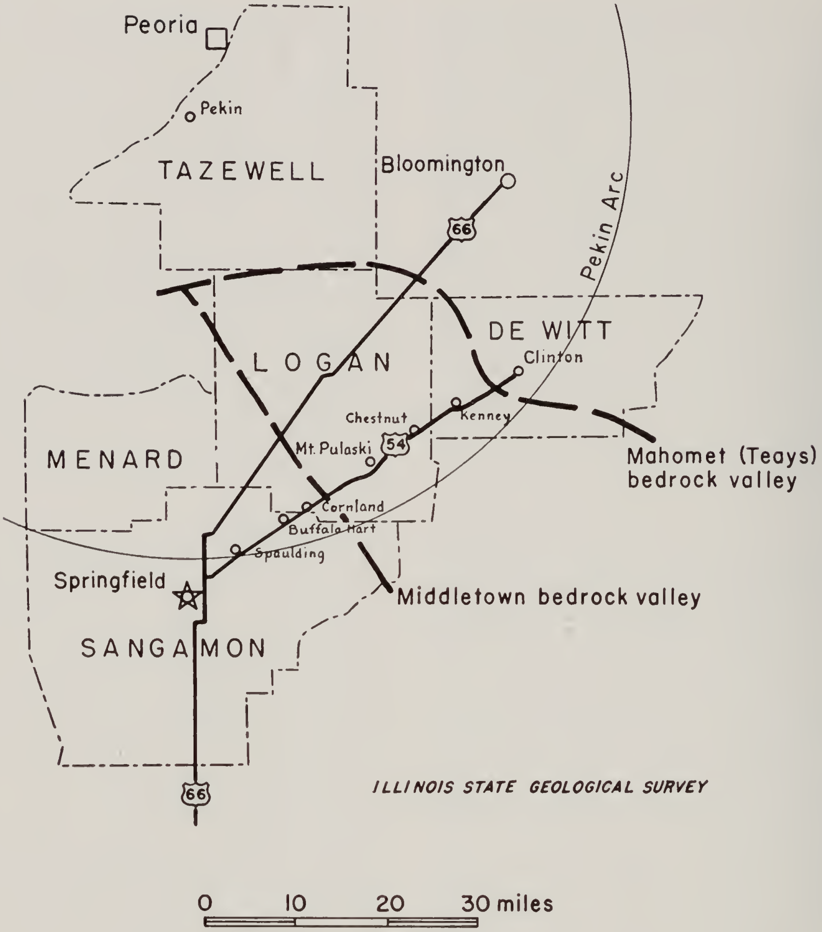


FIG. 39.—Location of 40-mile traverse along Illinois Highway 54 between Clinton and Springfield, Illinois. Bedrock valleys are after Horberg, Leland, Bedrock topography of Illinois: Illinois Geol. Survey Bull. 73, 1950.

SOILS

The Federal Communications Commission regulations require that standard broadcast transmitter locations comply with good engineering practice. The general requirements include the following:[30]

A map clearly showing:

1. Proposed location.
2. Surrounding business, industrial, residential, and unpopulated areas.
3. Density and distribution of population.
4. Heights of all tall buildings and other structures.
5. Location of airports, airways, and other radio stations.
6. The terrain and types of soil.

Concerning types of soils the Commission says:[31]

> The type and condition of the soil or earth immediately around a site is very important. Important, to an equal extent, is the soil or earth between the site and the principal area to be served. Sandy soil is considered the worst type, with glacial deposits and mineral-ore areas next. Alluvial, marshy areas, and salt-water bogs have been found to have the least absorption of the signal.

In the past, soils have been considered of prime importance in controlling the value of conductivity and dielectric constant of the earth along a signal path. In recent years, the amount of depth penetration of radio waves has been revised downward to

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[30] Standards of good engineering practice concerning standard broadcast stations 550-1600 kw.: Federal Communications Commission, U. S. Govt. Printing Office, Washington, D.C., pp. 29-30, 1940.

[31] *Idem.*, p. 33.

include not only the soils but earth material below.

Terman says:[32]

> The value of conductivity and dielectric constant that is effective for radio waves represents the average value for a distance below the surface of the earth determined by the depth to which ground currents of appreciable amplitude exist. This depth of penetration is commonly on the order of 5 to 10 feet at frequencies used in short-wave communication, and 50 or more feet at broadcast and lower frequencies. As a result, the earth constants are not particularly sensitive to conditions existing at the very surface of the earth, as, for example, recent rainfall.

If conditions, such as recent rainfall, at the very surface of the earth do not appreciably change the value of conductivity and dielectric constant, then soils, the thickness of which in temperate latitudes ranges from a few inches to several feet, should also cause little appreciable change.

Soil Influence on Signal Strength

Forty-mile traverses were run between Clinton and Springfield, Ill., along Federal Highway 54. Soil survey maps[33] are available for the three counties crossed by the traverse. The first traverse was run along a radial using the signal from WCVS, Springfield; the second, approximately along an arc using WSIV, Pekin (fig. 39).

More than 20 soil types, including sandy soils, are crossed and recrossed along the 40-mile traverses, but at no place is there an indication of a signal anomaly that can be construed to be related to the various soil types. Part of a recorded curve, chosen because it crosses several soil type boundaries in a short distance and because no wires or other field hazards are recognized, shows an almost constant signal intensity (fig. 40). This curve, representing a distance of 1 mile, runs 4 to 3 miles southwest of Kenny, DeWitt County, and is a segment of the continuous curve for 40 miles. The specific soil types traversed are indicated by patterns at the side of the chart.

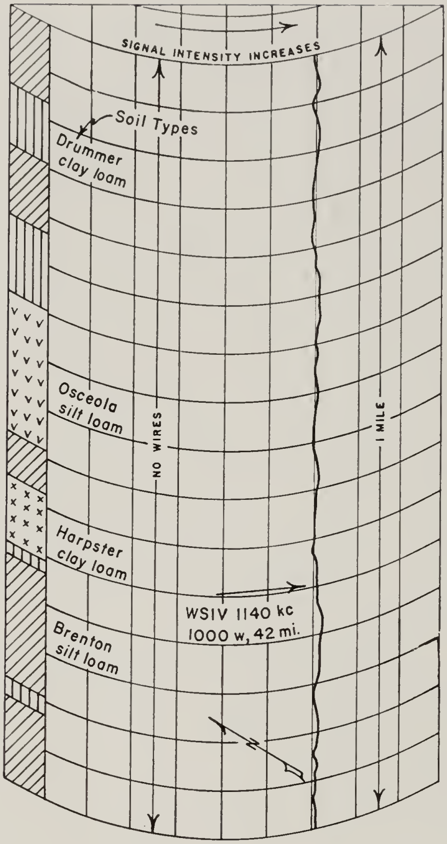

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FIG. 40.—Signal intensity curve, 3 to 4 miles south of Kenny, DeWitt County, Illinois. Signal intensity remains remarkably constant across different soil types (indicated to the left).

From the soil report of DeWitt County,[34] the Drummer clay loam occurs in the nearly level or depressional areas in the upland, the surface soil (10 inches) is a well-granulated black clay loam, the subsurface (10 to 15 or 18 inches) is a brownish-gray or very dark-gray clay loam, the subsoil (15 to 18 to 35 inches) is a gray clay loam mottled with pale yellow, below 35 inches the material is rather friable; the Osceola silt loam occurs on nearly level or slightly depressed areas on the outwash plains, the surface soil (7 to 8 inches) is a brownish silt loam with a gray cast, the subsurface (7 to 8 inches to 20 to 30 inches) is a dull-gray friable silt loam, the subsoil (20 to 30, to 50 to 60 inches) is a yellowish-gray clay, below 50 to 60 inches are stratified outwash sands; the Harpster clay loam occurs chiefly

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[32] Terman, *op. cit.*, p. 709.

[33] Soil reports of DeWitt, Logan, and Sangamon counties: Univ. of Illinois Agr. Expt. Sta., Urbana, Illinois.

[34] Smith, G. D., and Smith, L. H., DeWitt County soils: Soil Report 67, Univ. of Illinois Agr. Expt. Sta., Urbana, June 1940.

in depressions and in association with Drummer clay loam, the surface soil (5 to 10 inches) is a grayish-black clay loam or a silty clay loam, the subsurface is a dark yellowish-gray loam, the subsoil is a yellow-mottled light-gray clay loam. The Brenton silt loam occurs on the undulatory glacial outwash plains, the surface (8 to 10 inches) is a finely granular dark-brown silt loam, the subsurface (8 to 10, to 16 to 18 inches) is a light-brown silt loam, the subsoil (16 to 18, to 45 to 60 inches) is a yellowish-brown silty clay or clay loam, below 45 to 60 inches are beds of almost pure sand.

Examination of the signal intensity curve recorded across these soil types (fig. 40), in the absence of known or suspected field hazards, shows a remarkably constant intensity. Crossing soil-type boundaries appears to have little or no effect on signal intensity.

Collateral earth resistivity surveys were made by M. B. Buhle in a nearby area (Elkhart, Logan County). Resistivity values ranging from 2500 to 26,000 ohm-centimeters at depths of five feet were recorded crossing Drummer clay-loam and Brenton silt-loam areas. Thus it appears that Terman is correct in saying that conditions existing at the very surface of the earth do not appreciably change the value of effective conductivity and dielectric constant. Other collateral earth resistivity measurements made in Macon County (Harristown), Ford County (Gibson City), and Jackson County (Truax-Traer coal mines), show highly variable earth resistivities in soils of various types where signal intensity curves remain remarkably constant.

It would appear, from traverses run in Illinois, that soil types developed on glacial drift have little or no influence on signal intensity. However, in view of the effect of bedrock on signal intensity, it would seem reasonable to expect that residual soils in temperate latitudes, in unglaciated terrain, could influence signal intensity depending upon soil thickness and character of the bedrock.

BEDROCK VALLEYS AND DEPTH TO BEDROCK

Most of the field intensity surveys for the present work were run over terrain covered with glacial drift. The exceptions are those run in the driftless area of northwestern Illinois and adjacent Wisconsin, and south of the line of farthest ice advance in southern Illinois and adjacent Kentucky.

Nonglaciated Areas

Depth to bedrock in the nonglaciated areas is controlled mainly by the thicknesses of residual soil, wind-blown material (loess and sand), river and lake deposits, and in some areas glacial outwash.

Residual soils in the areas investigated are relatively thin, reaching maximum thicknesses on flats and valley bottoms and minimum thicknesses on the slopes. Bedrock, either in outcrop or close to the surface, undoubtedly influences signal intensity far more than the soils (figs. 31, 32, 33).

Loess and combinations of loess and sand attain thicknesses of more than 25 feet in some parts of Illinois.[35] These deposits, chiefly loess, cover glaciated as well as nonglaciated areas. Their influence on signal intensity is probably greatest where they are thickest. Traverses run over thick loess deposits on the Shawneetown Hills, Gallatin County, Ill. (figs. 18, 20), fail to provide clues on signal intensity influence by loess. Intensity decreases slightly over the hills, but this may be because of the loess, vegetation, or the erosional remnant of bedrock (the hills themselves) surrounded by the Ohio River alluvial plain.

River and lake deposits attain considerable thicknesses in parts of Illinois. Alluvial terrain absorbs the signal much less than glacial and loess-covered glacial terrain.[36] M. B. Buhle found in his extensive earth resistivity surveys throughout Illinois that alluvial material, chiefly sands and gravels,

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[35] Smith, G. D., Illinois loess, variations in its properties, a pedologic interpretation: Univ. of Illinois Agr. Expt. Sta. Bull. 490, July 1943.

[36] FCC, Standards of good engineering, *op. cit.*, p. 33.

usually has far greater electrical resistivity than glacial tills, that loess usually has low resistivity, and lake and river silts, even lower.[37] Field intensity traverses were run over parts of Gallatin County, Ill., and Union County, Ky., covered by 100 to 150 feet of Ohio River alluvium and glacial outwash (figs. 18, 27, 28). The curves recorded along these traverses show signal strength anomalies which appear to be best explained by faulting in the bedrock. If this is true, then the radio fields are penetrating 100 to 150 feet of alluvial material to reach bedrock, and alluvial influence (if present) on signal strength is less than that of bedrock structure.

Glaciated Areas

Where glacial drift is present in Illinois it ranges in thickness from a few inches to more than 600 feet where moraines cross deep bedrock valleys.[38] Horberg[39] has identified Kansan and possibly Nebraskan glacial deposits in samples from drill holes in the Mahomet bedrock valley in Champaign County. He recognizes three soils; the lowermost or Aftonian is underlain by sand and gravel. The Illinoian glacial deposit covers nearly two-thirds of the state and is 5 to 50 feet or more thick.[40] This drift consists largely of bluish-gray clayey till which has been weathered to depths of 15 feet or more.[41] Sangamon interglacial deposits separate the Illinoian from the overlying early Wisconsin drift which covers nearly a third of the state (east, central, and north). Deposits of middle Wisconsin age cover a small part of the state in the Chicago area and north.

Many miles of traverses of field intensity measurement in Illinois were run over glacial drift. A seven-mile traverse was run over the buried Mahomet bedrock valley, starting at the northwest corner of sec. 35, T. 21 N., R. 6 E., Piatt County, Ill., and running due east to the northeast corner of sec. 35, T. 21 N., R. 7 E., Champaign County, Ill. The traverse starts high on the west slope of the buried valley, crosses the west slope, the valley bottom, and ends half a mile up the east wall. Depth to bedrock at the starting point is 280 feet; the west slope is about five miles long; depth to bedrock at the foot of the west slope is 430 feet; the valley bottom is about one mile wide and depth to bedrock is greater than 430 feet; half a mile up the east valley wall, depth to bedrock is 375 feet; topographic relief along the traverse is approximately 80 feet.

The signal used was 1000 watts at 1020 kc, originating about 50 miles west and slightly north. The traverse is essentially along a radial from the transmitting station. Signal intensity on the recorded curves decreases as bedrock becomes deeper along the traverse, reaches a minimum over the valley floor, and increases again as the bedrock becomes shallower along the east wall. The overall signal intensity decreases gradually from west to east. This is to be expected along a radial away from the signal source. REA and telephone wires parallel the road along most of the traverse. There is a grounded-pole effect across the valley bottom (fig. 17). Here also, the present Sangamon River valley crosses the bedrock Mahomet valley, and signal decrease may be due in part to the influence of the water course. The signal decrease coincides with the place of greatest drift thickness (over the bedrock valley floor). However, field hazards (wires, grounded poles, the Sangamon River, and the radial traverse) make it difficult to prove that the signal anomaly is solely the result of increased depth to bedrock.

A traverse across the south wall toward the center of Mahomet bedrock valley (Area IV, fig. 21) is apparently not influenced by the valley. The 3960-foot traverse crosses at least 100 feet of valley slope without noticeable signal strength variation that can be attributed to depth of bedrock.

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[37] Buhle, M. B., Illinois Geol. Survey, personal communication, 1949.

[38] Horberg, Leland, *op. cit.*, Illinois Geol. Survey Bull. 73, 1950.

[39] Horberg, Leland, A major buried valley in east-central Illinois and its regional relationships: Jour. Geol., vol. 53, no. 5, 1945; reprinted as Illinois Geol. Survey Rept. Inv. 106, p. 353, 1945.

[40] Alden, W. C., Glacial geology of the central states: Sixteenth Int. Geol. Cong., Guidebook 26, Excursion C-3, p. 7, 1933.

[41] Leighton, M. M., and MacClintock, Paul, Weathered zones of the drift-sheets of Illinois: Jour. Geology, vol. 38, no. 1, pp. 28-53, 1930; reprinted as Illinois Geol. Survey Rept. Inv. 20, 1930.

However, this is hardly a fair test because the woods influence signal intensity along part of the traverse.

Other traverses cross a smaller bedrock valley, tributary to the Mahomet bedrock valley, near Fisher, Champaign County, Ill., and near Gibson City, Ford County, Ill., but because of numerous field hazards the recorded signal anomalies cannot be attributed with assurance to variations in drift thickness.

The 40-mile traverse between Clinton and Springfield, Ill., crosses the buried bedrock Mahomet valley and its tributary, the Middletown bedrock valley[42] (fig. 39). Depth to bedrock is more than 200 feet in the Middletown valley, more than 450 feet in the Mahomet valley, and less than 200 feet elsewhere along the traverse. Neither valley visibly affects signal intensity. This may be due to interference from field hazards, although it is considered unlikely because field hazards are few; or possibly the variation in depth to bedrock did not affect the field intensity of the two particular signals used along this traverse. There is a gradual thinning of the drift from 155 feet at Cornland to 10 feet or less at Springfield (fig. 39) accompanied by a corresponding decrease in signal intensity (from Pekin) towards Springfield. This signal decrease may result largely from drift thinning.

Several traverses cross the buried bedrock Saline valley in Saline County, Ill. Some signal anomalies were recorded near the position of the bedrock valley and its tributaries, but present drainage, geologic structures, and field hazards nearly coincide with the bedrock valleys and leave the true source of the anomalies uncertain.

Additional investigation is needed to determine the effect on signal intensity of thickness of cover over bedrock. A possible approach might be to energize electromagnetically a selected bedrock stratum and then measure the signal intensity over the energized area to find out if there are differences in signal strength caused by differences in thickness of the overburden.

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[42] Horberg, Leland, *op. cit.*, Illinois Geol. Survey Bull. 73.

CHAPTER 9 — SUMMARY AND CONCLUSIONS

This is a report on a preliminary investigation of features that affect radio field intensity in the ground-wave area at standard broadcast frequencies. Theoretical considerations of field intensity behavior have been treated only superficially, and primary attention has been given to signal strength behavior in the field. Hundreds of miles of traverses were run in Illinois and immediately adjacent areas, measuring and automatically recording signal intensity. These traverses were run chiefly in areas of known field hazard and geologic conditions. Experimental data were gathered on field strength behavior in the presence of cultural and natural features. These data were examined and evaluated for a cause-and-effect relationship between cultural and natural features and signal intensity anomalies.

The conclusions may be summarized as follows:

1. From the present and previous work it appears that radio waves penetrate bedrock. Numerous instances of penetration up to 1000 feet have been reported, and in one instance 6000 feet of quartzite was reported to have been penetrated by a signal from a 10-watt transmitter between 100 and 300 kc.

2. Satisfactory reconnaissance field intensity surveys can be made using battery portable and automobile radios by measuring variations of the intermediate frequency voltage.

3. Portable field equipment, capable of reliable detailed field intensity measurements, was developed for this investigation and proved satisfactory. It consists of an RCA 308-B field intensity meter with a bidirectional shielded loop antenna, a vibrator power supply for the 308-B meter, and an Esterline-Angus model A-W graphic recorder, driven by a Clark cable drive from a tee in the speedometer cable of the transporting vehicle. This equipment, suitably shock-mounted in a wooden-bodied station wagon, withstands rough field treatment. An improvement in this instrumentation would be incorporation of a device that automatically orients the shielded loop antenna in the direction of maximum signal intensity.

4. Continuous signal intensity measurements in the field have shown that spot readings, taken at large intervals along a traverse and without regard for field hazards, can be misleading.

5. The laboratory attenuation tests on diamond drill cores, although possibly indicative of electromagnetic conductivities of rocks, are not conclusive because of the great difference between laboratory and field conditions.

6. In field measurements, relative signal intensity curves, which are similar to actual field intensity curves, were used throughout most of the investigation because they require less calibration and setup time and thus make possible the surveying of greater areas more rapidly.

7. Field notes are best kept on the paper chart of the recorder so that all the pertinent data are in one convenient place. Field notes should include date, time, weather, station used (frequency, power, direction, and distance from traverse), notes on geographical orientation, on associated field hazards, and on signal anomalies, whether caused by obvious field hazards or by unknown features.

8. Signals to be measured should be selected well within their ground-wave areas. A weak (250 to 1000 watt) signal from nearby (5 to 50 miles, depending upon frequency) is to be preferred to a strong (5000 to 50,000 watt) signal because the weaker signal is more affected by a geologic discontinuity than a strong signal, which tends to overcome the discontinuity and minimize the signal anomaly.

9. The most common field hazards in Illinois are wires; overhead electric (REA) and telephone wires almost invariably cause

strong signal anomalies. These anomalies are usually sharp decreases in intensity, but rarely they are sharp increases. Wires parallel to a traverse commonly decrease the general signal intensity level along the entire traverse. Other field hazards that affect signal intensity similarly are bridges, railroad tracks, metal structures (towers and buildings), fences, and pipelines.

Anomalies caused by streams are usually sharp (either increase or decrease), but of relatively small magnitude.

Individual trees have little if any effect on signal intensity at broadcast frequencies.

Wooded areas, if large enough, sometimes cause shadow effects, and signal level decreases when the woods lie between the radio station and the point of measurement if the point of measurement is within 100 feet of the woods. Woods affect high frequency signals more than signals at low frequencies.

Topography as a field hazard in Illinois can be almost disregarded. Large hills are the only important topographic features that influence signal intensity. This influence is observed only when the hill is interposed directly between the radio station and the point of measurement, and if the point of measurement is within a few tens of feet from the hill.

Many field hazards that can seriously affect field intensity measurements may be recognized, therefore making it possible to evaluate the amount of geologic influence.

10. For any period up to six hours during the daytime, under relatively constant weather conditions, meteorological effects on ground-wave signal intensity appear to be negligible.

11. The Shawneetown - Rough Creek fault in Illinois and Kentucky and the Inman East fault in Illinois are apparently responsible for signal strength anomalies on traverses across them. Lithologic discontinuity probably causes a discontinuity in electromagnetic waves and is reflected in signal strength behavior. It would therefore appear feasible to map similar features by this technique.

12. Signal strength is affected near the Kentland quarries in the cryptovolcanic structure in northwestern Indiana. It increases for signals originating on Ordovician, Silurian, or Devonian terrain, but does not change for signals originating on Pennsylvanian terrain.

13. Signal intensity decreases over the core of Hicks dome in Hardin County, Ill. The signal, transmitted from Pennsylvanian terrain, decreased in strength as the dipping rocks were traversed from younger to older towards the core. It is expected that similar lithologic contrasts elsewhere can be mapped by this method.

14. Data from the traverses across known geologic features (11, 12, 13) suggest that part of a radio field may be transmitted or propagated by or along bedrock strata. Signal intensity is high over the Inman East fault. Here, the West Franklin limestone may be carrying some of the radio field from Evansville, Ind.

In the Kentland area in Indiana, part of the radio field appears to enter the cryptovolcanic structure along Ordovician, Silurian, and Devonian bedrock, thus increasing signal intensity measurably over the regional level.

At Hicks dome, signal intensity decreases over the older beds across the core of the dome. A signal, originating on Pennsylvanian terrain, was stronger over Pennsylvanian rocks around the flanks of the dome than it was over the Devonian and Mississippian rocks across the dome.

Signal strength behavior becomes more understandable if, in addition to atmospheric propagation, transmission along bedrock is postulated. Apparently limestone with high electrical resistivity offers a path for radio energy along which attenuation is less than it is along shales, siltstones, or sandstones. It seems probable that certain bedrock strata may act as wave-guides.

15. In the Galena area in Illinois no signal anomalies can be attributed solely to the influence of the poorly conductive zinc ore mineral sphalerite. A rich concentration of pyrite and marcasite at shallow depths caused at least one strong signal anomaly (decrease in strength). Signal anomalies over the Kittoe ore body are attributed at least in part to the conductive minerals

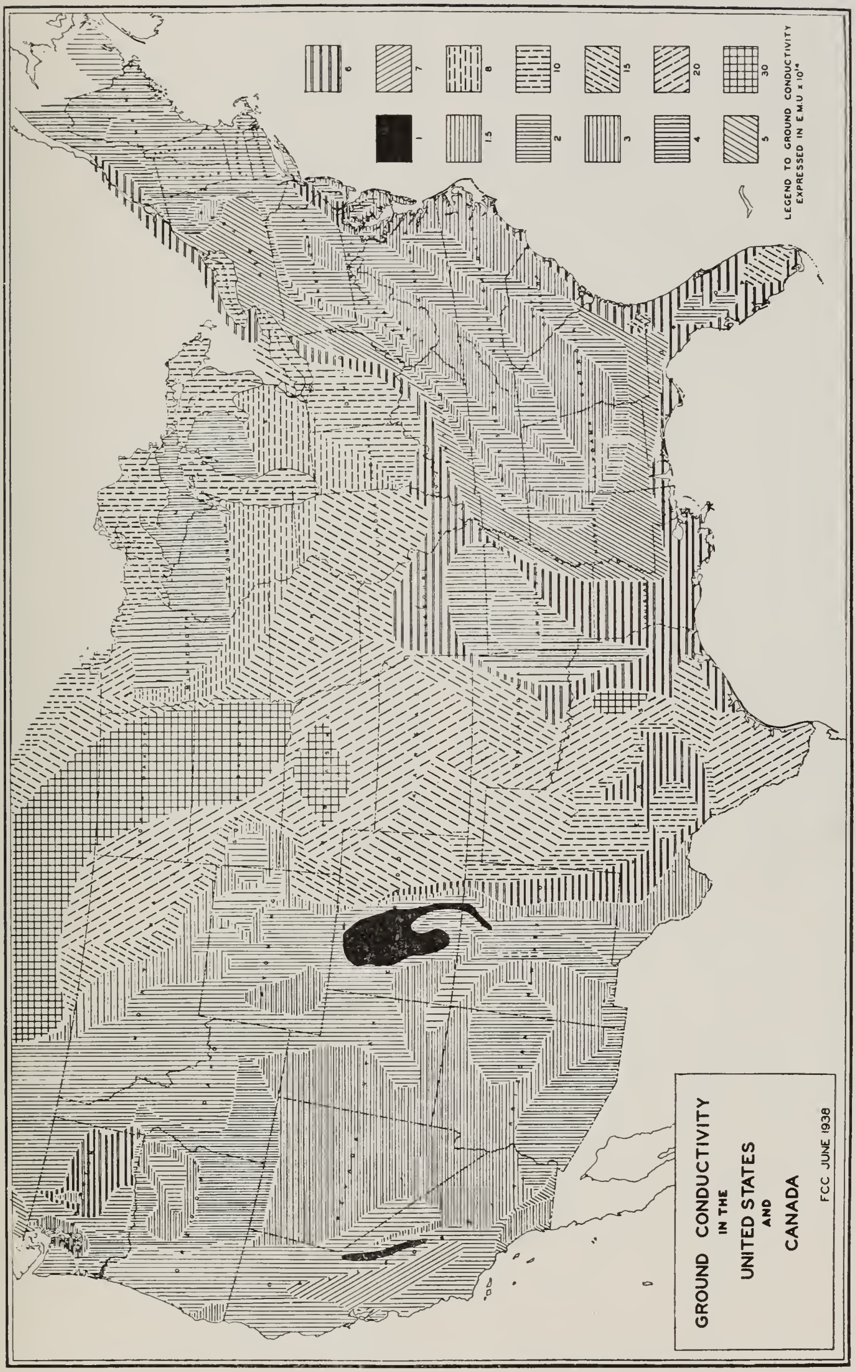

FIG. 41.—FCC map of ground conductivity in the United States.

associated with the ore at shallow depths. The Maquoketa shale in the Galena area and some Pennsylvanian shales in southern Illinois appear to act as shields to radio fields, thereby preventing penetration to the strata beneath the shales.

16. Soils developed on glacial till, or on loess overlying glacial till, appear to have little if any influence on signal intensity.

17. Depth to bedrock may influence signal strength in some places, but the kind and amount of influence has not yet been satisfactorily determined. Several traverses crossed bedrock valleys where depth to bedrock is known to be variable, but the signal anomalies cannot be attributed solely to changes in depth to bedrock.

The same is true of sand and gravel deposits in glacial drift; traverses run over known deposits sometimes produce signal anomalies but cannot be attributed solely to the influence of the deposits on signal intensity.

18. Where the geology offers discontinuities to electromagnetic waves, and field hazards are few, radio field intensity surveying offers promise of a rapid and economical means of getting data to construct reconnaissance geological maps. The steplike character of the intensity curve recorded across the flank of Hicks Dome is an example, and this kind of surveying should be applicable in any area where bedrock is within 50-100 feet of the surface and field hazards are few. If overwhelming field hazards along roads are unavoidable, the method could be tried by boat down rivers and streams. Intensity surveying from a slow, low-flying aircraft, above field hazards, could be tried.

19. In general, when transmitting and receiving antennas are on (or close to) the same rock strata, reception is best.

20. Direct electromagnetic energization of highly electrically resistant strata might be attempted. A section thus energized might be traced (in drill holes if necessary) to determine areal extent, structure, conductive ore deposits, and lithologic changes such as reefs. It is possible that a system of underground communication could be established which would prove practical under special circumstances.

21. Knowledge of the behavior of radio waves over, along, and through bedrock can aid in the selection of good locations for various types of radio communication equipment.

22. Further study of radio wave intensity and polarization, related to geologic structure, is needed to help resolve the method.

APPENDIX A

FCC GROUND CONDUCTIVITY MAP OF THE U.S.

A ground conductivity map[1] prepared in 1938 by the Broadcast Division of the Bureau of Engineering of the Federal Communications Commission, agrees remarkably well with the geological map of the United States (fig. 41). This agreement led to conjecture about the relationship between geology and radio wave transmission and was the starting point of the present work.

Communication with T. J. Slowie[2] revealed how the map was made. Field intensity measurements, taken by major broadcasting companies, individual stations, and the FCC staff, were examined for their association with soil types, geologic formations, topography, and vegetation. At that time there were comparatively few measurements, particularly over large distances, and ground conductivities for such areas were approximated from the values that soil types, geologic formations, topography, and vegetation exhibited in other areas where conductivities were known by actual measurement. In the preparation of the map, reference was made to the U. S. Geological Survey's *Geologic Map of the United States* and several "Soil Regions" maps of the U. S. Department of Agriculture.

The FCC has found discrepancies in certain areas. The most significant errors have been where conductivity estimates were made for restricted areas. Thus, conductivity along ridges in a mountainous region may be considerably less than estimated on the map; along the axes of valleys conductivity may be far greater than estimated. In general the map has been accurate, and the abundant conductivity data collected between 1938-1949 has not required any major revision.

ANALYSIS OF MAP

Ground conductivity is expressed in electromagnetic units (emu); 1×10^{-14} emu represents poor conductivity and 30×10^{-14} emu, good conductivity. Analysis of the ground conductivity areas of the map was made for the age of rocks outcropping in them.

Ground conductivity values for rocks of all ages were tabulated by outcrop areas, and an average conductivity value was estimated for each geological period. For pre-Cambrian and intrusive rocks, conductivity is low (3×10^{-14} emu); conductivity increases through the successive periods of the Paleozoic reaching a high of 15×10^{-14} emu in Permian outcrop areas; averages 7×10^{-14} emu for Triassic and Jurassic rocks; is 10×10^{-14} emu for Lower Cretaceous and reaches a high of 20×10^{-14} emu for Upper Cretaceous rocks; Eocene rocks average 14×10^{-14} emu, Oligocene 5×10^{-14} emu, and Miocene and Pliocene average 7×10^{-14} emu in their outcrop areas.

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[1] Standards of good engineering practice, *op. cit.*, Fig. 3.

[2] Slowie, T. J., Secretary of the FCC, Washington, D.C., 1949.

APPENDIX B

GLOSSARY OF RADIO TERMS

Absorption—The loss of energy from a wave by dissipation in propagation through or adjacent to a dissipative medium.

Atmospheric noise—Noise caused by natural electrical discharges in the atmosphere (also called "static").

Attenuation—Of a wave, the decrease in displacement with distance in the direction of propagation. If the attenuation varies with frequency, it is defined for a sinusoidal wave of a certain frequency and of constant amplitude at any point. The attenuation of a wave may be defined relative to the attenuation in some ideal conditions such as in free space or over a perfectly conducting plane.

Conduction of current—1. Metallic: conduction due to the movement of free electrons. 2. Electrolytic: conduction from the transport of ions in electrolytes. 3. Dielectric: no free electrons available.

Conductivity of earth materials—Good, 10 x 10^{-14} emu and above; intermediate, about 5 x 10^{-14} emu; poor, 1.0 x 10^{-14} emu. Specific rocks and minerals may be divided into three groups as to resistivity: Good conductivity, 10^{-6} to 10 ohm-centimeters; intermediate, 10^{2} to 10^{9} ohm-centimeters; poor, 10^{10} to 10^{17} ohm-centimeters.

db.—Zero decibel is the threshold of hearing, 60 db. is the level of ordinary conversation, and 120 db. is the level of thunder.

Dielectric—Nonconducting for direct current, an insulating medium such as air, glass, oil, or mica, but will conduct alternating current.

Dielectric constant—The presence of a dielectric other than a vacuum raises the capacity of a condenser in comparison to its capacity in the absence of the dielectric by a factor known as the dielectric constant. The dielectric constant of air is 1 and sea water is 81.

Displacement—A change in a medium, proportional to the square root of the stored energy of a certain kind. It is exemplified by compression in a sound wave and by electric or magnetic flux density in an electromagnetic wave.

Electromagnetic wave—A wave in which there are both electric and magnetic displacements. Electromagnetic waves are known as radio waves, heat rays, light, X-rays, etc., depending on the frequency.

emu—Electromagnetic cgs units. The electromagnetic system of cgs units (abbreviated emu) results if one uses centimeters, grams, and seconds, and then arbitrarily assumes that the magnetic permeance of a centimeter cube in a vacuum is unity.

Fading—The variation of radio field intensity caused by changes in the transmission medium.

Field—Open country, woods, swamps, hills, rolling land, place of outdoor operations in geologic and geophysical investigations.

Field—A portion of space controlled or affected by a force.

Ground reflected wave—The component of the ground-wave that is reflected from the ground.

Ground-wave—A radio wave that is propagated over the earth and is ordinarily affected by the presence of the ground. The ground-wave includes all components of a radio wave over the earth except ionospheric waves and tropospheric waves. The ground-wave is somewhat refracted by the normal gradient of the dielectric constant of the lower atmosphere.

Guided wave—A wave whose propagation is concentrated in certain directions within or near boundaries between materials of different properties located in a path between two places.

I.F.—Intermediate frequency.

Ionosphere—That part of the earth's atmosphere above the lowest level at which the ionization is large compared with that at the ground, so that it affects the transmission of radio waves. (Experiments indicate that this lowest level is about 50 kilometers above the earth's surface.)

Ionospheric wave (sky-wave)—A radio wave that is propagated by reflection from the ionosphere; sometimes called a sky-wave.

Noise—Rushing, crackling, popping sound heard in a receiver.

Noise level—Amount of noise with relation to the signal being received; signal to noise ratio.

Plane-earth attenuation—The attenuation over an imperfectly conducting plane-earth in excess of that over a perfectly conducting plane.

Radio field—Wave energy from an antenna with the following properties measurable: The potential of the field, the potential gradient or intensity of the field, and the direction and polarization of the field.

Radio field intensity, radio wave intensity, field strength, signal strength—The electric or magnetic field intensity at a given location resulting from the passage of radio waves. It is commonly expressed in terms of the electric field intensity. Unless otherwise stated, it is taken in the direction of maximum field intensity.

Radio frequency—A frequency at which electromagnetic radiation of energy is useful for communication purposes. (The present useful limits of radio frequencies are roughly 10 kilocycles to 10,000 megacycles.)

Radio interference—An undesired disturbance in reception, or that which causes the disturbance. It may be a disturbance in the radio transmitter, the transmission medium, or the radio receiver. Examples are: Background interference in the transmitter, undesired electromagnetic disturbance in the transmission medium as by lightning or undesired radio waves, and hum or thermal agitation in the receiver.

Radio wave propagation—The transfer of energy by electromagnetic radiation at radio frequencies.

Reflected wave—The wave caused by the reflection of part of an incident wave back into the first medium.

Refracted wave—The wave caused by the refraction of the part of an incident wave which travels into the second medium.

Resistance—The opposition to a steady electron flow.

Secondary fields—Eddy currents.

Sinusoidal wave—A wave whose displacement is the sine (or cosine) of an angle proportional to time or distance or both.

Spherical-earth attenuation—The attenuation over a perfectly conducting spherical-earth in excess of that over a perfectly conducting plane.

Transverse electromagnetic wave—An electromagnetic wave in which both electric and magnetic displacements are transverse to the direction of propagation; called a TEM wave.

Troposphere—That part of the earth's atmosphere in which temperature generally decreases with altitude, clouds form, and convection is active. (Experiments indicate that the troposphere occupies the space above the earth's surface to a height of about 10 kilometers.)

Tropospheric wave—A radio wave that is propagated by reflection from a place of abrupt change in the dielectric constant or its gradient with position in the troposphere.

Wave—A disturbance propagated through a medium. Also, the graphical representation of a wave or of any periodic variation.

Wave duct—A wave guide with tabular boundaries capable of concentrating the propagation of waves within its boundaries.

Wave-guide—A system of material boundaries capable of guiding waves.

Wave length—In a periodic wave, the distance between corresponding phases of two consecutive cycles. It is equal to the quotient of phase velocity by frequency.

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