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FOIA Request
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DEPARTMENT OF THE ARMY
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May 19, 2023

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Sincerely,

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Michael T. Heaton
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ELECTROMAGNETIC PROPAGATION THROUGH THE EARTH'S CRUST (U)

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ELECTROMAGNETIC PROPAGATION THROUGH THE EARTH'S CRUST (U)

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April 1968

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PREFACE

(U) ~~(C)~~ The purpose of this study is to provide information pertaining to the extent and nature of Soviet interest in the propagation of electromagnetic signals through the deep crust of the earth or in connection with the exploitation of a propagation capability for communication, command control, or detection. A projection is made through 1976.

(U) ~~(C)~~ Interest centers on A. C. propagation in the frequency range nominally from 1 or 2 Hz up to 10 kHz, but this range has been broadened to include the specific frequency ranges considered optimum for particular underground modes of propagation. Supporting research has included laboratory studies of the conductivity and dielectric coefficient of rocks as functions of structure, temperature, and pressure.

(U) ~~(C)~~ Only a few open-source references have indicated Soviet interest in underground communications, and these cite primarily US research. But the USSR is conducting several major programs that might serve as a valuable or necessary support in developing underground communications, and these programs are discussed.

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SUMMARY

(U) ~~(S)~~ A review of intelligence reports and of open literature indicates that the USSR is fully aware of each basic mode of underground electromagnetic propagation and is conducting many types of research that might support the planning of an operational communication system, but has not revealed any specific interest in developing such a system.

(U) ~~(S)~~ The modes of propagation considered include antennas buried just beneath the surface, antennas located deep in the upper layer of the earth's crust, antennas placed in the resistive waveguide layer below 10 km, and a nonradiative method of communication by ground conduction.

(U) ~~(S)~~ Shallow burial of antennas is easy to accomplish without technical complications, so the USSR should be assumed capable of using this mode of communication at any time to provide simple physical protection for terminal stations. Such a system would not be protected from jamming, from nuclear blackout, nor from monitoring.

(U) ~~(S)~~ Deeper burial of the antennas, short of the resistive waveguide layer, does not appear to offer a significant advantage except in a very special geological formation (such as a dry salt layer) or where communication is desired with an underground stronghold. The only technical problem is a requirement for enormous power and a restriction to low frequency ranges, with little information capacity.

(U) ~~(S)~~ If the many published accounts of the Soviet program in superdeep drilling are accurate--as they appear to be--the USSR will not be able to test a prototype communication or detection system in the resistive waveguide layer prior to 1976. At least two holes more than 10 km deep must be completed, and the less ambitious holes now in progress are advancing slowly. Drastic improvements in drilling technique will be required to overcome the problems imposed by high temperature and high pressure at the necessary depths.

(U) ~~(S)~~ The dipole method of electrical prospecting, originated by the USSR, might be used to meet special communication requirements where a system of moderate range and severely restricted information capacity is sufficient. This mode cannot be extended for ranges beyond about 100 km without multiple repeating stations or prohibitive power consumption. A signal might be difficult to monitor.

(U) ~~(S)~~ Many individual Soviet researchers are using electrical and seismic procedures to study the earth's crust, and their findings would be valuable for

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SUMMARY (Continued)

planning a communication or detection system. Other researchers have been studying the electrical properties of various types of rock at temperatures and pressures representative of the waveguide layer. These scientists do not appear to be organized into a formal development program for underground communications, but some work, particularly in the observation of magnetotelluric phenomena, may be redirected quite easily toward communication or detection.

(U) ~~(S)~~ The Soviets have been aware for some time of the capabilities of magnetotelluric nuclear explosion detection systems. They have operated a large network of telluric current stations since at least 1958.

ELECTROMAGNETIC PROPAGATION THROUGH THE EARTH'S CRUST (U)

A. (U) ~~(S)~~ TYPES OF UNDERGROUND COMMUNICATION AND DETECTION

1. (U) ~~(S)~~ GENERAL CONSIDERATIONS

Although the upper layers of the earth are electrically conductive and therefore absorb radio waves, special cases exist in which electromagnetic signals may propagate for fairly long distances underground. In some instances, these signals cannot be detected from above the ground. Several basically different mechanisms may be used to describe the various modes of propagation. Some of these mechanisms are suitable for creating hardened communication paths that would be indestructible and immune to jamming or detection. An excellent summary of the technical consideration for underground communication has been presented by J. R. Wait, who included many of the foreign publications in his review.[1*]

2. (U) ~~(S)~~ SHALLOW ANTENNAS

a. The simplest form of underground radio terminal requires only a buried directional antenna array and electronics, perhaps a meter or two beneath the surface.[2] The layer of dirt surrounding the antenna imposes some minor changes in the sizes and spacing of the antenna parts, but not much difference in design. The layer should be well drained to minimize its radio absorption. Much of the signal may be lost at each terminal, but virtually the entire propagation path is actually above the surface. Depending upon transmitter power, antenna burial depth, antenna configuration, ionospheric absorption, and other design and technical parameters, the terminals may be separated by 1000 to 3000 km utilizing radio frequencies in the HF band. A "hardened" system of this type would provide protection up to 1000 psi but would be vulnerable to nuclear atmospheric distortion, monitoring, and jamming in the skywave mode.

b. The technical aspects of this operation, sometimes called the "up-over-down" mode, have been summarized elsewhere.[3] There are three important types of signal loss: the attenuation because of antenna burial in a partially conducting medium, the coupling loss of the antenna, and the normal radio attenuation with range. The problem of antenna coupling has been investigated by A. P. Ivanov and others.[4] D. Staiman and T. Tamir, in the United States, have

*Superior numbers appearing throughout the study refer to references contained in the bibliography (Appendix I) shown how the signal may be optimized under special conditions by tilting the buried antenna.[5] G. A. Lavrov and A. S. Knyazev have discussed the use of near-surface underground antennas and have made actual measurements of direction patterns and field strengths.[8]

c. Because the technology needed to understand and construct a shallow-antenna communication system is practically identical to that required for conventional radio in the same frequency range, the Soviet Union may be considered fully competent to install and operate such equipment. Evidence suggests that such an antenna system has been installed in the Zossev Weinsdorf area of East Germany, which could portend its deployment within the Soviet Union. Measurement of the electrical properties of the soil in each selected terminal site, optimization of the directivity patterns of buried antennas, and selection of the most efficient frequencies for propagation would have to be accomplished before installation of such an antenna system.

3. (U) ~~(C)~~ THE WAVEGUIDE LAYER

a. If the antennas are buried progressively deeper, the absorption loss becomes severe; however, a substantial part of the signal travels entirely underground from one terminal to the other. The losses may be minimized by choosing favorable terrain and by using a low carrier frequency, with a corresponding decrease in information capacity. Deeper burial does not readily improve the system security, however, and probably would not be worthwhile unless a direct nuclear strike were anticipated. Under good conditions, a range of several kilometers might be possible.

b. With a much deeper burial--deeper than petroleum drilling technology has yet achieved--a particularly favorable condition becomes available, and it may provide a secure system. Radio absorption in rock depends upon the electrical conductivity of the rock; conductive rock absorbs radio waves. Near the earth's surface, the rock is interrupted by numerous fine cracks filled with water, and the water contains dissolved salts with high conductivity. Such rocks may exhibit an average bulk conductivity of 6×10^{-4}mho/meter or more. At greater depths, the rock is warm, dry, and nearly unbroken. Its conductivity may be as low as 2×10^{-6}mho/meter, a 300-fold decrease. But still deeper, the rocks are hot enough that ionic conductivity is important, and the rocks become even more conductive than those near the surface. The intermediate layer of lowest conductivity is typically 3 or 4 km thick and may be 10 km or more beneath the surface. This layer would be a good medium for the propagation of radio waves, as in a large waveguide, if an antenna could be placed in it--but no hole deep enough has yet been drilled. Knowledge of the electrical properties of the deep rocks has come from direct resistivity measurements (with widely separated electrodes in the surface of the earth) and from indirect resistivity measurements obtained through observations of telluric currents. Certain other information, such as the frequency dependence of the electrical properties, has been found by laboratory studies of rocks at high pressures and temperatures.

c. The waveguide layer will be selective in the frequency band that may propagate. Absorption losses are great at high frequencies since the attenuation of the signal is exponential, with the exponent roughly proportional to the square root of the frequency. At low frequencies there is another limit, for the waveguide will not pass wavelengths longer than about twice the electrical thickness of the layer. Depending upon local conditions, the optimun propagation frequency will be somewhere between 100 kHz and 1 MHz, with frequencies outside of the band sharply attenuated.

d. This waveguide-layer mode has been discussed at length in a review paper by A. M. Ryazantsev and A. V. Shabel'nikov.[7] Although their bibliography contains 176 literature references, the Soviet papers cited discuss only geological considerations and laboratory measurements. Nearly all the technical discussion of underground electromagnetic propagation is represented by US sources--most of them from a single volume of an I. E. E. E. journal.[8] One may speculate about the absence of Soviet literature on this subject, in view of the broad USSR interest and competence in all forms of radio propagation. Perhaps Soviet experiments in underground communication exist and are classified just high enough to be kept out of professional literature, but not so high that all discussion is prohibited. M. P. Dolukhanov has casually included underground radio waves in a general review article about radio wave propagation, but has not cited particular work.[9] A bibliography of Soviet-Bloc literature on underground communications, compiled by A. I. D. of the Library of Congress in 1963, lists not one publication specifically showing an interest in underground radio.[10]

4. (U) ~~(C)~~ GROUND CONDUCTION

a. An entirely different mode of signal propagation, not truly a form of radio, may be practical for some purposes. When an electric current is applied to a pair of electrodes grounded some distance apart, a current distribution pattern is established in the earth, and the size of this pattern is much greater than the electrode separation. A second pair of grounded electrodes, distant from the first, will exhibit a very small voltage difference related to the current flow in the first pair. The strength of a signal received in this way diminishes much faster with distance than a radio signal would, but further losses from ground absorption may be made quite small by using a very low frequency, perhaps in the audio range or below. (Even a direct current could be used, although the received signal would be impractical to detect.) Since essentially no electrical signal enters the air, a communication system based on this mode of propagation is fairly secure, although the signals may be monitored with very sensitive receiving equipment attached to another pair of grounded electrodes. Monitoring quickly becomes impractical at distances farther than the intended range of the system.

b. If the receiving electrodes are moved farther from the transmitting electrodes, while maintaining the same separation in each pair, the received voltage will at first fall with the cube of the range at low frequencies. For ranges on the order of 20 km and beyond, the voltage received will vary with the inverse square of the range, as a result of the insulating layer some 10 km deep. For higher frequencies, those inverse-cube and inverse-square formulas must be multiplied by an exponential attenuation factor. (The exponent depends upon range and upon the square roots of frequency and conductivity.) The power input for a short-range communication system of this type has very little influence on the range: doubling the power would increase the range only 12%. Even without the exponential attenuation, a long-range system (more than 20 km) could be extended only about 20% in range by a doubling of the power. With high frequencies, and therefore more exponential attenuation, added power has even less influence upon maximum range.

c. An increase in the electrode pair separation at the transmitter, at the receiver, or at both is far more effective for achieving longer range. A fairly large electrode spacing may still require much less wire than would a buried telephone line directly connecting the terminal stations. The range (for low frequencies) may be doubled by increasing both spacings by a factor of 2 8, in the case of ranges less than about 20 km, and by doubling both spacings in a longer range system.

d. Even with ideal conditions, a long-range system of this type will be so severely restricted in frequency and bandwidth that only the simplest messages can be carried in a reasonable time; but for some special purposes (such as an alert signal or a command to fire), this mode might be entirely adequate. The restriction on the frequency bandwidth arises in the exponential attenuation factor cited above. At 1 Hz, a signal propagating through average surface rock and soil will drop to 63.2% of its strength, through absorption, in every successive interval of about 28 km. At 1 kHz, the reduction to 63.2% occurs every 0.89 km, which may be prohibitive. These absorption losses are in addition to the inverse-cube or inverse-square decrease.

5. (U) ~~(S)~~ DETECTING NUCLEAR EXPLOSIONS

a. A nuclear explosion generates an intense electrical impulse that may be detected with a radio receiver or by measurement of sudden voltage gradients set up in the earth's crust. Very little energy would reach the low-conductivity waveguide layer 10 km or more deep, but the small signal which did reach that layer might be expected to travel large distances. Either this waveguide-layer mode of propagation or the ground-conductivity mode might, in principle, be used to detect surface or underground nuclear explosions. C. C. Bates has explained some of the limitations and possibilities.[11] Soviet open literature does not appear to offer more information or to disclose an interest in this application, but the potential is obvious, and Soviet scientists are now using perfectly suitable nuclear-voltage receiving equipment for their studies of telluric currents and for some types of geophysical exploration.

b. When a nuclear device is buried deeply enough to attenuate the emitted radio signals in some frequency band, but not deeply enough to penetrate to the waveguide layer near 10 km, that frequency band will be essentially worthless for detection and none of the mechanisms of underground radio progagation will improve remote sensing. If the nuclear device were actually placed in or near the waveguide layer--a remote prospect for another decade or more--an electromagnetic signal undetectable at or above the earth's surface would indeed be expected to propagate long distances in the waveguide layer, detectable only with an antenna buried to similar depth. The problem of burial attenuation does not apply to use of ground currents for detection, and the distant signal received by a telluric current recorder will be about the same with or without burial of the device.

c. The electromagnetic effects of a nuclear explosion are recognized by the Soviets. An article by Eng. Col. Ya. I. Fayenov and Eng. Maj. I. S. Krasil'nikov reported the electromagnetic results of US and British nuclear tests held from 1958 to 1963 and the probable mechanisms by which radio waves are produced.[12] They also report an American estimate that a 50-megaton bomb exploded at an altitude of 80 km would cause a radio communication blackout for about one day within a radius of 400 km. Underground communication of the waveguide type would be virtually immune to such a blackout, but shallow burial of the antennas offers no real improvement, except for short distances (usually less than 50 km) where a ground wave component of the buried antenna would be effective.

d. Many of the electromagnetic and seismic properties of nuclear explosions have been described in an excellent bibliography by Goldblatt.[13] Other sources of electromagnetic disturbance may also be detected by these same underground propagation modes, but extremely favorable conditions (of amplitude, range, background noise) will be required.

e. Magnetotelluric systems are capable of detecting subionospheric and ionospheric events, such as air-dropped exploded weapons. These systems are capable of giving rapid warning of the detonation of strategic size nuclear weapons at long distances. The magnetotelluric nuclear detection system achieves its greatest detection distance on the ionospheric explosions that are barely detectable with seismic systems.

f. Since 1958 the Soviets have operated a large network of earth-current stations. Many of these stations were reportedly directed by V. A. Troitskaya. Emphasis of these stations has been on measurements of the telluric electric field, rather than the magnetic field. This emphasis is probably because these systems are inherently more sensitive to wavelike pulsations of the earth's electromagnetic field in the frequency range of the solar wind and nuclear bomb disturbances than their magnetometer counterparts. The Soviets have done much of the pioneering work related to the amplitudes of the magnetic and electric field components of magnetotelluric disturbances.[14]

B. (U) ~~(C)~~ RELATED RESEARCH

6. (U) ~~(C)~~ DEEP DRILLING (6-12 km)

a. The low-conductivity electrical waveguide layer in the earth's crust can be exploited for propagation of communication signals only if an antenna is inserted into that layer by means of a deep hole. No hole yet drilled has been deep enough to test the feasibility of this mode.

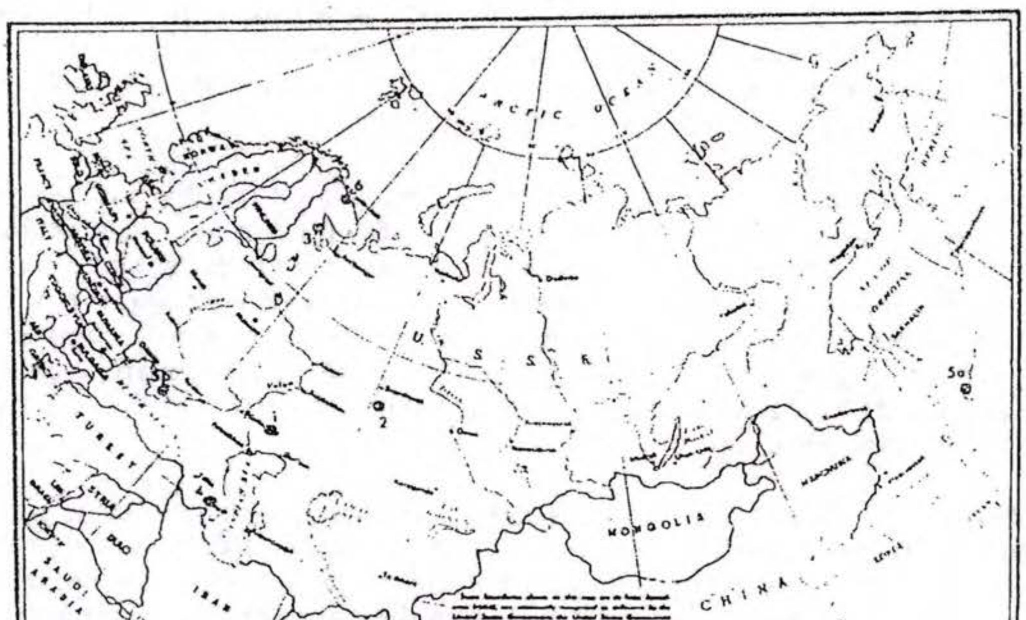
b. Since 1960, the Soviet Union has shown remarkable enthusiasm in drilling deep holes for "geological research" purposes. The economic value of such deep holes for petroleum or mining exploration is doubtful, and Soviet geologists who have been asked to explain the project have countered by asking why the United States wants to dig the Mohole. The planned deep holes actually would yield important basic geological information, and past Soviet geophysical projects, particularly in petroleum exploration, have never been affected noticeably by arguments that they were absurdly impractical.

c. Locations of the holes now planned, underlying geological structures, and status of the work are of more direct interest here. The Soviet Union has published many descriptions of the deep holes, both in professional journals and in the popular press.

d. N. A. Belyayevskiy has outlined the wishes of the geologists and discussed the types of location that might be selected for superdeep holes.[15] The earth's crust, extending from the surface downward to the Mohorovicic discontinuity level and the upper part of the earth's "mantle" layer, varies in thickness from 3 to 7 km under oceans, 60 to 75 km in the high mountain regions of the land masses. Seismic studies show that the crustal layer is composed of thinner layers with different physical properties. From the top, the three major layers are sedimentary, granitic, and basaltic rock. Depending on the location, the sedimentary layer may be absent or may be as much as 15 km thick. The granitic layer may be from 0 to 30 km deep, and the basaltic layer varies in depth from 5 to 40 km. Under a typical ocean the sedimentary and granitic layers are thin or absent, and the basaltic layer is no more than 5 km thick. Under the mountains of a continent, such as the Asiatic land mass, the sedimentary and granitic layers may total 45 km in thickness, and the basaltic layer may be 25 to 30 km thick. Although indirect geophysical techniques provide much information about the materials of the crust, Soviet geologists desire a series of superdeep holes drilled in various parts of the USSR to explore and sample the different types of layering.

e. Belyayevskiy believes that two of the holes should be drilled in the Caspian depression (platform structure) and in the Urals (geosyncline) to penetrate the full depth of sedimentary rock. Another should be drilled in Karelia to study the granitic layer, and a fourth in the Trans-Caucasus to study the basaltic layer. A fifth hole is suggested for the Kuriles island chain to penetrate the Mohorovicic discontinuity and reach the upper mantle, as the US "Mohole" was intended to do.

(1) The Caspian depression, in the region of the Aralsorsk and Khobdinsk gravitational maxima (site 1, figure 1), is of particular interest because of its steep subsurface temperature gradient and the large gas and petroleum deposits in the area. Belyayevskiy suggests that the lowest sedimentary rocks there may be undergoing metamorphosis and hopes that the lower limit of petroleum deposits can be learned. According to D. I. Mendeleyev, petroleum may originate inorganically by polymerization of gas at extreme pressures, and a deep hole in the Caspian depression could test this view. Such a hole would establish the stratigraphic sequence in the region and would clarify the physical properties of the lower rocks. The total depth required might be 13 to 15 km. A test hole planned for 7 km was in progress in 1961.



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1. epi-Caspian depression
2. Urals
3. Krelia
4. Trans-Caucasus
5a. Southern Kuriles
5b. Crimean Peninsula
6. Kola Peninsula

Figure 1. Proposed superdeep drilling sites in the USSR (U)

(2) The Ural geosyncline contains large concentrations of copper, iron, titanium, chromium, aluminum, and other ores and might provide an opportunity to study ore formation at great depths. The region of Karabash has the greatest quantity of these deposits, and superdeep drilling equipment can be constructed in the nearby industrial centers. In the Urals the temperature gradient is small, the temperature rising to about 200°C or less at 15 km deep. Bulashevich et al. believe that the most favorable site in the Urals is in the Tagil-Magnitogorsk synclineorium in the Verkhotur'ye-Krasnoural'sk region[16] (site 2).

(3) Northern Karelia, in the Kem' region (site 3), is one of the few places in the USSR where the granite-basalt boundary is only 8 to 10 km deep. The geologic formations are quite ancient and are related to the Baltic crystalline shield. Information learned by deep drilling will be easier to interpret at this because the geology of the region has been studied extensively. Uniform structure will facilitate drilling, and the hole should extend to 15 km.

(4) In Azerbaydzhan, near the settlement of Karadonia in the eastern part of the Kurina depression (site 4), seismic depth soundings have shown that the basaltic layer is only 5 to 8 km deep. There is probably no granitic layer in this part of the Trans-Caucasus. Little is known about the actual state of the rock in the basaltic layer, and a hole to investigate it would provide knowledge valuable for understanding the geology of seas and oceans as well. Other questions that might be answered pertain to the deep origins of ores, a study of water and aqueous solutions at high temperature and pressure, and also the vertical distribution of petroleum deposits common to the region.

(5) Kunashir, in the Kurile Islands (site 5a), offers the shortest route to the Mohorovicic discontinuity level in the entire Soviet Union. That level is only about 12 km deep there. Volcanic accumulations cover the surface to a depth of 3 to 4 km. A deep hole at Kunashir might also help to understand the unexplained origin of "island arcs," the strange groups of islands and mountain ranges that surround the Pacific Ocean. Belyayevskiy expects a steep temperature gradient and possibly some difficulty in drilling. (Presumably the USSR will select a substitute location before reaching the discontinuity.)

f. This brief outline has shown the geological purposes behind the Soviet deep-drilling program and the tentative selection of sites. Perhaps the USSR has no other motive for drilling superdeep holes. The sites actually chosen, as listed more recently by Academician Shcherbakov, are the same as those suggested by Belyayevskiy except that the Crimean Peninsula (site 5b, figure 1) replaces the Kurile Islands as the location of the Soviet "Mohole."[17] A. Simirnov has listed a sixth drilling site, on the Kola Peninsula, where an attempt may be made to learn more about granite and basalt and the gradation from continent to ocean.[18]

g. The deepest hole yet drilled by the Soviets is near Lake Aral-Sor in the Zapadno-Kazakhstanskaya Oblast, in the Caspian Depression north of the Caspian

Sea. Drilling began late in 1961. This work has been conducted by the Ministry of Geology and Ore Conservation of the Kazakh SSR, aided by scientists from the Moscow Institute of the Petrochemical and Gas Industry imeni I. M. Gubkin.[19] Vast reserves of petroleum and natural gas are expected at great depths. Two wells were planned, the first situated between two salt domes 25 km north of Lake Aral-Sor. By 1964 the first hole was 5.43 km deep, and by late 1966 it had penetrated to 6.3 km. At this depth it was abandoned because of technical difficulties in drilling. Two professional papers have described the temperature profile and other early measurements in this hole.[20 21] Its depth was to be 7 km--a good beginning for the superdeep drilling program but still short of the 7.77-km depth reached in Texas during 1958. A. A. Ali-Zade and G. A. Akhmedov have discussed the geology of the nearby Apsheron Peninsula, where the second Caspian superdeep hole is being drilled.[22] This hole had reached a depth of 6.5 km in January 1967. If they ultimately are made deep enough, these two holes might be excellent for underground communication experiments.

h. In addition to the argument that the deep holes may reveal mineral wealth, various Soviet geologists have advocated tapping the high-temperature rocks at great depths as a source of heat for geothermal power generation. Although geothermal power is practical, the suggestion of drilling deep holes for it is not. The higher temperatures in deep layers offer both greater heat flow and higher conversion efficiency, but the advantages increase no faster than the square of the depth. Costs increase much faster with depth, so a given amount of power may be obtained more efficiently from several holes of moderate depth than from one superdeep hole.

i. In 1961, the program of superdeep drilling was reported to be part of the 7-year plan then in effect for developing the national economy of the USSR.[23] In 1966, a proposed 5-year plan for economic development also included superdeep drilling, with emphasis on the study of deep mineral deposits.[24] Evidently the USSR plans to pursue the drilling programs that have been publicized, and may eventually have antennas deep enough to communicate through the electromagnetic waveguide layer.

j. Participating organizations include the Institut Fizik, Zemli, ANSSSR; the Moskovskiy Institut Nefte-Khimicheskiy i Gazovy Promyshlennosti imeni I. M. Gubkina; the Vsesoyuznyy Nauchno-Issledovatel'skiy Institut Burovoy Tekhniki - VNIIBT; the Gusudarstvennyy Nauchno-Issledova-tel'skiy i Proyektniy Institut Neftyanogo Mashinostroyeniya; and the Vesesoyuznyy Nauchno-Issledovatel'skiy Geologorazvedochnyy Institut.[18]

7. (U) ~~(C)~~ DEEP ELECTRICAL MEASUREMENTS

a. The electrical properties of the earth's mass may be measured by applying current to buried electrodes and observing the resulting voltage distribution. When the electrodes are all spaced far apart, the electrical effects measured are influenced by properties of the rock at great depths. For practical reasons, four electrodes are generally used: two carry a standard current, and two are used to chart the distribution of voltage at the surface of the ground. Commonly, the four electrodes have been spaced along a straight line, with the voltage electrodes between the current electrodes.

b. The electrode spacing must be much greater than the depth investigated, and electrical measurements of a layer 10 km deep may require an electrode pattern 100 km long. Great practical difficulties exist in setting up the apparatus to provide high enough voltages and currents over such a distance. L. M. Al'pin and his students in the Soviet Union have demonstrated that deep measurements may be made much more simply if the two current electrodes are located within a few kilometers of each other at one end of the 100-km path and the voltage electrodes are similarly spaced at the other end.[35] No wires run the full distance. Significantly, this arrangement would also be effective for communicating with low frequbncy current over similar and greater distances.

c. G. V. Keller and others have reviewed the results, methods, and problems of studying the electrical properties of the earth's crust and underlying rock.[36-38] Keller and L. A. Anderson have also described a typical experiment in which a signal was propagated 60 km from a 5-km sending-selectrode pair to a 1-km receiving pair.[37] Their frequency was only 0.017 Hz, but a somewhat higher frequency could have been used. D. B. Jackson[28] attained a range of 100 km with an 8-km sending pair, a 1-km receiving pair, and a 720-volt, high-current power supply delivering 10 to 100 kw. Signals as weak as 10 μv/km could be detected at the receiver.

d. In typical soviet field measurements, a 50-ampere direct current is passed through a cable 4 km long with a grounded electrode at each end. A receiving loop antenna, in the form of a horizontal square 200 m on a side, is located 20 km away on a line perpendicular to the direction of the cable. Transmitted current pulses are of 1-minute duration.[29] To reduce the effect of noise, 100 received pulses are sampled at 5-second intervals, and the data is averaged digitally. Rocks as deep as 11 km may be studied with this arrangement. In 1965, about 750 electrical exploration crews were working in the Soviet Union; 500 were exploring for minerals and 250 were exploring for petroleum. Of those exploring for petroleum, 50 measured resistivity directly, 100 used the transient resistivity methods outlined above, and 120 used telluric current methods that will be described. Some miscellaneous Soviet research was reviewed in 1964.[34]

e. Key Soviet research in this field through 1963 has been collected in one volume.[30] This publication contains a review bibliography, an extensive analysis of the complex interpretation of measured electrical quantities, and a comprehensive graphical atlas of computed theoretical properties of specific geological configurations. These calculations would be of direct value in planning an earth-conduction communication facility, and the geological information found by conduction studies would also be needed for planning a radio communication path in the underground waveguide layer.

f. Aside from the use of electrical methods in geophysical prospecting, the conductivity of the earth's surface layers has an important influence upon the propagation of ordinary radio signals. Radio amateurs throughout the USSR were recently invited to make local measurements for compilation into a conductivity map of the USSR. Certain problems in making these measurements have been discussed by S. Ordzhonikidze of the Geological Survey Institute, Moscow.[31] Yu. K. Kalinin has also discussed the measurement of soil conductivity,[32] and V. S. Yampol'skiy has measured the frequency dependence of conductivity for surface rocks in Western Siberia, Kazakhstan, and Central Asia.[33] Most of these studies are concerned with rocks and soils too near the surface to have much importance for true underground communication.

8. (U) ~~(C)~~ MAGNETOTELLURIC STUDIES

a. In addition to electrical studies made with currents artificially applied to the earth's crust, much can be learned by careful measurements of natural electric and magnetic fields and by analysis of their fluctuations. Field variations are of several types, including the familiar slow drift of the magnetic poles. Irregular electrical pulses are generated by distant electrical storms, and disturbances of natural current in the ionosphere also appear as induced fields in the earth's crust. Other fluctuations may represent low-frequency electromagnetic radiation traveling through space and impinging upon the earth. These different types of fluctuation may be identified by characteristic patterns in a chart recording.

b. Cagniard has shown that measurement of fields associated with impinging radiation or ionospheric fluctuations can yield information on resistivity of the earth as a function of depth.[35] An effective resistivity can be found for each recorded frequency of fluctuation by taking the ratio of electric to magnetic field strength, squaring it, and multiplying by the period. The difference in phase between the electric and magnetic fields is also useful. The resistivity found for longer-period fluctuations is to some degree a measure of the average for rocks at great depths, and the variation of apparent resistivity with period is therefore a rough profile of resistivity at various depths, perhaps to a few hundred kilometers. Typical measurements in the United States and Canada have been reported by D. Plouff[36] and by K. Vozoff and R. M. Ellis.[37]

c. Soviet interest in the use of natural electric and magnetic fields for geological studies began during the International Geophysical Year activities.[38] A. N. Tikhonov and M. N. Berdichevskiy of the All-Union Scientific Research Institute of Geophysics, Moscow, recently reviewed the various forms of magnetotelluric exploration used in the USSR and outlined the advantages of these different techniques.[39]

d. The Soviet geophysical journals carry frequent reports of this research on natural electric and magnetic fields. Because the frequencies monitored are generally lower than the range emphasized in this study (less than 1 Hz--sometimes to 0.0001 Hz or lower), this work will not be detailed. But the associated technology, particularly the methods of extracting weak electrical signals from background noise of all kinds, is of some interest. (These methods are rarely mentioned in the reports of research projects, presumably because many of the geologists using the equipment know very little about it.) Soviet experience in geophysical exploration is certainly an asset in underground communication and detection, and the USSR is now conducting the world's largest programs in electrical geophysics.

e. In addition to the 120 or more field crews using natural electric and magnetic fields for local exploration, the USSR operates more than 20 fixed magnetotelluric observatories that constantly record natural variations. These observatories are located mainly along the perimeter of the USSR--perhaps to obtain the most representative data for the Soviet Union, but also possibly to optimize the reception of electrical signals from other parts of the world.[42] The magnetotelluric recording equipment is well suited for recording impulses generated by nuclear explosions, since it includes an electric or magnetic field sensor, low-noise amplifiers, a filter network to select a desired frequency band, and a chart recorder to display the wave form of each impulsive field variation.

f. Soviet programs appear to have departed only slightly from those described in a previous comprehensive study of this field.[40] This research will provide some data useful for evaluating the characteristics of the underground waveguide layer and could also be useful in a possible Soviet warning system.

g. Tikhonov, Deputy Director of the Mathematics Institute, ANSSSR, was awarded the 1966 Lenin Prize for an undisclosed series of experiments.[41] His active theoretical studies of telluric currents and wave propagation in an absorbing medium, in conjunction with the Institute of Physics of the Earth, probably have been followed by a successful experimental program of some practical interest, perhaps toward development of underground communication.

9. ~~(C)~~ (U) SEISMIC STUDIES

a. Notice should be taken of the excellent seismic research conducted in the USSR. The top Soviet seismologists lead their field. Although the USSR lacks the most modern instrumentation for collecting and rapidly processing large quantities of seismic data, very competent research is being done, and the theoretical interpretations are generally more advanced than those in the West. Seismic techniques must also be considered, in addition to electromagnetic techniques, in evaluating the Soviet capability to detect and evaluate nuclear detonations. Results of seismic measurements and theoretical research are published in great numbers in open literature.

b. Although the electrical methods used in geophysical exploration are of more direct interest for application to communication and detection, seismic methods have provided more detailed information about the layering of the earth s crust. This background understanding is essential for interpreting the electrical observations and is vital in selecting a site for a superdeep hole. Seismic studies, both with natural earthquakes and with explosive charges as acoustical sources, provide fairly detailed information about the character and depth of layers within the crust.

c. Typical recent seismic research which may be useful for the detection of nuclear explosions, or is indicative of the present level of Soviet competence in seismology, has been reviewed in the Geosciences and Technology Bulletin.[43]

10. (U) ~~(C)~~ LOW FREQUENCY RADIO

Historically, the USSR has shown more interest than the rest of the world in the propagation of low frequency radio waves and has a broad competence in the theory and practice of electromagnetic propagation. S V. Borodina et al. have surveyed the study of very long electromagnetic waves (between 10 Hz and 50 kHz) and cite 109 references, 12 of them Soviet.[44] (The predominance of non-Soviet reference does not reflect upon Soviet technology, because this is a review paper apparently written to acquaint Soviet researchers with work done elsewhere.) P. Ye. Krasnushkin and N. A. Yablochkin have also reviewed this topic, with emphasis on relating theory to experiment.[45] Both of these works consider waves propagating through the space between the earth's surface and the ionosphere, which acts as a type of waveguide. Although the underground waveguide layer is rather different in character, being filled with a glossy material, its boundary conditions are somewhat simpler, and much of the same type of theoretical treatment is applicable. This theoretical work will not eliminate the need for extensive testing before an underground waveguide system is developed, but may help in predicting the probable success of the venture.

11. (U) ~~(C)~~ LABORATORY SUPPORT

a. Because measurements of the electrical properties of deep rocks have been subject to experimental uncertainties, supplementary work has been undertaken in laboratories to determine the conductivity and dielectric coefficient of many types of rocks as functions of temperature, pressure, dampness, and frequency. Ryazantsev and Shabel'nikov have cited more than 40 of the many publications describing this research.[7] S. G. Hibben has cited eight more publications in a review paper on underground electromagnetic wave propagation.[46] These measurements support the conclusion that electrical conductivity should increase with depth in the earth, mostly because of the higher temperatures.[47] Pressure has a minor influence.[48] Apparently the conductivity also increases with frequency, except at the very highest temperatures studied.[47] The dielectric coefficient of rock, which also influences wave attenuation, increases with increasing temperature and slightly decreases with increasing frequency. Damp rocks, similar to

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those in the uppermost layers, exhibit the expected high conductivity.[49] These studies are entirely consistent with indirect measurements of conductivity in the earth's crust, and support the presumed existence of a waveguide layer.

b. Studies of the electrical properties of rocks at high temperatures and pressures do not appear to be classified in the USSR. This work is quite straightforward and would be useful for interpreting geophysical prospecting data as well as for planning a communication system.

C. (U) ~~(S)~~ SOVIET INTERESTS AND CAPABILITIES

12. (U) ~~(C)~~ INSTITUTIONS AND PROGRAMS

a. Soviet authors who have conducted research relevant to underground communication and detection are scattered among more than 20 institutes, most of them already named. Only one to four scientists at any one institute have reported such work, with one important exception: more than a dozen of the authors are associated with the Institute of the Physics of the Earth imeni O. Yu. Shmidt, AN SSSR. Their interests include shallow antennas, electrical prospecting, deep drilling, magnetotelluric studies, and some laboratory support work--a broad representation of the research applicable to communication or detection. These personnel are A. G. Ivanov, V. N. Nikitina, B. S. Eneshteyn, D. N. Shakhsuvarov, Ye. V. Rybakova, E. I. Parkhomenko, M. P. Volarovich, I. I. Rokityanskiy, Yu. I. Vasil'yev, B. P. D'yakonov, A. N. Tikhonov, V. A. Troitskaya, Yu. P. Bulashevich (Ural Affiliate), and A. G. Bondarenko.

b. Other institutions that have contributed very few known studies are the Sci. Res. Inst. of Geophysical Methods of Prospecting, the Math. Inst. imeni V. A. Steklova (AN SSSR), the Inst. of Mining and Geology (Ural Affiliate, AN SSSR), Moscow State U. imeni M. V. Lomonosov, Sci. Res. Inst. 88 (Podlipki), the Inst. for Geology of Useful Minerals (AN SSSR), the Leningrad State U. imeni A. A. Zhdanov, the Inst. of Radio Eng. and Electronics, the Inst of Terrestrial Magnetism, Ionosphere, and Radio Wave Propagation, the All-Union Sci. Res. Inst. for Geology, the Ministry of Geology and Mineral Conservation, the Inst. of Geophysics (Ural Affiliate, AN SSSR), the Inst. of Geology (AN SSSR), the Far Eastern Affiliate imeni V. L. Komarov (AN SSSR), the Moscow Petroleum Inst. imeni I. M. Gubkin, the (AN AzSSR), the Inst. of Geophysics (AN TuSSR), the Geology Inst. imeni I. M. Gubkin (AN AzSSR), the Moscow Inst. of Geophysical Prospecting imeni S. Ordzhonikidze, the Molotov State U. imeni A. M. Gor'kiy, and the All-Union Sci. Res. Inst. of Geophysical Prospecting. These establishments may have only a sporadic interest in the relevant research topics reported by them, or one or more classified programs may actually be in progress. No confirming information is available, and the work reported could be fully justified for scientific or industrial purposes.

(U)
13. ~~(S)~~ PROSPECTS FOR OPERATIONAL SYSTEMS

a. A hardened shallow-antenna type of communication system would be easy to build and operate with routine radio technology. If the Soviets have any interest in such a system, it will be easy for them to install, and assessments of the Soviet communication network should assume a capability for this mode of operation. Such a system affords the long-range skywave component no protection from jamming, monitoring, nor nuclear blackout; however, the system does afford the short-range ground component some added protection in all areas.

b. The existence of radio terminals with deeply buried antennas is doubtful. Little is to be gained by deeper burial (short of the waveguide layer), and enormous power must be used to overcome nearly prohibitive losses. Special cases exist, however, where an anomalous geological formation--such as a layer of dry rock salt--might provide the advantage of an underground waveguide without superdeep drilling. Locations for such a system would be restricted severely. Possibly a suitable layer exists in the Caspian depression, accessible to the deep holes now being drilled there. If the USSR is working on such a system, the work must be in a preliminary stage. This assessment does not rule out the use of a powerful radio system as an emergency communication link between the surface and an underground stronghold analogous to the US installation in Cheyenne Mountain, where an uneconomic method might be justified for an unusual purpose.[50]

c. The USSR apparently will require at least a decade to test a communication system in the natural rock waveguide layer near 10 km deep, and merely drilling holes that deep will be a burden for Soviet capabilities. Indications are that the USSR, for scientific prestige value, will announce most of the success in drilling such holes. To date, the Soviets have provided a surprising amount of publicity for their drilling endeavors, particularly in view of their lag of more than a decade behind the United States.

d. Soviet experience in electrical prospecting, particularly with Al'pin's dipole technique described earlier,[30] would make the ground-conductivity mode of communication available whenever desired. The information capacity of this system is severely restricted, but the information passed would be difficult for a monitor to identify or interpret. This mode offers little protection against the electrical jamming effect of multiple nuclear detonations. Longer ranges than the 60 km to 100 km now practical may be achieved by a series of relay stations. The USSR has expressed no interest in developing such a communication system from the geophysical prospecting apparatus. Soviet use of similar receiving equipment for nuclear detection, as well as for magnetotelluric studies, should be considered operational. The threshold of detection will be improved as better equipment is developed for research purposes.

APPENDIX

Bibliography

1. Wait, J. R. Proc. of the I. E. E. E., Vol 54, No. 8, pp 1020-1025 (1966), "Some Factors Concerning Electromagnetic Wave Propagation in the Earth's Crust"

2. Defense Intelligence Digest, Vol 5, No. 1, Jan 1967, p 2, "Soviets Harden Antenna Sites" ~~(SECRET)~~ (U)

3. USASA Combat Developments Study CD-10-OJ, 31 Jan 65, Appendix IX, Annex D, pp D 5-14, 27. ~~(SECRET)~~ (U)

4. Ivanov, A. P., Nikitina, V. N., and Enenshteyn, B. S., Izvestiya AN SSSR, Seriya Geofizicheskaya, No. 9, pp 1399-1404 (1964), "On the Input Impedance of a Grounded Electric Dipole."

5. Staiman, D., and Tamir, T., D. D. C. No. AD 632 378, "On the Nature and Optimization of the Ground (Lateral) Wave Excited by Submerged Antennas." (1966)

6. Lavrov, G. A., and Knyazev, A. S., Moskva, Izd-vo "Sovetskoya Radio", 1965, 472 pp. "Prizemnyye i Podzemnyye Antenny" (See F. S. B. Vol 3, No. 3, March 1967, pp 20-32.)

7. Ryazantsev, A. M., and Shabel'nikov, A. V., Radiotekhnika i Elektronika, Vol. 10, No. 11, Nov. 1965, pp 1923-1940, Moscow, "Propagation of Radio Waves Through the Earth's Crust (A Review)" 8. I. E. E. E. Trans.

8. Antennas and Propagat., Vol AP-11, 1963 (Entire volume, which contains a special issue, No. 3, devoted exclusively to this topic)

9. Dolukhanov, M. P., et al., Moscow, Izd-vo "Svyaz'", 1965, pp 169-189, "Radio Wave Propagation." Edited by Prof. A. D. Fortushanko (JPRS 34, 766)

10. A. I. D., Library of Congress, Report B-63-99, "Underground Communications -- Annotated Bibliography of Soviet-Bloc Literature for the Period 1960-1962" (D. D. C. No. AD 412427)

11. Bates, C. C., I. R. E. Proceedings, Vol 50, No. 11 pp 2201-2208 (1962), "Detection and Identification of Nuclear Explosions Underground"

12. Fayenov, Ya. I., and Krasil'nikov, I. S., Vestnik Protivovozdushnoy Oborony, Moskva, No. 1, 1966, pp 88-90, "The Effect of Nuclear Explosions on Radio Communications and Radar Operations" (D. O. D. Report No. 6010 2601 66) ~~(FOUO)~~

APPENDIX (Continued)

13. Goldblatt, S. L., DASA Report No. 1565-1, "A Summary of Unclassified Literature Pertaining to the Effects of US and USSR High Altitude Nuclear Explosions" (1964) DDC No. AD 356449 ~~(CONFIDENTIAL)~~ (U)

14. Wade, L. C. (1964), "Soviet Magnetotelluric Developments and Probable Military Applications", OSI-SR/64-50, b3 ~~(SECRET)~~ (U)

15. Belyayevskiy, N. A., Sovetskaya Geologiya, No. 12, pp 55-77 (1961). "Study of Deep Interior of the Earth and Problems of Super Deep Drilling" (JPRS No. 13516)

16. Bulashevich, Yu. P., Khalevin, N. I., Timofeyev, A. N., and Kuznetsov, A. A., AN SSSR, Ural'skiy Filial, Institut Geofiziki, Trudy No. 3, 1965. Geophysical Paper No. 4. "Methodological Problems of Mining Geophysics of the Urals" (ATD Press Vol 4, No. 115, 6 Dec 1965)

17. Shcherbakov, Red Star article quoted in radio broadcast, Moscow, 0600 GMT, 30 January 1966

18. Smirnov, A., Narodnoye Khozyaystvo Kazakhstana, No. 1, pp 93-94 (1966). "The Earth is Revealing its Secrets" (ATD Press Vol 4, No. 207, 18 April 1966)

19. Vadetskiy, Yu., Alma-Ata, Kazakhstanskaya Pravda, 11 October 1961, p. 1. "The First Superdeep Well" (JPRS No. 12,445)

20. Vardiyev, V. D., Neftyanoye Khozyaystvo, No. 3, pp 52-57 (1964), "The Deepest Well in the Soviet Union"

21. Vasil'yev, Yu. M., D'yakonov, D. I., and Char'ygin, M. M., Doklady AN SSSR, Vol. 168, No. 4, pp 871-873 (1966), "The Temperature of Abyssal Depths of the Near-Caspian Depression According to Data of The Aral-Sor Super-deep Borehole"

22. Ali-Zade, A. A., and Akhmedov, G. A., Izvestiya A. N. Azerb. SSR --- Seriya Geologo-Geographicheshikh Nauk i Neft;, No. 4, Baku, pp 3-14 (1962), "Ten Thousand Meter Exploratory Well in Azerbaydzhan" (JPRS No. 23, 030)

23. Varvarov, N., Nauka i Zhizn', No. 2 pp. 18-21 (1961), "Satellites --- Explorers of the Earths's Interior" (JPRS No. 8114)

APPENDIX (Continued)

24. Sadovsky, M. A., quoted in Pravda, p 3, March 15 (1966). "Scientists Propose" (Current Digest of Soviet Press, Vol XVII, No. 11, pp 30, 31. Apr 6, 1966.)

25. Keller, G. V., Anderson, L. A., and Pritchard, J. I., Geophysics, Vol XXXI, No. 6, pp 1078-1087 (1966), "Geological Survey Investigations of the Electrical Properties of the Curst and Upper Mantle"

26. Keller, G. V., Geophysics, Vol XXXI, No. 6, pp 1088-1104 (1966), "Dipole Method for Deep Resistivity Studies"

27. Anderson, L. A., and Keller, G. V., Geophysics, Vol XXXI, No. 6, pp 1105-1122 (1966), "Experimental Deep Resistivity Probes in the Central and Eastern United States"

28. Jackson, D. B., Geophysics, Vol. XXXI, No. 6, pp 1123-1144 (1966), "Deep Resistivity Probes in the Southwestern United States"

29. Keller, G. V. et al., Geophysics, Vol XXXI, No. 3, pp 630-637 (1966), "Tour of Petroleum Geophysics Activities in the USSR"

30. Al'pin, L. M., Berdichevskii, M. N., Vedrintsev, G. A., and Zagarmistr, A. M., "Dipole Methods for Measuring Earth Conductivity," 302 pages, Consultants Bureau, Plenum Press, New York (1966)

31. Ordzhonikidze, S., Radio Engineering and Electronic Physics, Vol. 8, No. 7, pp 1247-1251, (1963), "Influence of Rock Formations on Radio Propagation"

32. Kalinin, Yu. K., Geomagnetizm i Aeronomiya, Vol 4, No. 5, pp 892-897 (1964), "Methods for Measuring the Local Conductivity of Soils at Radio Frequencies"

33. Yampol'skiy, V. S., Geomagnetizm i Aeronomiya, Vol 6, No. 2, pp 409-411, (1966), "Dispersion of the Electrical Properties of Soils"

34. Sargent, C. J., (1964) "Soviet Underground Radio Propagation Research Related to the Development of an Underground Communication System," OSI-SR/64-1, b3 ~~(SECRET)~~ (U)

35. Cagniard, L., Geophysics, Vol. XVIII, pp 605-635, (1953) "Basic Theory of the Magnetotelluric Method of Geophysical Prospecting"

APPENDIX (Continued)

36. Plouff, D., Geophysics, Vol. XXXI, No. 6, pp 1145-1152, (1966), "Magnetotelluric Soundings in the Southwestern United States"

37. Vozoff, K., and Ellis, R. M., Geophysics, Vol XXXI, No. 6, pp 1153-1157, (1966), "Magnetotelluric Measurements in Southern Alberta"

38. Troitskaya, V. A., Moscow, Geofizicheskiy Byulleten', Mexhduvedomstvennyy Geofizicheskiy Komitet, No. 14, pp 55-66 (1965). "Results of a Study of Earth Currents" (JPRS No. 32,048)

39. Tikhonov, A. N., and Berdichevskiy, M. N., Izvestiya AN SSSR, Fizika Zemli, No. 2, pp 34-41 (1966), "Experience in Use of Magnetotelluric Methods in Study of the Geological Structure of Sedimentary Basins" (JPRS No. 35,809)

40. US Army Signal Intelligence Agency, ST-141-62 (June 1962), "Soviet Activities in Geomagnetics (Communication and Detection) (U) ~~(SECRET)~~

41. JPRS No. 35,358 (5 May 1966)

42. Wade, L. C. (1964), "Recent Developments in Soviet Geomagnetic Research," OSI-SR/64-22, p. 17, C. M. ~~(SECRET)~~ (U)

43. Geosciences and Technology Bulletin, Vol 2, No. 2, Feb 1967 (A. T. D., Library of Congress)

44. Borodina, S. V., Katinin, Yu. K., Mikhailova, G. A., and Fligel', D. S., Izvestiya Vyshikh Uchebnykh Zavedenii, Radiofizika, Vol 3, No. 1 pp 5-32 (1960), "Study of the Present State of the Investigation of the Propagation of Very Long Electromagnetic Waves" (Library Translation #1004, Royal Aircraft Establishment, UK)

45. Krasnushkin, P. Ye., and Yablochkin, N. A., Vychislitel'nyy Tsentr AN SSSR, Moskva (1963), "Theory of Propagation of Very Long Waves" (FTD-MT-65-397)

46. Hibben, S. G., Foreign Science Bulletin, Vol 3, No. 3, pp 20-32 (March 1967), "Underground Electromagnetic Wave Propagation"

47. Tarkhov, A. G., Izvestiya AN SSSR, Ser. Geofiz, Vol 5, p. 599 (1956)

48. Parkhomenko, E. I., and Bondarenko, A. G., Izvestiya AN SSSR, Ser. Geofiz., Vol 12, p. 1823, (1963)

APPENDIX (Continued)

—

49. Kobranova, V.N., Gostoptekhizdat (1962), "Physical Properties of Rocks"

50. Tsao, C.K.H., "Communications and Data Processing Radio Propagations via Subsurface Rock Strata," (DDC. No. [illegible] 615 785)

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13. ABSTRACT

(U) ~~(S)~~ Several types of research in progress in the Soviet Union will provide useful data to support the planning and development of several forms of underground electromagnetic communication and detection systems. The technical advantages and limitations of the potential modes of propagation are discussed, current Soviet research is related to them, and an estimate is made of future development. The modes considered include shallow burial of antennas, use of the electromagnetic waveguide layer, and nonradiative ground-current fields.

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