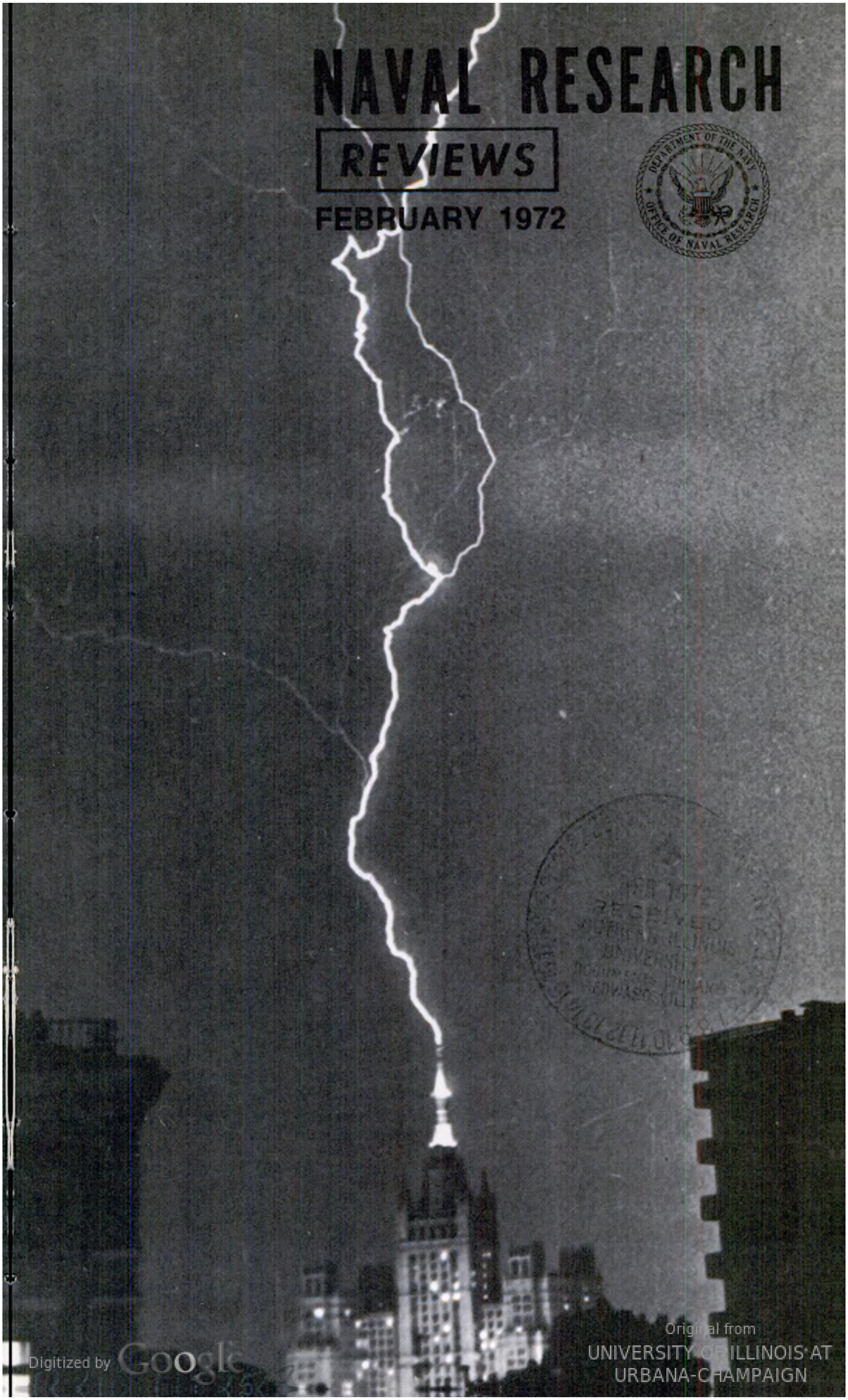
NAVAL RESEARCH REVIEWS

FEBRUARY 1972



PROFILES IN SCIENCE

Dr. Marcella L. Phillips

Dr. Marcella Lindeman Phillips joined the government service in the early days of World War II following a distinguished career in the academic and industrial communities. During WW II while with the Radio Division of the National Bureau of Standards she conducted extensive and original research in the complex behavior of the earth's ionosphere in response to the effects of solar radiation. She devised methods for quantifying the behavior of such previously unpredicted phenomena as sporadic-E and the F-1 layer of the ionosphere and applied the results of this research to the global communication problems of WW II. Following the war she was selected to prepare an international position paper on radio noise for the URSI (International Scientific Radio Union) and served for several years as the elected chairman of the Wave Propagation Committee of URSI during the early 1960's. Since the late 50's Mrs. Phillips has been a full time private consultant to several universities and contractors of the Office of Naval Research. Her later work has concerned itself with the establishment of precise measurements of the ionosphere and the development of adaptive systems for use in high frequency (HF) radars. Marcella is married to Major General James Phillips, USAF (Retired), a former director of the Air Force Cambridge Research Laboratories.

A Study of the Possible Biological Effects of SANGUINE

Leonard L. Libber and Thomas C. Rozzell
Office of Naval Research

The Navy has been conducting research and development on extremely low frequency (ELF) communications concepts. Early research in the program, known as Project SANGUINE, was oriented toward determining whether ELF communication is physically possible. This research was successful, and ELF communication was proved feasible as early as 1963.

SANGUINE if built, would be a single transmitter complex able to communicate with American submarines while they are submerged in the ocean at operating depth. At present, messages are sent by a number of stations located around the world but can only be received by submarines with their antennas on or near the surface. SANGUINE would provide the capability of communicating with submerged submarines from a single transmitter site in the United States.

The SANGUINE system would transmit at the extremely low frequency range (*i.e.* below 100 Hz). In contrast, AM radio stations broadcast between 500 and 1600 thousand Hz (cycles per second) and shortwave, television and other broadcasts range into the hundreds of millions of Hz. The environmental effects of SANGUINE is anticipated to be no different than that caused by commercial power lines, which are supplied at 60 Hz, though not used to send messages. It is characteristic of these frequencies that the signals penetrate water effectively, and,

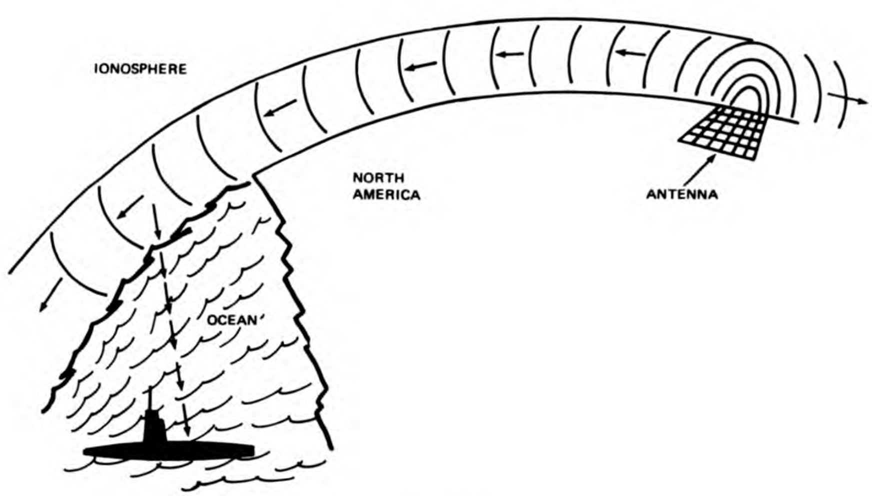


Figure 1

in fact, random signals from our 60 Hz power systems can be detected at great distances (Figure 1).

Low frequency radio signals are characterized by very long wave lengths and require a broadcasting antenna, if it is to work well, of sufficient size to be a significant portion of one wave length. The wave length of a television signal, for example, is only a few feet, and there-a compact antenna can be used. In the case of 45 Hz, a possible SANGUINE frequency, the wave length is 4,140 miles and would require a single antenna many miles long just to constitute a small fraction of one wavelength. Trade-offs between antenna size, antenna configuration and power requirements can be made acceptable to the Navy because once the signal is transmitted it loses very little strength and penetrates water well (Figure 2).

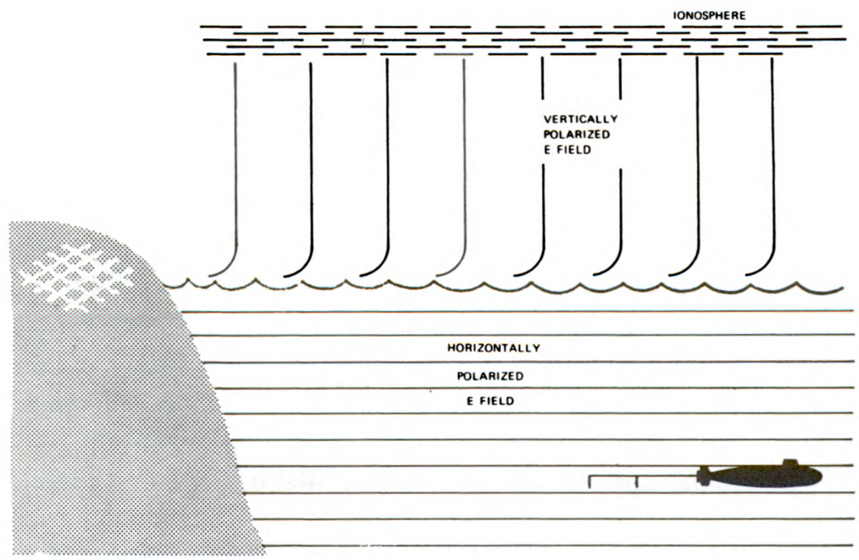


Figure 2

In a full-scale installation the SANGUINE transmitting antenna would be powered by a series of generators located along an insulated cable many miles long and buried at a depth of about six feet and grounded at each end to provide an earth return circuit. The terminal grounds at either end would consist of many vertical ground rods connected together by a buried horizontal wire. This type of distributed ground system is similar to that used near commercial radio, television and power generating stations. A distributed ground provides the required very low electrical impedance (several ohms) and distributes the current to prevent heating, corrosion, excessive power losses and high voltage gradients.

One cable, however, is not enough to provide the desired omnidirectional capability since a single wire antenna has directional characteristics. A second antenna needs to be constructed at right angles of the first to produce an all-directional signal pattern. In order to obtain the required signal output without use of unusually high currents, a number of others are added in parallel to each to form a gridlike pattern. The number of elements could be only several or as many as 20 in each direction, with the distance between adjacent elements varying from 4 to 10 miles. This would result in high reliability since several cables or transmitters could be inoperative while transmissions continued (Figure 3).

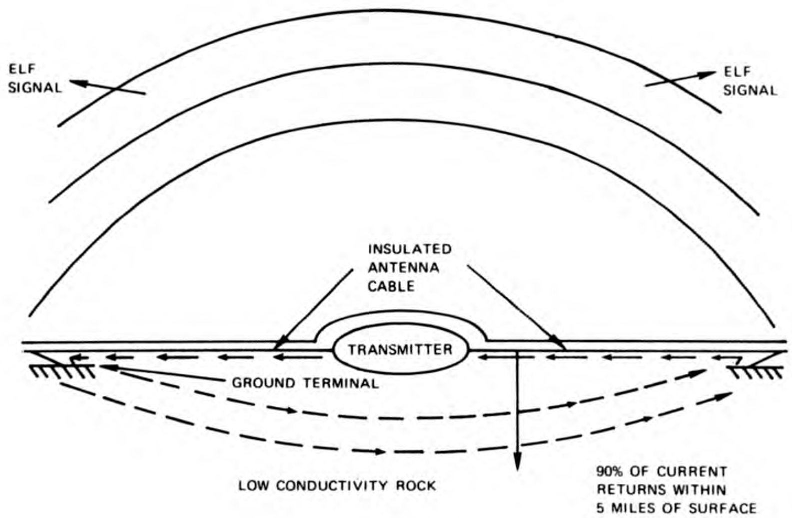


Figure 3

An ELF transmitter, therefore, is unusual in that it requires an antenna network deployed over many square miles. Although the extensive electrical field that would be produced by this system is no greater than that produced by commercial power lines in many rural areas, there has been some concern about possible side effects, particularly on the environment. This has led to a major biological research program under the direction of the Office of Naval Research to seek answers to the questions raised.

The electromagnetic fields predicted for the present conceptual ELF communications system would be very low. Many home appliances, for example, develop high fields. The magnetic flux density measured near a woman's hair dryer was several times the level expected at the surface of an antenna cable. Electric field strengths near commercial radio and television transmitting antennas are orders of magnitude higher than those expected from SANGUINE.

A SANGUINE system must be compatible with the environment in which it is placed. There must be assurance that there will be no harmful or undesirable biological effects. A pilot research program was initiated by the Navy through the Naval Electronic Systems Command in 1969 to determine whether biological problems might be associated with ELF frequencies. Two of the research objectives were to develop the necessary ELF electromagnetic field simulation techniques and to define electric and magnetic field levels that would not produce biological reactions.

Since the results of this study were not definitive, the Navy determined that it should conduct research on a variety of biological organisms. This was based on the recommendations made by the Biological/Ecological Subcommittee of the SANGUINE Environmental Compatability Assurance Group. The subcommittee consisted of biologists, biophysicists, physicians, psychologists and ecologists from different departments of the federal government. It was realized that it would be wholly impractical to study low level ELF effects on every living creature or plant that might be exposed to these conditions. The Subcommittee, therefore, developed a research matrix (see Table 1) to indicate the areas in which additional research was desirable. In the opinion of the Subcommittee, good scientific investigations in those problem areas indicated in the matrix should yield information upon which sound guidelines to insure environmental compatibility could be based.

Since little is known about the perception of ELF electromagnetic fields by animals, it was felt that representative species of mammals (markedly different with respect to size) should be studied in regard to various physiological rhythms and behavioral aspects. In addition, experiments on representative lower animal were recommended to determine if there are any effects on growth, development, genetic and reproductive factors. Behavioral studies (which might include migratory patterns) on representative species from this groupwere also considered desirable. It was also recommended that field studies should be conducted on isolated ecological systems exposed to electromagnetic fields analogous to those proposed by Project SANGUINE. Food cycles of representative fresh water organisms, soil organisms and land forms were also proposed as subjects for investigation. In addition, scientific and clinical studies on humans working in such fields or similar fields would be undertaken by the Navy.

The Office of Naval Research was requested to administer and monitor this comprehensive research program as part of its Physiology Program. Accordingly, the scientific community was invited to submit appropriate research proposals to ONR to cover any of the scientific aspects outlined in the matrix. These proposals were reviewed last spring for scientific merit by an ad hoc Committee of the American Institute of Biological Sciences (AIBS), which selected 15 proposals as being scientifically sound. In order to insure relevance and prevent

TABLE 1

SANGUINE Biological/Ecological Research Matrix

Research Areas	Humans			Mammals			Lower Animals					Interaction Organisms	
	Workers	Residents	Lab Subjects	Small	Medium	Large	Fish	Amphibia	Birds	Invertebrate	Cellular	Aquatic	Terrestrial
I. Laboratory Studies* A. Physiological													
1. Rhythm			x	x	x	x			x				
2. Systemic													
a. Reproduction				x			x	x	x	x	x		
b. Other													
3. Cellular Function											x		
B. Genetic													
C. Growth and Development													
1. Organogenesis							x	x					
2. Hatchability							x	x					
D. Behavioral													
1. Perception			x				x	x		x			
2. Preference							x	x		x			
3. Reaction Time			x										
4. Learning					x		x		x				
5. Migratory													
6. Activity				x						x			
II. Field Studies A. Health Surveys													
1. Clinical	x												
2. Epidemiological		x											
B. Ecological Impact												x	x
C. Migratory Patterns									x				

*Exposures at 1 and 10 v/m, 0.5 gauss, and 45 and 75 Hz.

duplication nine of these were recommended by the Biological/Ecological Subcommittee. The research contracts have been signed, the projects are now underway and should be completed in one to two years. Although the electric and magnetic field levels expected from a SANGUINE System is 0.07 volts per meter and 0.2 gauss, respectively, the biological research is being performed with much higher levels of exposure.

(1) One of the projects will evaluate the effect of extremely low frequency (ELF) electric and magnetic fields (45 and 75 Hz with exposure at 1 and 10 v/m and 1.0 gauss) upon growth, development and behavior in the domestic fowl *Gallus domesticus*. Growing chick embryos will be exposed to ELF radiation in specifically modified incubators and observations will be made of the effects of the radiation on such things as: (a) hatchability and embryonic abnormalities, (b) livability, (c) growth rates of the embryo and extra-embryonic tissues, (d) growth rate and development of fibroblastic and epithelial cells in culture, (e) CO_2 production during incubation, (f) histopathological surveys, and (g) embryonic survival during exposure to low temperature.

Chicks hatched from eggs exposed to ELF radiation during incubation will be subjected to similar radiation for up to four weeks after hatching for observation and measurement of: (a) early post-hatching behavior, (b) early post-hatching growth rate and feeding efficiency, and (c) learning and memory consolidation. Some of the early post-hatching behavior observations will include such things as effects on balance and coordination, social interaction, nervousness, responsiveness to heat and light, water and feed acquisition and preference for food types. Social interaction and behavior of irradiated chicks will be studied *via* the "social tension index" (number of aggressive minus number of submissive acts) and compared with controls. The effects of ELF radiation on the reproduction in the female will be measured by egg production. The effect on fertility in the male will be measured by embryonic development and semen examination.

The principal investigator for this research is Dr. Wayne K. Durfee, at the University of Rhode Island.

(2) Another research project is concerned with possible changes in operant behavior of pigeons and rats due to electromagnetic fields such as those generated by the SANGUINE system. It will also seek to determine whether pigeons and rats can detect ELF radiation and whether or not they have a preference for its presence or absence.

In a temporal discrimination study, pigeons will be trained to peck an illuminated key centered between two non-illuminated, inoperative keys. Following the initial peck, the color of the key changes to white for a selected discrete time interval. The white key then goes dark and the two side keys are turned on, one key green, the other red, in an irregular alternation from trial to trial. If the white key were on 1-5 seconds, then a response, for example, to red would be correct; if the white key were on 6-10 seconds, then a response to green is correct. Correct responses will be reinforced with a presentation of food. After stable behavior is obtained, the birds will be exposed to an ELF signal for a number of sessions.

A number of parameters will be explored, with frequencies of 45 and 75 Hz and with fields of 1-10 v/m and 0.5 gauss. Both rats and pigeons will be used to determine if ELF signals can be detected. In this experiment the rate of response prior to the onset of the signal will be changed so that the termination of the signal will be accompanied by a 0.5 msec., 1 ma shock. The extent to which the animals are able to detect the signal will be measured by changes in the suppression ratio over the no-shock condition. Preference for the presence or absence of the ELF radiation will also be determined.

The principal investigator in this project is Dr. M. Marr at Georgia Institute of Technology.

(3) A third research project will study the possible effects of electromagnetic fields on the biological rhythm of animals. This research will evaluate the effect of magnetic fields of extremely low frequency and 1-2 gauss intensity on the circadian, estral and other rhythms in body temperature, as well as on the life span and other variables in non-pregnant and pregnant female rats and their offspring.

Temperature monitors will be implanted intraperitoneally in rats which will then be housed in special environmental chambers and exposed to the magnetic fields. The body core temperature will be monitored every ten minutes and recorded in digital form on magnetic tape. After required background data are available, three-month old offspring of rats kept during pregnancy in magnetic fields will be subjected to detail study of their body temperature rhythm.

Principal investigator for this project will be Dr. Halberg at the University of Minnesota.

(4) A fourth research project will investigate the influence, if any, of ELF radiation on the induction of chromosome aberrations in the fruit fly, *Dropsophila melanogaster*.

In this study one group of male adult genetically marked Dropsophila will be exposed for 5 days to 45 Hz, 10 v/m and 0.5 gauss and another group to 75 Hz, 10 v/m and 0.5 gauss radiation. The exposed males will then be mated to unexposed, virgin females. Recessive sex-linked lethals, translocations between II and III chromosomes, and the loss of the X or Y portion of the Y chromosome will be determined. To determine whether any dominant lethals have been produced, the females that the exposed males have mated with will be isolated into plastic vials. They will be permitted to lay eggs which will be evaluated after 24 hours as to whether a larva has emerged. The failure to hatch will be an indication of a dominant lethal, usually the result of gross chromosome aberrations. If the genetic data indicates damage then the electric field gradient will be decreased to 1 v/m for another set of experiments. In another series Dropsophila eggs that have just been deposited on the food media will be exposed continuously for 12 days at 45 Hz, 10 v/m and 0.5 gauss. Thus all the larval stages, pupa and the adult will be exposed to the ELF radiation.

Principal investigator for this study will be Dr. Sidney Mittler, Northern Illinois University.

(5) The study of the response of plants and soil microorganisms to electromagnetic fields will be another research project under contract to ONR. This research will investigate the possible effect of ELF radiation upon water and ion uptake by plant roots and upon solute transport and metabolic activity in soil microorganisms.

Single plants will be grown in the appropriate media under conditions of controlled temperature, light, relative humidity, and CO_2 concentration. When the plants have reached the desired stage of growth, the test organisms will be subjected to ELF radiation. Measurements will then be made of transpiration flux of water through the plant, water potential drop, stomatal resistance and rate of nitrogen uptake. Many soils are poorly drained, so particular attention will be paid to systems which are poorly aerated as well as to relatively dry soil systems. Microorganisms to be evaluated will be chosen from the representative soil bacteria and fungi with which the researchers have direct familiarity. Initial studies will concentrate on evaluation of the effect of electric fields on solute transport and metabolic activity. Other studies will investigate the effect of ELF fields on the growth cycle of bacteria by following such cell growth and activity parameters as turbidity, viable cells, ATP and key enzyme systems.

The principal investigator is Dr. W. R. Gardner, at the University of Wisconsin.

(6) A sixth project will seek possible effects on the neurophysiology and behavior of monkeys in 45 Hz and 75 Hz electromagnetic fields.

Small EEG monitoring electrodes and brain temperature thermistors will be implanted in the hippocampal region of the brains of five monkeys. The monkey will then be trained to perform a specific task (push a lever) within a given period of time. After the task has been well learned, the animals will be subjected to the ELF radiation, randomly dispersed with no-field conditions. The changes in EEG and response time will be studied and an attempt will also be made to determine if the animals can sense the presence of, or detect, ELF radiation. Mathematical statistical analyses will be made with the possibility of elucidating meaningful relationships among these three parameters using various types of regression analyses, a method called "reverse correlation" and statistical clustering techniques.

Principal investigator for this project will be Dr. Adey, at the Brain Research Institute, UCLA.

(7) Another of nine research projects selected by the Department of the Navy will study the effect of extremely low frequency radiation on chromosomes—particularly during cell division (*i.e.* mitosis).

Parameters to be investigated include mitotic indices, and the presence or absence of chromosomal aberrations (stickiness, shattering, rearrangements, fragmentation and alterations in ploidy). The exposures will include those of the SANGUINE project: *i.e.*, 45 and 75 Hz at 1 and 10 v/m and 0.5 gauss. The test species will be the root tip cells of the bean *Vicia faba*. Studies will be made of the effects on cell division following irradiation (both chronic and acute exposures), of the induction of chromosome aberration and of the ability of the cells to repair chromosome damage if it occurs.

Principal investigator will be Dr. Miller of the University of Rochester.

(8) Number eight in this series of projects is a study which is being carried out by Dr. E. M. Goodman at the University of Wisconsin on the effect of ELF on the growth and development of the slime mold, *Physarum polycephalum*. This species is not only very useful from the standpoint of its biological characteristics which lend themselves to carefully controlled experiments on mitotic synchrony but also from its importance in maintaining the natural ecology of the soil.

The first phase of this investigation will consider the effect of extremely low frequency electromagnetic fields on the onset of mitosis in *Physarum*. The frequencies to be used will be 45 and 75 Hz at fields of 2.0 gauss and 0.7 volts/meter. A culture will become stationary by undergoing a naturally synchronous mitosis at predictable intervals. Effects of ELF fields will be determined by looking for statistically significant deviations in the onset of mitosis in experimental *versus* control cultures. Another function to be investigated in *Physarum* is oscillatory protoplasmic streaming. This constant to-and-fro oscillation, as seen under the dissecting microscope, provides another very sensitive physiological-morphological parameter for determining the effect of ELF fields on biological rhythms. Certain biochemical parameters such as DNA replication, RNA and protein synthesis will be investigated. Any anomalies in the bio-synthetic patterns of these macromolecules due to ELF fields on the reproductive processes in *Physarum* will be studied.

(9) The ninth research project will study the effect of electromagnetic fields on migratory fishes. Specifically, the research will seek to: (1) determine if these species can detect weak magnetic fields; (2) define

closely their sensitivity to weak electric fields; (3) measure the periodicity and accuracy of biological clocks under constant photoperiods; (4) determine if weak magnetic or electric field fluctations can serve to drive these biological clocks, and (5) determine if low frequency alternating electric and magnetic fields alter activity levels or the periodicity of the clocks.

The first phase of this investigation will involve cardiac deceleration studies. It has been found that the heart rate of many vertebrates, including fishes, slows momentarily following certain stimuli such as the electric shock, a loud noise, a flash of light, *etc*. The rate rapidly returns to normal. This phenomenon has been combined with classical conditioning techniques to provide a powerful tool in the analysis of sensitivity of animals to certain environmental factors. In this study, the heart beat of the fish will be monitored in a suitable apparatus and attempts made to condition cardiac deceleration using a flash of light, a loud noise, or an electric shock as the unconditioned stimulus (UCS) and a weak magnetic or electric field as the conditioned stimulus (CS). Changes in the heart rate when only the ELF field is on would indicate that the fish can sense the field. Electrocardiograms will be recorded on a 6 channel physiological recorder from electrodes immersed in the water. Effects of the ELF radiation on the biological clocks of the fishes will be studied by introducing weak magnetic and electric fields into each fish tank and causing the fields to fluctuate with a period near (but not equal to) 24 hours, *e.g.*, 23 hours. Thus an attempt will be made to entrain the clock with a weak field. Six aquaria will serve as experimentals, six as controls in each experiment. Comparison of periodogram analysis of experimentals and controls can then be made. The third approach will be an attempt to change the overall activity level or the shape of the activity rhythm curve by alternating three day periods of exposure and non-exposure to the weak fields. Finally, attempts will be made to determine if the fishes prefer to be in the presence of weak electric and magnetic fields or tend to avoid these fields.

The principal investigator will be Dr. J. D. McCleave of the University of Maine.

In summary, the biological/ecological research program of Project SANGUINE, under the direction of the Office of Naval Research, is seeking to determine whether ELF radiation levels associated with a SANGUINE System can be expected to have any effect on the biological species in the environment. A number of species, (both plants and animals) have been chosen to represent a cross-section of those appearing in nature. The results of the independent researchers will hopefully serve as a basis for a rational evaluation of the potential biological impact of Project SANGUINE. These results will be published in the open literature.

Acknowledgment

The authors wish to thank Cdr. W. K. Hartell USN, Special Communications Project Manager, Naval Electronic Systems Command for his many important contributions to this paper relative to the technical aspects of Project SANGUINE.

About the Authors

Dr. Libber is the Director of the Physiology Program of the Biological and Medical Sciences Division at the Office of Naval Research. Dr. Libber joined ONR after several years of laboratory experience at what was formerly known as the Aerospace Crew Equipment Laboratory of the Naval Air Material Center, Philadelphia. While there he worked on physiological problems related to environmental stresses.

Dr. Rozzell is Project Officer (Non-Ionizing Radiation) in the Physiology Program of the Biological and Medical Sciences Division at ONR. His areas of responsibility include supervision of the research programs related to the effects of non-ionizing electromagnetic radiation on man and the environment. Prior to joining ONR, he was Assistant Professor of Environmental Radiation at the University of Pittsburgh.

Lightning Radiation More Powerful Than Suspected

A Navy study concerned with measuring the electric and magnetic radiation fields of lightning has revealed that these fields are much stronger than previously assumed. The findings will be of great value in the design of electronic circuitry that must operate in an environment subject to radiation effect of lightning.

In the design of such circuitry, engineers usually consider radiation from lightning in terms of average currents of 20,000 amperes. The Navy study, sponsored by the Office of Naval Research, indicates that peak currents sometimes exceed 100,000 amperes.

The lack of accurate data is due to the fact that, in the past, measurements have been made of lightning striking tall structures which tend to draw lightning. It is only recently that methods have been developed to estimate lightning currents from remotely sensed data. These methods have been devised also through ONR-sponsored research.

The ONR study is part of a broad program of investigations into atmospheric phenomena that can affect naval activities, such as communications. Lightning, besides the obvious threat of a direct strike, can disrupt the operation of solid state circuitry and computer memories through its radiated magnetic and electric fields, even though the lightning may be some distance from the electronic components.

The ONR-sponsored investigations were conducted by Dr. Martin Uman formerly with the Westinghouse Research Laboratories, Pittsburgh, Pa. Dr. Uman, now with the University of Florida, Gainesville, Florida, monitored lightning strokes over flat land and ocean in the vicinity of Cape Kennedy, Florida.

In the summer of 1971, he and his associates measured the radiation fields of 164 strokes. In about 10 percent of the strokes, the peak current exceeded 100,000 amperes. One of them had a rate of rise of 300,000 amperes per microsecond.

Intermediate and Deep Properties of the Earth's Crust, A Possible Electromagnetic Wave Guide

John G. Heacock
Office of Naval Research

The idea that an electromagnetic wave guide may exist in the earth was postulated some 10 years ago on the assumption that conductive wet surface layers and conductive hot mantle layers enclose a resistive zone of dry "basement rocks." Little is known in detail about the precise nature of the materials and physical properties of the deeper parts of the earth's crust where the resistive "basement" rocks were presumed to exist.

Continuous zones may exist in the deeper parts of the earth's continental crust that could form an electromagnetic wave guide and provide new pathways for communication. To form such a wave guide, these earth zones must not only be continuous but must also have a resistive interior bounded by conducting walls. A high interior resistivity of 10^6 or 10^7 Ω-m is necessary if attenuations appreciably less than 1 db/km and significant ranges are to be achieved, [*Wait*, 1971; *Wait and Spies*, 1971].

Neither the magnitude of deep earth resistivities nor their continuity over extended regions has been established since the extensive data required to supply this information are not available. The purpose of this paper, however, is to determine from existing data whether indications are favorable for the possible existence of an electromagnetic wave guide in the earth.

The Navy's objective in pursuing this research is to evaluate whether a natural wave guide exists within the crust of upper mantle of the earth capable of providing a new pathway or communications through the earth. Such a new communications link could provide unique characteristics for the transmission of information potentially at high data rates over a hardened and possibly a secure path. Exact applications depend on actual earth properties which have yet to be measured precisely. Workshops to outline an appropriate field program are currently being organized in order to eliminate the ambiguity in our knowledge of the electrical properties of the earth.

Lithospheric Wave Guide

Wait [1954] first noted that electromagnetic energy might propagate through earth layers with low attenuation provided a wave guide configuration could be found. As postulated by *Wheeler* [1961], approximate wave guide conditions may exist in the earth because surface layers are made conductive by the presence of ground water; the dielectric resistive interior of the wave guide is formed by dry basement rocks, and the lower conductive wall if formed by heated rocks in the lower crust or upper mantle. Later reviews emphasized assumed resistivity-depth profiles in the earth are based on reasonable estimates from laboratory and field data. Papers on this subject were published by *Levin* [1962, 1966], *Ames et al.* [1963], *Keller* [1963], and others.

Electromagnetic propagation through an earth wave guide has been studied by *Ghose* [1960], *Wait* [1963*a, b,* 1966*a, b, c, d*], *Schwering et al.* [1968], *Tsao and deBettencourt* [1968], and others. *Wait* [1971] reviews the basic mathematics of the major aspects of these treatments. *Ryazantsev and Shavel'nikov* [1965] wrote an extensive review of papers by United States authors on this subject. *Dolukhanov* [1970] discusses several types of underground communication and speculates that underground radio propagation will find many applications as technical development proceeds.

The essential element lacking in this field is a clear knowledge of the physical properties of the earth at the depths of interest; in particular, we must determine: first, the distribution of resistivity and permittivity with depth; second, whether the wave guide conditions postulated by Wheeler exist; and third, where these conditions are continuous and the ranges over which energy will propagate effectively.

Continuity Requirement for Wave Guide

Earlier analyses for crustal wave guides have assumed an average resistivity-depth profile. Yet, most geologists and geophysicists strongly question the possibility that zones of continuous physical properties extend over significant ranges in the earth's crust. Attempts to trace seismic reflection horizons have rarely succeeded over distances of more than a few kilometers [*James and Steinhart,* 1966]. Surface geology and geological province boundaries are clear evidence for strong lateral discontinuities. Even sub-surface structures and stratigraphic pinchouts from shallow crustal data support the concept that the crust is broken and disturbed laterally.

Rather recently, however, a sequence of papers has been published that describe a widespread seismic low-velocity zone in the continental crust that occurs in a fairly characteristic depth range at approximately

10-km depth. These results tend to provide a new picture of crustal structure at 10 km and below and suggest that there is an increasing tendency toward continuity of various physical properties at these depths in the crust.

Crustal Seismic Low-Velocity Zones

The concept of a low-velocity zone in the continental crust was first discussed critically by *Gutenberg* [1950, 1951, 1954]. It was not widely accepted then nor is it yet. The goal of this study is not to argue the existence of the crustal low-velocity zone. Instead, to simplify the argument, the existence of these zones is assumed as described elsewhere in the literature and as summarized briefly below.

The question of a crustal seismic low-velocity zone was recently revived by *Mueller and Landisman* [1966] who identify the characteristics of an arrival they call P_c. This arrival is associated with wide-angle reflections and refractions from the bottom of a shallow seismic low-velocity zone. This shallow or sialic low-velocity zone [*Mueller and Landisman,* 1966] is typically found at depths of 10 ± 3 km, is usually several kilometers thick, and is assigned by these authors a probable velocity of 5.5 km/sec on the basis of earthquake data. It has been observed at roughly the same depths beneath a variety of geological provinces, including shield, sedimentary, and active tectonic regions.

Based solely on the characteristics of P_c, *Mueller and Landisman* [1966] identify the shallow low-velocity zone at approximately twelve locations in the crust beneath all the continents except Antarctica, where they have not yet studied the matter. Although the results have not been published, M. Landisman (personal communication, 1970) also identifies P_c, on records taken from the Argentine continental shelf.

Data have been used for the identification of P_c as just described, and data have also been inverted to a velocity-depth function in the following areas: the Black Forest southeast to the German Alpine foreland [*Landisman and Mueller,* 1966]; the south German triangle in central Western Germany [*Fuchs and Landisman,* 1966]; the Alps [*Choudbury et al.,* 1967]; the Ukrainian Shelf [*Pavelnkova,* 1969]; South Africa [*Bloch et al.,* 1969]; the Basin and Range province [*Mueller and Landisman,* 1971]; southeastern Oklahoma, where a deep low-velocity zone is noted but where a shallow zone is barely developed [*Mitchell and Landisman,* 1970 and 1971]; the Rhine graben and vicinity, in Germany [*Ansorge et al.,* 1970 *and Landisman et al.,* 1971]; the Precambrian Grenville-Superior boundary in northeastern Canada (M. J. Berry and K. Fuchs, personal communication, 1971); and the

Great Slave Lake region of west-central Canada (K. G. Barr, personal communication, 1971).

From the apparently widespread occurrence of the sialic low-velocity zone, the impression is created that at least an appreciable degree of lateral continuity of physical properties may exist at depths below roughly 10 km in the continental crust. It is still true, however, that more data are needed to establish the characteristics of the shallow seismic low-velocity zone in relation to various geological provinces. If it is valid, the sialic low-velocity zone seems to signal the shallowest depth at which an appreciable degree of lateral continuity can be found.

Prodehl [1970] indicates that the sialic low-velocity zone may be more limited in extent than is suggested by the earlier results. Using data acquired earlier from 64 profiles of the United States Geological Survey, he finds a low-velocity zone at 10 km in both the Basin and Range province and in the southern Cascade Mountains of northern California. Prodehl does not find a low-velocity zone beneath the Colorado Plateau, the Sierra Nevada Mountains, the Great Valley, the Coast Ranges, or the Transverse Ranges of California.

It is conceivable that, if additional studies are made in these regions of the western United States specifically in search of seismic low-velocity zones, detection of energy from phases associated with low-velocity zones can be increased by using different filter settings or closer station spacings. It is also conceivable that the low-velocity zones may be more extensive than Prodehl's data indicate. It should be noted, for example, that through the use of different interpretational techniques, *Mueller and Landisman* [1971], in studying the Basin and Range data, obtain different results in that they find an additional low-velocity zone at 20 km, whereas none is reported by Prodehl. Nevertheless, the Prodehl study indicates that the sialic low-velocity zone is discontinuous in some areas.

Factors Controlling the Distribution of Physical Properties in the Crust

For any attempt to gain insight into the relation between the distribution of various physical properties in the crust, it should be noted that seismic velocities in a given section depend on the distribution of the materials and their physical properties, as determined by the development of the crust in geological time or by processes that are currently active in the crust. More basically, seismic velocities depend on elastic parameters and densities and may be affected by certain dissipative processes. These factors are determined by the lithology, porosity, mechanical strength properties, and stress distributions as they affect fracture patterns, the presence or absence of pore fluids, and temperatures and pressures as they affect the mineralogical phases present and their elastic constants. In addition, of course, intrusives and tectonic forces can disrupt established velocity patterns.

Internal frictional processes and their influence on seismic velocity are discussed by *Gordon and Rader* [1971]. Melting conditions will probably occur no shallower than 20 km in the crust, as reviewed by *Wyllie* [1971], or perhaps below 30 km, as suggested by *Boettcher* [1971]. The effect of melting on velocity is discussed by *Vaisnys* [1968] and by *Walsh* [1969]. Lithologic control by the intrusion of granitic loccoliths is proposed for the sialic low-velocity zone by *Landisman* [1971].

Clearly, factors that control the seismic velocities in earth materials are different from those that determine the distribution of other physical properties, *e.g.*, density, resistivity, and magnetic susceptibility. Resistivities, for example, are controlled primarily by porosity and the presence of fluids or, in dry rocks, by the resistivities of the mineral components themselves.

This raises the question of whether the distribution of various additional physical properties of the crust can be deduced from the apparently widespread occurrence of the sialic low-velocity zone at typical depths. This question relates directly to the possible existence of an electromagnetic wave guide, since, to be effective, the resistivity distribution defining such a wave guide would have to be continuous, or subject only to minor discontinuities.

Primary Control of the Sialic Low-Velocity Zone – Temperature-Pressure

Despite the need for much additional data to aid in our adequate understanding of the deep crustal environment, it may nevertheless be useful as a guide to future research to attempt to deduce possible additional crustal relationships from the evidence we now have. It is clear that, if we knew the causes of the sialic low-velocity zone, we would be in a better position to infer the distribution of physical properties other than seismic velocity at similar and greater crustal depths. Yet, on considering the possibilities described in the preceding section for the control of seismic velocity, I constantly find myself logically returning to the idea that, in some way, temperature and pressure must be primarily responsible for the occurrence of the zone at characteristic depths.

Initially, the characteristic-depth result seems complex if it is truly independent of geological province, since it implies that the low-velocity zone persists at or about the same depths despite tectonic uplifts and heat flow rates in various geological provinces. As *Blackwell* [1971] points out, uniform mantle heat-flow values are characteristic of certain broad geothermal provinces across the continental United States, whereas surface heat-flow values differ from region to region and depend on the variations in near-surface radioactivity content. Hence, temperatures at the depth of the sialic low-velocity zone are only indirectly related to surface heat-flow values. Further details on the depth of the sialic low-velocity zone in various regions may demonstrate slight variations that can be correlated with mantle heat flow or with regional tectonic uplift, for example. If this is true, it could greatly simplify the problem of identifying the cause of the sialic low-velocity zone. It opens the possibility that a direct *in situ* temperature-pressure dependence may control the location of the sialic low-velocity zone.

As noted by *Boettcher* [1971] *and Wyllie* [1971], the material must not be molten at the relatively shallow depth of 10 km. If it is intruded *Landisman et al.,* [1971], a mechanism for depth control is needed. Therefore, although *in situ* temperature-pressure control seems reasonable, further study is needed to determine the precise nature of the controlling mechanism.

Relation Between the Seismic Low-Velocity Zone and Crustal Resistivity

If the effect of temperature and pressure is primary in controlling the location of the sialic low-velocity zone, as postulated, their effect may produce additional zones of continuous physical properties at greater depths. If we consider the possible complexities in the control of seismic velocity, such a simple result suggests that it would not be surprising if other physical properties exhibit an equally simple dependence on *in situ* temperature and pressure. Resistivity, for example, the property most important in determining the existence of a crustal wave guide, has a relatively simple dependence on external factors in comparison to those which control seismic velocity. Since, as noted by *Brace* [1971], rocks whose pore spaces are saturated with water of a salinity appropriate to the crustal environment will have resistivities no higher than about 10^5 ohm-m, it will be necessary to find a zone of dry rocks if sufficiently high resistivities are to be found for low-attenuation wave guide propagation.

If zones of dry rock can be found at depth in the earth, if we take into account the apparent tendency for the sialic low-velocity zone to occur at fairly characteristic depths, and if zones of dry rock are also controlled by *in situ* temperature and pressure (which seems likely), then it seems reasonable that these zones of high resistivity will also tend to be continuous. Furthermore, since the sialic low-velocity zone seems to be the shallowest continuous zone for which we have any evidence at all in the continental crust, it is probable that continuous high-resistivity zones, if they exist, will not be found much shallower than 10 km. At greater depths in the crust, there should be an increased tendency for layers to form and a greater likelihood that they will be more nearly continuous than shallower ones because of the greater geochemical reaction rates caused by higher temperatures, provided that any vertical motions occurring at a given depth are slower than the rates at which the physically identifiable zones are formed there.

Although few data exist on the effect of pressure on reaction rates and although it is not usually possible to predict which way pressure will drive a reaction rate, temperature is the predominant factor, as noted by *Turner and Verhoogen* [1960], who state, "Reaction rates increase exponentially with increasing temperature; the effect of pressure is, in comparison, very small." On this basis, provided we are dealing with a geochemical rate process, it is probable that, if a highly resistive zone can be found at a depth below the sialic low-velocity zone, it will tend to be more extensive and more nearly continuous than the shallower seismic zone.

Physical Identifiable Zones Below 10 Kilometers

Having reasoned that, owing to increased geochemical reaction rates, deeper zones can be anticipated that are more extensive and nearly continuous than the sialic low-velocity zone, let us look at the evidence. Strangely, although mantle properties have been extensively studied, little effort has been concentrated on a study of the deeper crust. There are, however, several references reporting a seismic low-velocity zone at about 20 km beneath the continents.

Mitchell and Landisman [1970; see also their work in 1971] describe a deeper seismic low-velocity zone at a depth of 17 to 18 km that continues beneath the Wichita Mountains of Oklahoma. A shallower seismic low-velocity zone is not very strongly formed, but it seems to occur near 10 km in the depth range associated with sialic low-velocity zone, and it bottoms at 12 to 13 km. Unlike the deeper zone, the shallower low-velocity zone is not continuous through the Wichita Mountain belt. *Ansorge et al.* [1970 and 1971] demonstrate both a sialic low-velocity zone near 10 km and a deeper low-velocity zone near 20 km, both of which continue beneath the Rhine graben. M. J. Berry and K. Fuchs (personal communication, 1970), on studying the boundary between the Grenville and Superior provinces in northeastern Canada, find a possible low-velocity zone at 25 km whose presence is allowed by the data but that is not necessarily required by their interpretational technique. *Mueller and Landisman* [1971] find a low-velocity zone at both 10 and 20 km in the Basin and Range province.

There are not enough examples of the deeper low-velocity zone to establish its properties under various geologic conditions or to determine how extensively it occurs. The fact that the deeper zone exists, however, may support the idea that increased geochemical reaction rates tend to produce additional layers at greater depths in the crust. The one example cited above contrasting the continuity of the shallow and deep low-velocity zones tends to support the idea that the deeper zones are less disrupted by vertical motions than the sialic low-velocity zone. Applied to the wave guide concept, this line of reasoning suggests that, if a deep highly resistive zone can be found, it may have a reasonable chance for continuity beneath various zones of tectonic activity or between different geologic provinces.

Need for Multidisciplinary Approach to a Study of the Crustal Environment

Even if they are controlled *in situ* by temperature and pressure, as postulated, various physical rock properties behave in different ways in response to these factors. Thus, phase changes, resistivity distributions, and seismic velocities, *et cetera,* are not necessarily subparallel to each other. However, to speculate on the detailed nature of these interrelationships at this time, when few data are available, would be wasteful. By obtaining data on the structure and physical properties of the deeper parts of the crust, where a degree of continuity is suggested, and by noting the interrelationships of physical properties here, the exciting possibility exists that we may be able to infer both the characteristics of this environment and the processes that actively or historically have produced it.

Not only must seismic reflection and refraction studies be performed, but measurements of the electrical properties of the crust must also be conducted in the same areas in a variety of geologic provinces. These studies and measurements, combined with gravity, magnetic, electromagnetic and geothermal measurements, must be coupled with laboratory studies of the physical properties of rocks made at the high temperatures and pressures corresponding to those found at the depths of interest in the earth. Such studies will be required for the identification of materials at depth, for the gradual elimination of ambiguities that currently beset the clear identification of various physical properties in the crustal environment.

Observed Distribution of Resistivity in the Earth's Crust

Having postulated an ultimate dependence of various physical properties, including resistivity, on the *in situ* temperature and pressure in the crust and shallow upper mantle, and having concluded that a certain degree of continuity is a reasonable expectation, it is now appropriate to consider the actual depth dependence of crustal resistivity according to data and interpretations that are currently available.

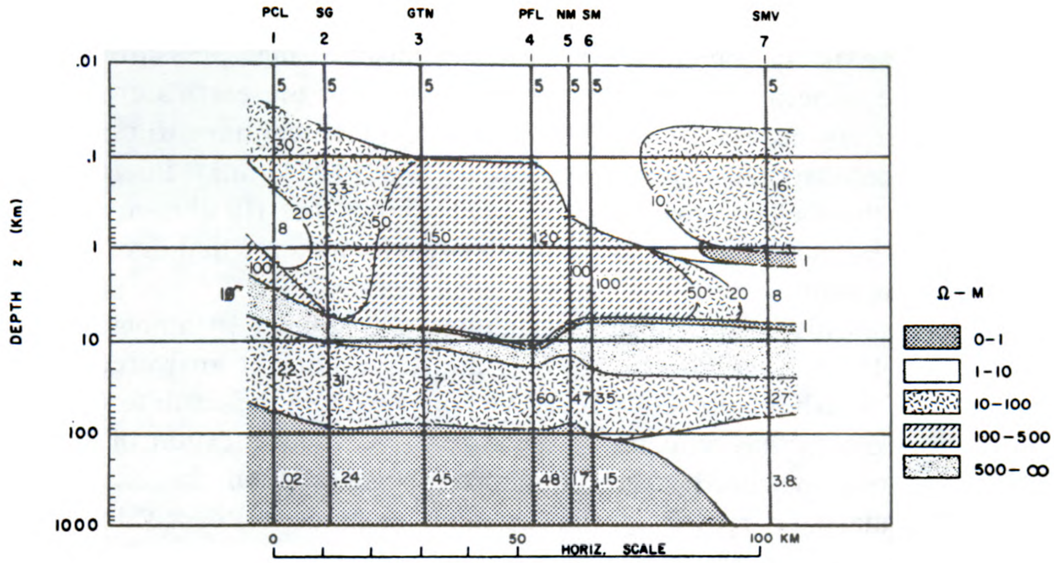
Keller [1971] concludes that certain generalizations can be drawn regarding the variation of electrical resistivity with depth from one geological province to another. The maximum resistivity is given as just under 10^6 ohm-m for stable continental areas. A slightly lower maximum is found for mobile crustal areas, and a very low resistivity of between 1 and 10 ohm-m is found in volcanic rift areas and subduction zones at rather shallow depths. Thus, it appears from present data that marked lateral-resistivity changes occur from one geologic province to another. This result means that, if highly resistive layers exist in the regions of high average conductivity, either they have not yet been detected in the more conductive background or zones of high resistivity may be confined to certain geologic provinces.

There are, however, two considerations that seem to encourage the possibility that 10^6 and 10^7 ohm-m resistivities can be found in the resistive sections of the crust. First is the general inability of measuring methods, *i.e.*, of the magnetotelluric technique, to measure the magnitude of highly resistive sections on an absolute scale or of present electrode measurements to resolve the problem, since they give only a resistivity-thickness product, as discussed by *Madden* [1971]. Furthermore, lateral discontinuities tend to distort measured resistivity values as discussed by *Porath* [1971]. *Keller* [1971] finds that, on using existing resistivity data, if in stable continental regions he allows for a transition zone between a highly resistive zone followed by a resistivity that gradually decreases at mantle depths, then resistivities of 10^6 and 10^7 are quite possible in the resistive zone. The values that Keller infers approach the maximum of 10^6 to 10^9 ohm-m observed in the laboratory for dry rocks [*Parkhomenko and Bondarenko,* 1963].

At temperatures below those causing significant solid-state conduction, the existence of high resistivities in deep rocks depends greatly on whether they are dry or wet with pore fluids. As indicated by the studies of *Brace* [1971] a finding of resistivities of 10^6 ohm-m or greater will indicate that dry rocks do exist at depth in the earth.

Resistivity of Seismic Low-Velocity Zones

It is interesting to note the results of *Word et al.* [1971], which show a high conductivity layer at a depth of roughly 10 km in the Texas Gulf coast, seaward of their station 3. No correlations between the sialic low-velocity zone and resistivity have been reported in the literature, but *Mitchell and Landisman* [1971] note a possible correlation between the 20-km seismic low-velocity zone in eastern New Mexico and a low-resistivity zone observed in a nearby area. Caution is needed on this point, however, until combined experiments are conducted in the same areas to establish this relationship clearly.



This figure is taken from the work of Word, Smith and Bostick. *Depth is shown on a log scale; resistivity is represented by approximate values overprinted on the cross section in ohm-meters. A highly resistive zone extends from Station 3 seaward. A 10^4 ohm-meter value is shown for the resistive section. This is an approximation since the magnetelluric method is incapable of measuring high resistivities precisely. If the section actually has a 10^7 ohm-meter resistivity, a not unreasonable possibility judging from laboratory data for dry rocks, this section would form a wave-guide capable of propagating radio waves over long ranges of several thousand kilometers. The wave guide is formed by the resistive interior and by the conductive layers above and below this section.*

Oceanic-Crustal and Upper-Mantle Resistivities

Only limited studies of earth resistivities beneath the ocean have been conducted. *Cox* [1971] reports some of the pioneering work on this problem. Based on temperature, earth materials in the upper mantle beneath the oceans may be highly resistive, provided they are dry. Whether these rocks are dry and what absolute resistivities they have remain to be determined. Cox, however, finds that appreciably conductive rocks do not occur until depths of roughly 30 km beneath the ocean. Clearly, the impact of major geologic structures in the oceanic crust on the distribution of resistivities is an open question.

Conclusions

Although sections of sufficiently high resistivity for long-range wave guide propagation have not yet been reported in the published literature, recent calculations by *Keller* [1971] indicate that, if transition zones are included in the calculation, existing data in tectonically stable areas yield zones of 10^6 and 10^7 ohm-m resistivity. If these zones exist, wave guide attenuations as low as 0.1 db/km (*Wait and Spies* [1971]) are possible. Laboratory measurements on rocks indicate 10^8 and 10^9 ohm resistivities for dry rocks, which makes it possible that highly resistive zones may exist in the earth's crust. Specialists in high-pressure high temperature mineralogy indicate that free water in the earth's crust is possible but not necessary and the the geophysicist will have to resolve this question through experimentation (*Wyllie* [1971] *and Boettcher* [1971]). If the rocks are wet, *Brace* [1971] shows that 10^5 ohm-m resistivities will be maximum. Thus the Keller results indicate that dry rocks may exist at depth.

Present resistivity measuring techniques are subject to ambiguities (*Madden* [1971] *and Porath* [1971]) and have not yet answered the question of whether sufficiently resistive zones exist in the earth to make long-range electromagnetic propagation feasible. The question of continuity in resistive earth zones remains unanswered on the basis of available field data. However, the argument is made intuitively that *in situ* temperature and pressure must control the presence of an apparently widespread seismic low-velocity zone reported elsewhere as occurring in a characteristic depth range at about 10 km in the continental crust. Assuming an *in situ* temperature and pressure control for resistivity, it appears reasonable to inquire into the possibility that, should a highly resistive zone in dry rocks be found at depths below 10 km, such a zone could extend across geologic province boundaries, perhaps relatively undisturbed by tectonic activities.

If a zone of sufficiently resistive rocks can be found, bounded top and bottom by conducting material, it could form an electromagnetic wave guide whose range would depend not only on its electrical properties (*Wait* [1971] *and Wait and Spies* [1971]) but also on its extent and degree of lateral continuity.

Because of the difficulties involved in measuring the electrical resistivity distribution in the earth's crust, it seems probable that a multidisciplinary approach must be made to this problem. Laboratory studies of physical rock properties combined with multidisciplinary field data, should help us to identify the materials that exist at depth. Through such studies, it should be possible to eliminate some of the ambiguity that now makes it difficult to determine the distribution of electrical resistivity with depth in the earth.

An improved knowledge of the crustal environment should contribute major potential benefits to mankind, which could be used in the development of new techniques for communication, in the identification of deep mechanical properties in order to reduce earthquake hazard in stressed regions, and in the solution of environmental problems related both to waste disposal and to the acquisition of new natural resources. The need for geochemical experiments combined with laboratory studies of physical properties and with carefully designed multidisciplinary studies in given areas of various geologic provinces cannot be overemphasized.

The development of techniques to identify precisely the nature of the earth's internal environment is a major need today.

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About the Author

Mr. Heacock is director of the Earth Physics Program (Code 417) at the Office of Naval Research. He is the editor of AGU Monograph No. 14, *The Structure and Physical Properties of the Earth's Crust* (1971), from which the above paper was taken. This book contains the scientific background material upon which the mentioned paper is based. Papers in Monograph 14 were originally presented at an ONR symposium held in Bolder, Colorado July-August 1970.

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Scientist Patents New Computer Storage Elements

Dr. Irwin Schneider of the Naval Research Laboratory has patented a new method for computer information storage with optical materials.

In the new method, anisotropic color centers, such as the Na center in optical materials like sodium-doped potassum chloride (similar to table salt) crystals are used for the storage of information.

The color centers are first oriented in a common lattice direction with polarized light, and information is then stored by effectively causing reorientation of the color centers with radiation of the same wavelength but of altered polarity.

Information can then be read with polarized light at a longer wavelength without destroying the information. Dr. Schneider said optical materials are particularly useful for computer storage elements since they have a greater information storage capacity than conventional magnetic core memories.

Work is continuing on the project; and other patents on the subject by Dr. Schneider and his co-workers are pending. His approved U.S. Patent number 3,580,688 is titled, "Information Storage with Optic Materials."

On the Naval Research Reserve

NRRC 13-1 Completes Three Research Projects

NRRC 13-1, Seattle, has reviewed its training program and attempted to engage its members more actively in the undertaking of group research projects of interest and use to the Navy. Last year the Company completed a pilot study on "Motivational Factors Affecting Affiliation of Officers and Enlisted Personnel in the Naval Reserve" which was forwarded to the Chief of Naval Research and the Chief of Naval Personnel. Directed by CDR Ambrose Clegg and LCDR F. Paul Carlson, the project found that five key variables were powerful and influential factors in the decision to affiliate or not with a Naval Reserve program. They were: socio-economic factors, knowledge of Reserve programs, role conflicts, attitudes formed while on active duty, and attitudes formed toward national policy.

Combining the medical and engineering talents of the members the company undertook a second project on "Some Bio-engineering Aspects of the Detection and Display of the Fetal Heart Rate" led by CDR Stewart Hilscher, and LCDR Carlson. The study was a small scale exploratory study in the theoretical and clinical data-gathering activities of the investigation. Data from this first test indicated that the problem of fetal heart tone detection will require several sophisticated techniques in data processing, including acoustic arrays, real-time correlations, or signature detectors.

The company completed its third "contributory support project" in February 1972, when it finished compiling and analyzing the data on attitudes and feelings of enlisted members aboard the USS HANCOCK (CVA-19).

Naval Reserve Research Company 13-1 was named the outstanding Research Reserve Company in the Thirteenth Naval District for 1971.

NRRC 13-4

NRRC 13-4, Portland, Oregon has enhanced member interest by establishing a theme of reccurring topics of general interest: computer science, nuclear power, and ecology. The Company recently visited the Portland Police Department Data Processing Center, which is automating its information retrieval system to expedite squad car call-ins.

Nuclear power was the topic when NRRC 13-4 visited the Reed College experimental reactor, and when they viewed construction at the site of the Trojan Nuclear Power Plant.

Future plans call for a session on the environmental considerations concerning the proposed expansion of the Portland International Airport.

Research Notes

New Oceanographic Facility

A ship schedule for the coming year of UNOLS (University National Oceanographic Laboratory System) has been detailed and made available to member insititutions sharing common research interests, it was announced by Robert P. Dinsmore, Executive Secretary of UNOLS. The UNOLS organization was recently developed as a planning and coordinating mechanism for oceanographic research facilities and its office is located at the Woods Hole Oceanographic Institution. The UNOLS efforts are funded by the National Science Foundation and the Office of Naval Research, who are the primary funding agencies in ship time to the various institutions.

Representing a joint effort by the academic community and federal funding agencies, the principal purpose of UNOLS is to review and coordinate utilization of and access to oceanographic research facilities. The ship schedule, distributed at the first meeting held last month in La Jolla, Calif., represents the first time such information has been made available to the 18 charter members who represent the country's major oceanographic research centers. The meeting featured the establishment of a liaison between the facilities and their research vessels, highlighted operational areas of common interest, and revealed to investigators ship time which was potentially available for their studies.

The UNOLS Advisory Council, selected at this meeting from a list of forty nominees consists of:

John V. Byrne, Oregon State University; John P. Craven, University of Hawaii; Charles L. Drake, Dartmouth College; David W. Menzel, Skidaway Institute; Robert A. Ragotzkie, University of Wisconsin; Henry M. Stommel, M.I.T.; Warren S. Wooster, Scripps Institution.

The UNOLS Advisory Council held its first meeting earlier this month at San Francisco with the purpose of establishing ground rules for co-operative use of ships, aircraft, submersibles and technical personnel. The operations of nongovernment vessels now exceeds \$20-million annually. Dr. Arthur E. Maxwell, Provost of the Woods Hole Oceanographic Institution convened the meeting.

Many institutions both research and academic have the need of ships and aircraft but cannot afford to buy or lease for their research. The charter institutions are seeking ways of making vessels, aircraft, and personnel available to the more than 100 institutions that need them.

It was noted at the meeting that information on larger vessels was developing but that more information on coastal-type vessels 65′ and under was greatly needed. Only five of these vessels now have direct Federal support.

A subject of common interest to all participants was the developing situation of the research fleet in the matter of vessel construction and the support for design and construction. Some of the institutions brought forth their needs for coastal research vessels to which they could have blocks of time made available to their institutions. These centers have a need for vessels but do not own or have access to the use of existing vessels.

Considerable discussion was generated amongst the participants as to the precise role of UNOLS in the coordinating of these functions. The office currently seeks to accomplish the organization's aims through the use of questionaires and fact finding.

The 18 Institutions forming the charter membership of UNOLS include: the University of Alaska; Duke University; Florida State University; the University of Hawaii; the Johns Hopkins University; Lamont-Doherty Geological Observatory at Columbia University; the University of Miami; the University of Michigan; Nova University of Fort Lauderdale, Florida; Oregon State University; the University of Rhode Island; Scripps Institution of Oceanography of the University of California, San Diego; Skidaway Institute of Oceanography in Georgia; the University of Southern California; Stanford University; Texas A & M University; the University of Washington; and the Woods Hole Oceanographic Institution.

New Types of Metallic Solid Solutions: Interstitials and Di-Substitutionals

Metallic solid solutions form when solute atoms occupy certain positions in the host metal structure. As solid solution formation is a major strengthening mechanism for metals, the preparation of new alloys of this type is important for the development of strong materials.

Until recently, only two types of terminal metallic solid solutions had been observed: substitutional solid solutions, with a solute atom replacing a solvent atom, interstitial solid solutions, with a solute atom occupying a "hole" between solvent atoms. Extensive substitutional solid dissolution of metals in metals occurs only if the atomic sizes of solute and solvent differ by <15 percent (Hume-Rothery's Rule); there are also other limiting factors, such as the difference in electronegativity and valence in solute and solvent which affect maximum solid solubility. Extensive interstitial solid solution formation occurs only if the solute size is $< \sim 59$ percent of the solvent size (Hagg's Rule) and is limited to small non-metals such as H, B, C, and N as solutes. Beyond this, there was strong indirect evidence that very small amounts of metal (<0.1 percent) can dissolve interstitially in other metals; however, direct proof for this type of alloy had not been obtained and extensive interstitial metal-metal solid solutions were not known.

By extending the search for new materials to non-equilibrium alloys, this gap has now been filled. Experimental quantities of concentrated, nonsubstitutional metal-metal solid solutions have been prepared as metastable phases by Drs. B. C. Giessen, R. Ray and their collaborators under an Office of Naval Research contract at the Solid State Chemistry Laboratory of Northeastern University in Boston. They found that in yttrium-rich Y-Cu alloys with up to 12.5 percent Cu, copper atoms occupy almost purely interstitial sites in the hexagonal close-packed yttrium host structure; beyond 12.5 percent Cu, substitutional positions begin to be occupied. (In a related study, they found that iron dissolves in gadolinum by forming di-substitutionals, *i.e.* clusters of two solute atoms substituting for one solvent atom.) The metastable alloys were produced by ultra-rapid quenching from the metal at 10^6 to 10^8°C per second (splat cooling); once formed, these alloys do not decompose at temperature below ~ 300°C. The solute-solvent radius ratio is about 0.7; several other metal combinations with radius ratios in this previously unexamined region yield similar solid solutions.

The new non-substitutional solid solutions are expected to have superior strength properties, as interstitial metal atoms will effectively block the motion of dislocations by which deformation proceeds. Indeed, a large microhardness increase (up to ~100 percent) has been found in Y-based interstitial alloys. It is possible that in some alloy combinations a major advance in alloy strengthening can be achieved by quenching-in metastable non-substitutional solid solutions.

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Microwave Used to Determine Oil Slick Thickness

Scientists at the Naval Research Laboratory have developed a new method for the remote determination of water surface oil slick thickness using multi-frequency passive microwaves.

The new technique permits thicker slicks to be measured day or night and nearly independent of weather conditions; optical and infrared determination techniques have time and weather limitations.

The oil acts as a matching layer between free space and the water, increasing the emissivity of the surface. Using several frequencies allows ambiguities resulting from interference effects to be removed and a unique thickness determined.

An aircraft-borne measurement program of controlled oil spills is now underway to consider the NRL technique on an operational basis.

Details of this work will be presented at the 1972 USNC/URSI-IEEE meeting, April 13-15 which will be held in Washington, D.C.

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An instance of lightning initiated by a tall building in Moscow. *See page 11.*

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