A LABORATORY FOR EARTH AND PLANETARY SCIENCES

EARTH and PLANETARY SCIENCES LABORATORY

of the

SOUTHWEST CENTER FOR ADVANCED STUDIES

A Division of The
GRADUATE RESEARCH CENTER
of the SOUTHWEST

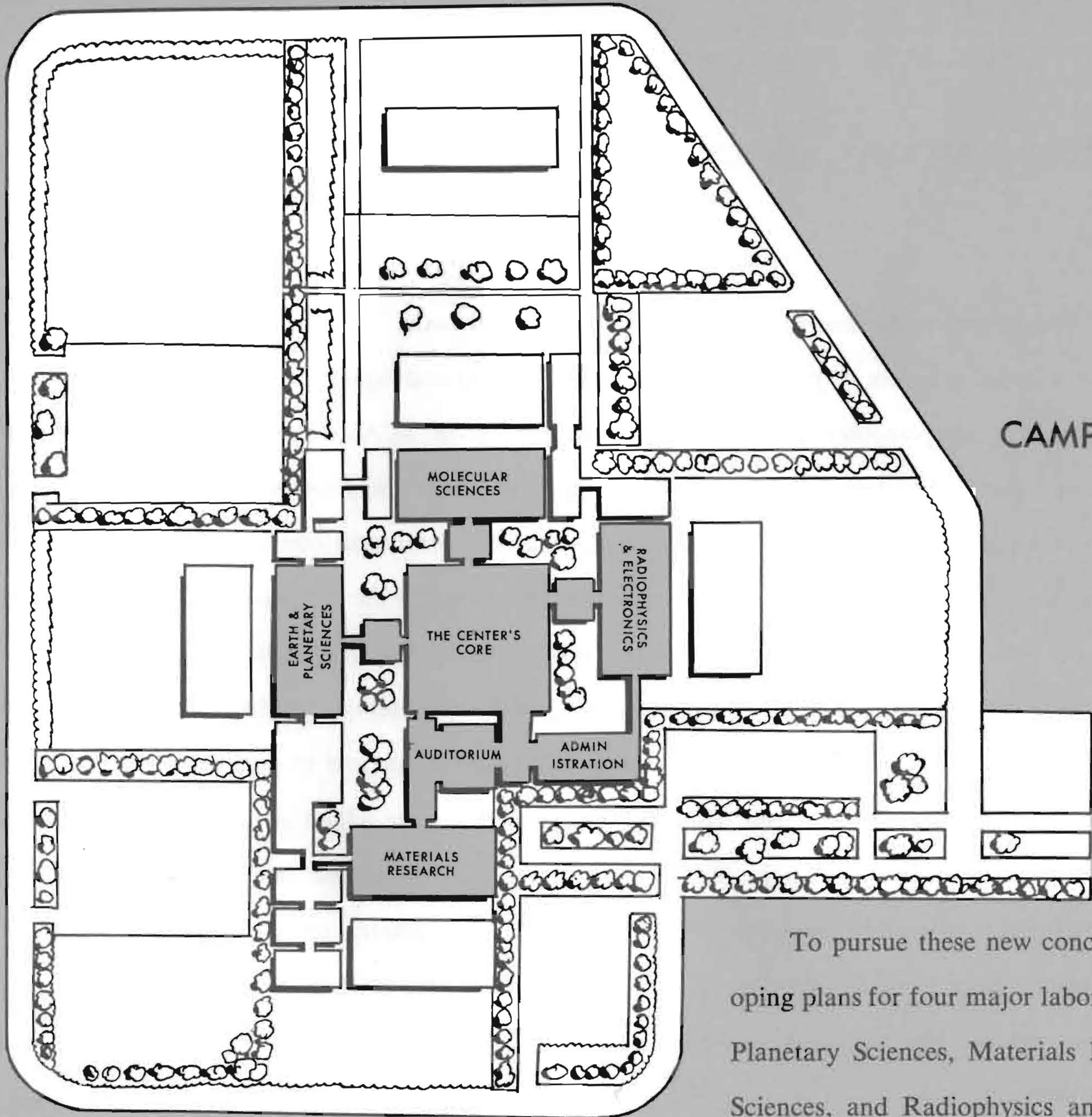
THE GRADUATE RESEARCH CENTER OF THE SOUTHWEST

was founded in 1961 as a stimulus to improving science education in the Southwest through the conduct of fundamental research and the support of the universities of the region. To achieve this objective, the Center, under the direction of Dr. Lloyd V. Berkner, has evolved a basic concept of coordinated fundamental research designed to complement and enlarge many diverse efforts in the Southwest, all having the common goal of stimulating a distinguished graduate educational program in the region.

GRCSW has established in Dallas the Southwest Center for Advanced Studies, conceived upon the principles of academic excellence and research at the frontiers of knowledge. Staffed by distinguished scientists in their fields and afforded research facilities often beyond the means of many educational institutions, SCAS is developing programs which probe the limits of basic research in selected fields. The scientific opportunities thus afforded, and the intellectual quickening derived from a wide diversity of talents, will enable participating faculty from the region and post-doctoral scholars participating in the Center's program to guide their students also to new advances in fundamental scientific research. Inevitably, also, the intellectual and scientific environment of the Center with its program of investigations in many scientific fields, will provide a rich harvest of advanced scientific knowledge for the expanding technological complex of industries now developing in the Southwest.

GRADUATE RESEARCH CENTER OF THE SOUTHWEST

EDUCATION INDUSTRY COMMUNITY



CAMPUS PLAN

To pursue these new concepts, SCAS is developing plans for four major laboratories in Earth and Planetary Sciences, Materials Research, Molecular Sciences, and Radiophysics and Electronics.

THE EARTH AND PLANETARY SCIENCES LABORATORY

first of these four laboratories to be established, is assembling an academic staff of recognized competence to plan and conduct a broad program of basic investigations of the solid and liquid Earth, the near and distant reaches of our atmosphere, interplanetary space and the planets themselves. SCAS scientists are using the Earth and its atmosphere as a giant laboratory, where the resources of all scientific disciplines will be applied to fundamental problems. New scientific discoveries, new tools and exciting new theoretical concepts are being brought to bear upon critical geophysical investigations to understand more thoroughly the world in which we live. These investigations, and the knowledge and experience which this research contributes, also provide the foundations for an imaginative program in space science: the investigation of the Earth's outer atmosphere and interplanetary space, the solar atmosphere, and the geophysical characteristics of the other planets in our solar system.

As other SCAS laboratories are developed, these scientists will have the added advantage of working in an environment of strong interdisciplinary forces. The scientific resources of academic institutions in the Southwest and the talents and capabilities of the extensive southwest industrial complex, comprising in one geographical region the largest group of practicing geophysical scientists and engineers in the world, will be coordinated with the program; in turn, the resources of both the universities and southwestern industry will be strengthened by the Center's scientific activities.

The Earth and Planetary Sciences Laboratory conducts its program in two divisions: The Geosciences Division under the direction of Professor Anton L. Hales, and the Atmospheric and Space Sciences Division, under the direction of Professor Francis S. Johnson. The following pages describe the programs of these divisions and, it is hoped, reveal a glimpse of the scientific discoveries toward which the research will be directed. Basic scientific discoveries, however, most frequently illuminate new questions whose answers must be sought or new avenues toward which the next phases of research should be directed. Scientific research is dynamic. Thus, flexibility will be the hallmark of the Laboratory's program — the courses of discovery will be followed wherever they may lead, and programs will be modified whenever new and promising research avenues become apparent.

THE GRAVITY FIELD OF THE EARTH

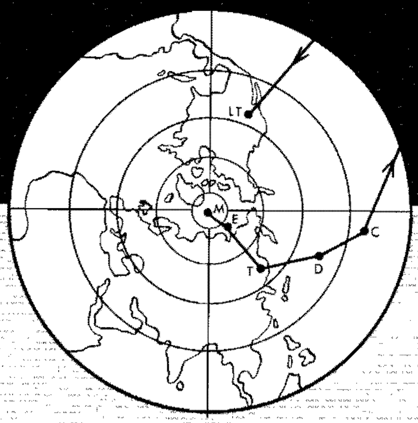
Gravitation, perhaps the oldest physical effect known to man and one of the first to be described theoretically, is still most inadequately measured for many remote regions of the Earth. From the standpoint of theoretical physics, new opportunities for fundamental experiments regarding the nature of gravitation are available through space experimentation, and the Geosciences Division expects to develop programs for research in this field. Initially, however, the Division will devote its attention to measurements of the gravity field at the surface of the Earth, particularly as this field relates to the shape of the planet. This relation is still very poorly known primarily because so much of the Earth's surface is covered by the oceans.

For this reason, the Geosciences Division has an interest in the establishment of large-scale programs in this area: gravity measurements at sea and a world-wide air gravity survey. Capitalizing upon recent technological advances which enable precise gravity measurements at sea to be undertaken, the Division plans to undertake such measurements in conjunction with a program of oceanographic and crustal research of ocean areas. As the program develops, plans will be pursued for installing gravity meters on a number of vessels to extend the measurements widely over the ocean areas. Developments in achieving accurate gravity measurements at sea also support the feasibility of Division plans to extend these investigations through aerial surveys. Observations will be made first over terrain where the values of gravity are already precisely known. With these calibrations as a base, plans are being developed to establish a world-wide air gravity survey as rapidly as possible.

Thus, by sea and air, there is in prospect a gravity survey over wide regions of the Earth previously inaccessible for precise measurement — and the consequent prospect for obtaining on a global basis new knowledge of the structure of the Earth.

GEOMAGNETISM

Although for centuries scientists have measured the magnetic field of the Earth and its intensities over the world, even today little sure knowledge of the causes of this field exists. However, it now seems certain that the main field is internal in origin and is associated with electric currents circulating in the Earth's core. Scientists are, nevertheless, uncertain how this circulation is maintained, a fundamental question which must be answered in understanding the geomagnetic field.



Wandering of the magnetic pole as shown by European rocks, (M) Miocene, (E) Eocene, (T) Triassic, (D) Devonian, (C) Cambrian, (LT) Lower Torridonian.

The Geosciences Division has developed a program of systematic theoretical and experimental studies of various possible causative mechanisms. Secular variations in the field, as observed at the Earth's surface by the slow temporal drift of the magnetic poles, are evidence of variations in the internal mechanisms and will be investigated. Discrepancies between earth-air currents deduced from magnetic data and those obtained by direct measurements are known to be substantial; causes for these discrepancies will be examined. A supporting program to study the orientation and strength of vestigial or fossil magnetism in ancient rocks will be undertaken. Here, it has been established that most rocks older than about 100 million years demonstrate that the magnetic field has changed substantially since earlier epochs of the Earth's history. This phenomenon may be due to long-interval reversals in the magnetic field or, possibly, continental drifts relative to the mean directions of the Earth's magnetism. The implications to geophysics in these discoveries are fundamental to many other studies of the solid Earth and a vigorous Divisional program in this area is planned.

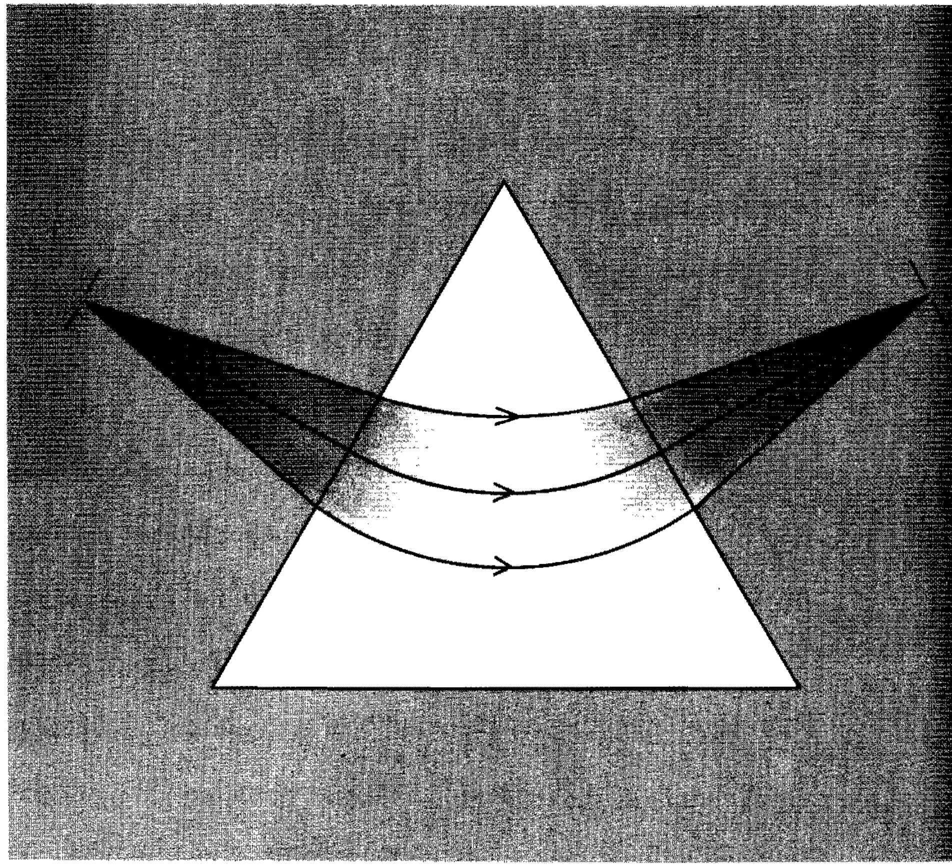
OCEANOGRAPHIC INVESTIGATIONS

Many aspects of the Geosciences Division program, e.g., gravity, seismic and heat flow investigations, require research in oceanic areas to achieve an understanding of the physical processes prevailing in the Earth's crust and interior. In the progress of these investigations the Division is developing plans for a coordinated program of shipboard investigations for three-month periods each year, followed by laboratory and theoretical study of the data which are acquired. Seismic refraction measurements will be made, complemented by continuous profile reflection measurements. Measurements of the magnetic field, utilizing a towed magnetometer, will be undertaken to supplement other programs. Advantage will be taken of ship cruises to secure ocean bottom cores. Initially, studies will be concentrated on the deep ocean trenches for the study of these features is thought to be of great significance for the understanding of the development of the Earth.

GEOCHRONOLOGY

The origins and development of the continental land masses pose some of the most puzzling scientific questions facing geophysicists today. For example, radioactive dating has established the approximate age for the solid Earth at about 4.5 thousand million years. However, the oldest rocks known to scientists, established by similar dating systems, are some three thousand million years old. The reasons for this time difference are unexplained although many theories have been advanced.

The Geosciences Division is developing a major program of research in this field. Initial investigations will be directed toward total rock measurements of rubidium-strontium radioactive decay measurements, the method of age determination primarily used by previous



FOCUSING OF A DIVERGENT ION BEAM BY A WEDGE-SHAPED MAGNETIC FIELD IN A NIER MASS SPECTROMETER

RADIOACTIVE DECAYS USED IN MEASURING THE AGE OF ROCKS

$U^{235} \Rightarrow Pb^{207}$ in 1,030 million years

$K^{40} \Rightarrow A$ in 1,400 million years

$U^{238} \Rightarrow Pb^{206}$ in 6,500 million years

$Th^{232} \Rightarrow Pb^{208}$ in 20,000 million years

$Rb^{87} \Rightarrow Sr^{87}$ in 50,000 million years

investigators. Analyses of granite rock samples, known to be rich in rubidium, provide the age and initial values of Sr^{87}/Sr^{86} ratio at the time the rock system formed, thus enabling the samples to be analyzed in terms of this basic ratio. By comparison, it is possible to determine whether the samples in question were formed by differentiation of more ancient material or by reworking of other materials. The extension of this procedure to other radioactive decay systems will also be pursued. In particular, use of the thorium-lead and the uranium-lead chains appear applicable and will be used as the program is developed.

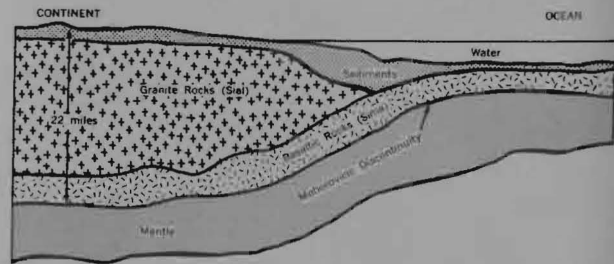
Study of rock specimens from many parts of the world is contemplated, if possible enlisting the cooperative assistance of other qualified research teams and laboratories. As the program develops, it is planned to extend these radioactive dating techniques also to the study of meteoric materials.

The foregoing programs are all directed toward achieving a fuller understanding of the origins of the Earth and the processes by which it has developed to its present state. In addition to these programs, the Division has developed plans for a number of other research projects directed toward the same goals.

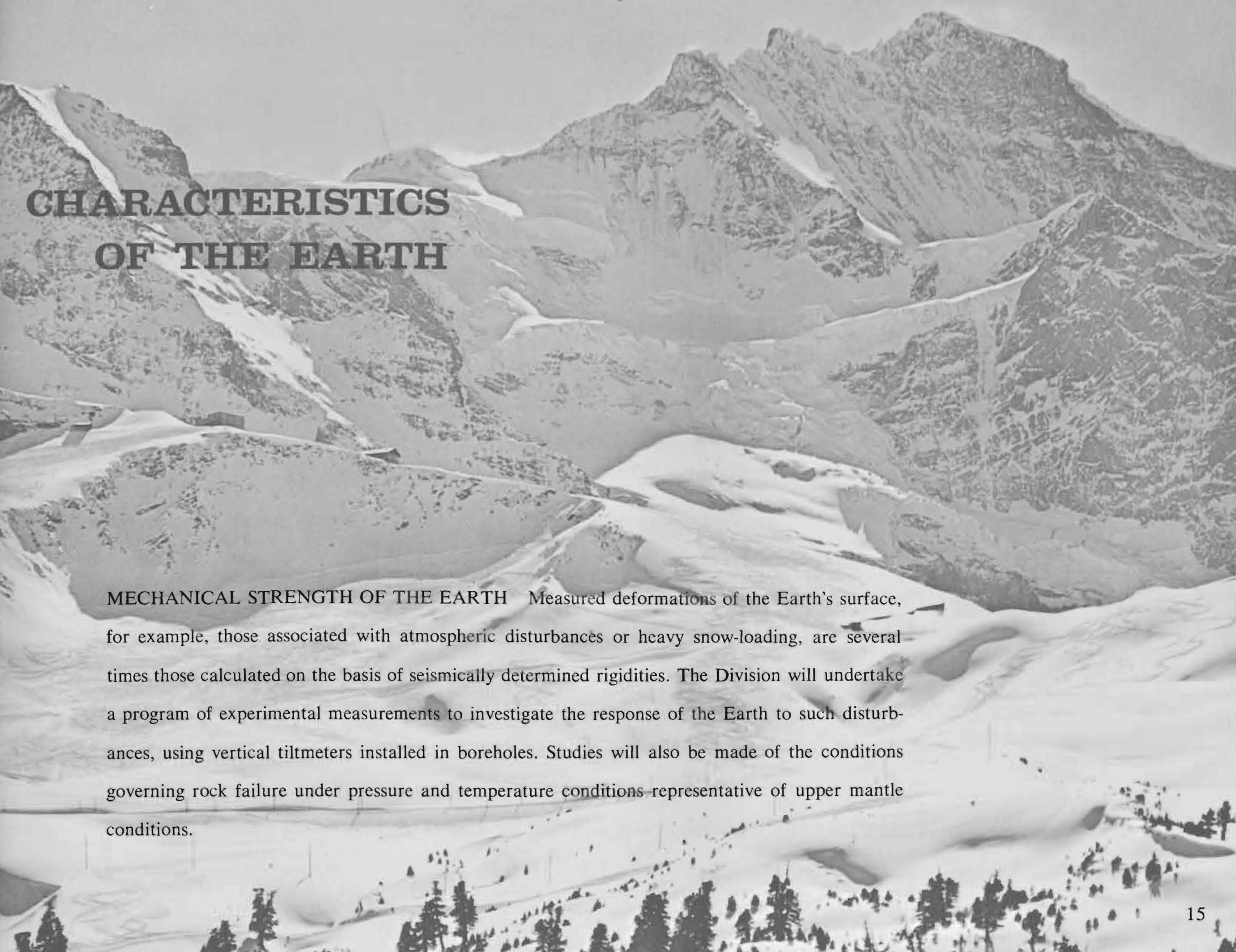
COMPOSITION OF THE UPPER MANTLE Materials having the assumed compositions of selected interior regions will be investigated in the laboratory, correcting for temperature and pressure differences, to obtain possible verification of the supposed compositions. Samples of ultrabasic materials, representing materials formed at upper mantle levels and recovered as inclusions in diamond mining, will be acquired for detailed laboratory study and analysis.

HEAT GENERATION AND FLOW A Division program is planned to investigate regions of unusually high heat flow from the Earth's interior recently discovered in oceanic areas. Findings in this program will be compared with measurements obtained in studies of heat generation in continental areas heretofore believed to be the greatest source of heat at the Earth's surface. Other aspects of the program will investigate the pattern of isolated regions of high heat flow in the ocean areas.

COMPOSITION AND STRUCTURAL



CRUSTAL STRUCTURE MODEL OF THE EARTH



CHARACTERISTICS OF THE EARTH

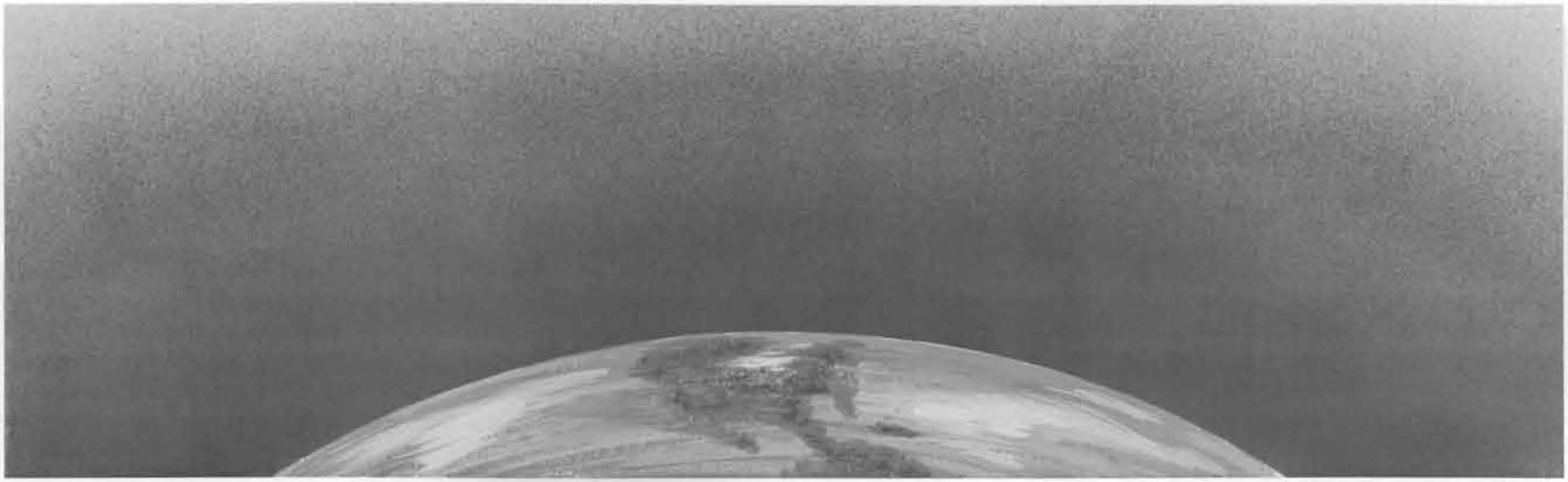
MECHANICAL STRENGTH OF THE EARTH Measured deformations of the Earth's surface, for example, those associated with atmospheric disturbances or heavy snow-loading, are several times those calculated on the basis of seismically determined rigidities. The Division will undertake a program of experimental measurements to investigate the response of the Earth to such disturbances, using vertical tiltmeters installed in boreholes. Studies will also be made of the conditions governing rock failure under pressure and temperature conditions representative of upper mantle conditions.

THE ATMOSPHERIC AND SPACE SCIENCES DIVISION

PROFESSOR
FRANCIS S. JOHNSON
DIVISION HEAD

The research program of the Atmospheric and Space Sciences Division is directed toward achieving the fullest possible understanding of planetary atmospheres and interplanetary space; of necessity, the program objectives also include investigations regarding the atmosphere of the Sun, since solar influences are the primary causes of many atmospheric effects. Early emphasis in the program is placed on the Earth's atmosphere where an extensive body of data already exists. Research on the atmospheres of other planets will occupy an increasing proportion of the Division's effort as opportunities in the space program make this possible.

Although knowledge of the characteristics of the Earth's atmosphere has increased explosively in recent decades, a vast amount of fundamental research is still needed to develop a fully comprehensive scientific picture. The reasons for this are readily apparent. Scientists must determine vertical distributions of composition, temperature and density out to ranges of tens of thousands of kilometers — characteristics which vary with latitude, time of day, season and year. Both regions of neutral constituents and those with ionized constituents are involved. The upper atmosphere is strongly affected by radiations, primarily from the Sun, whose activity varies greatly with phases of the sunspot cycle. The ionized portion of the upper atmosphere has a strong influence on



the Earth's magnetic field. Dynamic atmospheric motions induce large scale atmospheric movements which further complicate studies of upper atmosphere composition and structure.

Despite the complexity of this atmospheric system, a general picture of the Earth's atmosphere has been developed since World War II through the efforts of many eminent scientists and the interrelated applications of theory and experiment. In recent years many new scientific instruments and new tools — rockets, satellites and interplantetary probes — have enabled direct high altitude atmospheric measurements to be undertaken for the first time in scientific history. Even more dramatic has been the development of information relating to high energy charged particles in space — galactic and solar cosmic radiation, Van Allen radiation, auroral radiation, and interplantetary plasma — and the relationships between these particles, the interplanetary magnetic fields and the outermost portions of the geomagnetic field.

Thus, increasing scientific opportunities, both theoretical and experimental, are now in sight to determine values of the many atmospheric and space environmental parameters needed for precise description of the physical state of the Earth's atmosphere and the interplantetary medium. The Atmospheric and Space Sciences Division has assembled a group of eminent scientists to lead the SCAS attack on these problems through the research programs suggested in the following pages.

$$P(h) = P(h_o)\, e^{-\frac{(h-h_o)}{H}}$$

$$O^+ + N_2 \rightarrow NO^+ + O$$

$$O_2^+ + e \rightarrow O + O$$

$$O + O_2 + M \rightarrow O_3 + M$$

$$O_2 + h\nu \rightarrow O_2^+ + e$$

HISTORY OF THE EARTH'S ATMOSPHERE

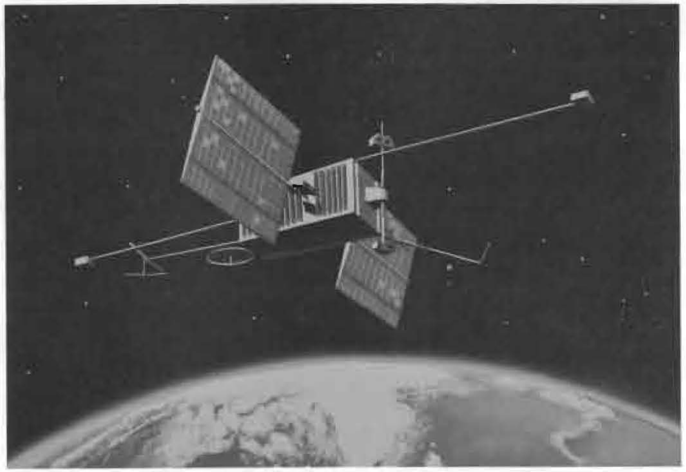
Of basic importance to the comprehension of the Earth's atmosphere as it exists today is the understanding of how this atmosphere has evolved from a very primitive medium in previous eras to its present state. Moreover, understanding of this history enhances the prospects of predicting the characteristics of atmospheres to be found on other planets, or to developing scientific descriptions of those atmospheres from fragmentary data.

Consequently, a theoretical study has been initiated to investigate the evolution of the Earth's atmosphere, using primarily geologic evidence and the evidence for evolution of biological organisms combined with present knowledge in such fields as the properties of atmospheric gases, photo-chemical processes and physical chemistry studies. A review of calculations and hypotheses developed by previous theorists will be undertaken. A series of seminars to consider various aspects of the problem and to isolate specific questions for more intensive study has been initiated. Based upon these studies, mathematical models with various atmospheric constituents will be formulated to obtain a correspondence between particular models and the available evidence from all sources.

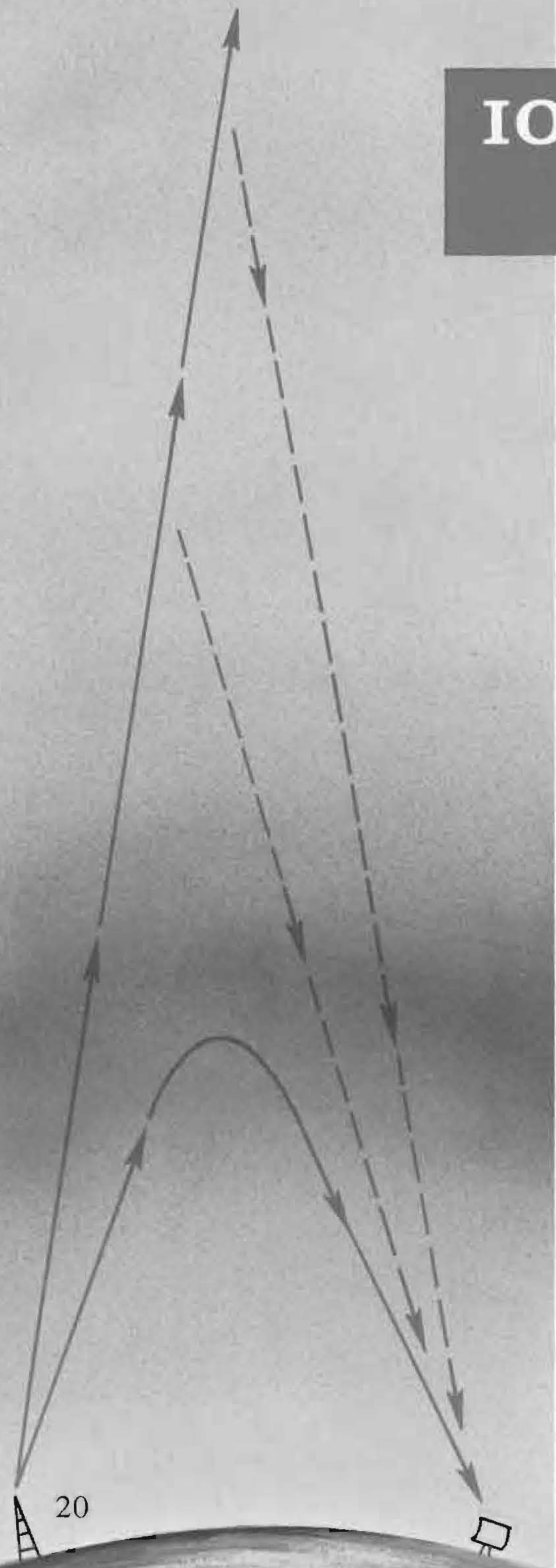
ATMOSPHERIC STRUCTURE

To describe an atmospheric system requires investigations of its composition, temperature and density out to distances of many tens of thousands of kilometers where it then merges with the interplanetary medium. Even for the Earth's atmosphere, exact values of most of these parameters are considerably uncertain since only in recent years have the means been available for *in situ* measurements of these characteristics, and then only at altitudes below 500 kilometers.

The program of the Atmospheric and Space Sciences Division is directed toward obtaining reliable values of composition, temperature and density in the Earth's atmosphere, and their variations with time. Initially, existing data are being studied and analyzed to develop the fullest possible understanding of the current state of knowledge of these atmospheric parameters. Attention will be given to the effects of large scale atmospheric motions, both horizontal and vertical, which extend far above strictly meteorological levels and have profound effects on the upper atmospheric characteristics of interest.



A program of direct measurements of atmospheric structure and composition will also be undertaken, utilizing such instruments as mass spectrometers, ion traps, and density gauges. Many of these measurements can be most satisfactorily made in a satellite whose aspect is controlled relative to the flight direction.



IONOSPHERIC RESEARCH

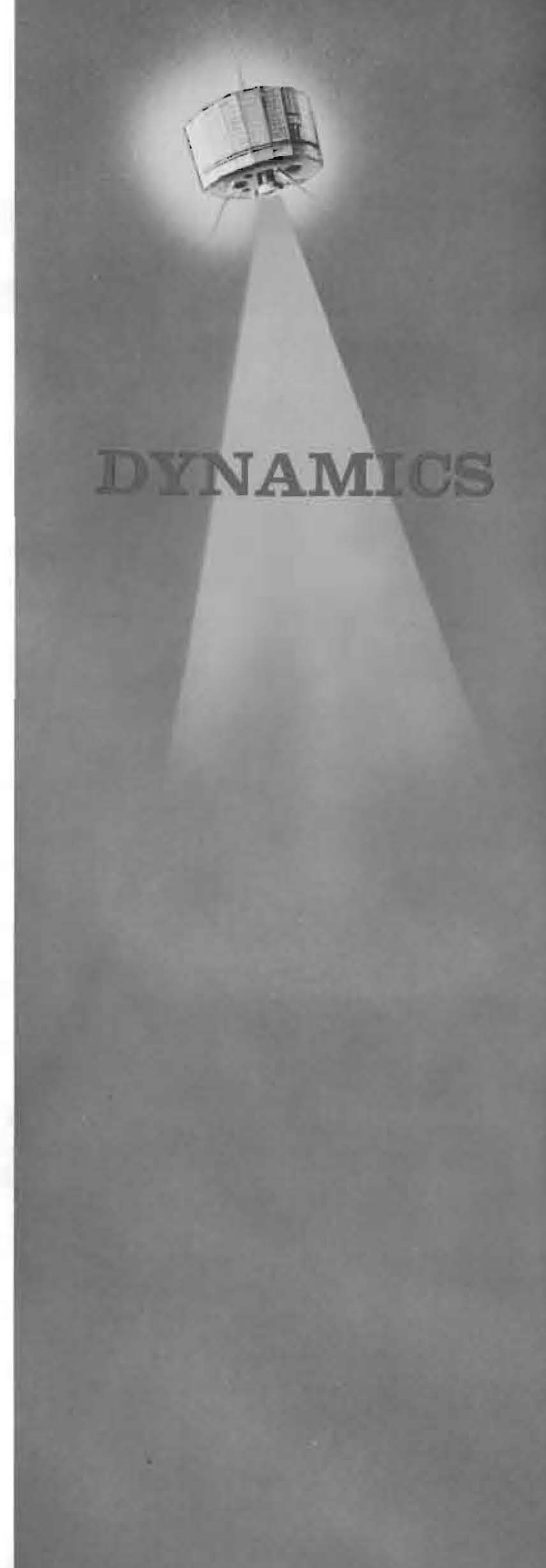
The study of the ionized regions of the upper atmosphere requires a basic knowledge of the atmospheric chemical constituents, gaseous physical chemistry and the behavior of these gases in their ionized state. At levels between about 90 and 400 kilometers several zones of electron concentration occur; during the past several decades these regions have been studied by radio reflection techniques at many locations throughout the world and a vast quantity of valuable data acquired. Above these regions of maximum ion concentration, the atmosphere continues to be partially ionized out to its extreme limits; direct measurements of these higher regions can only be made by means of rockets and satellites and, consequently, a great amount of research remains to be undertaken.

An extensive theoretical investigation of the ionosphere has been undertaken; this involves analysis of data extracted from the reservoir of measurements which have been made in the past by observers over the entire Earth. In addition, the program of the Division will involve ground based experiments and direct measurements utilizing equipment carried in rockets and satellites. The instrumentation for direct measurements includes mass spectrometers and ion traps. Radio propagation experiments in space will also be conducted to determine electron concentrations.

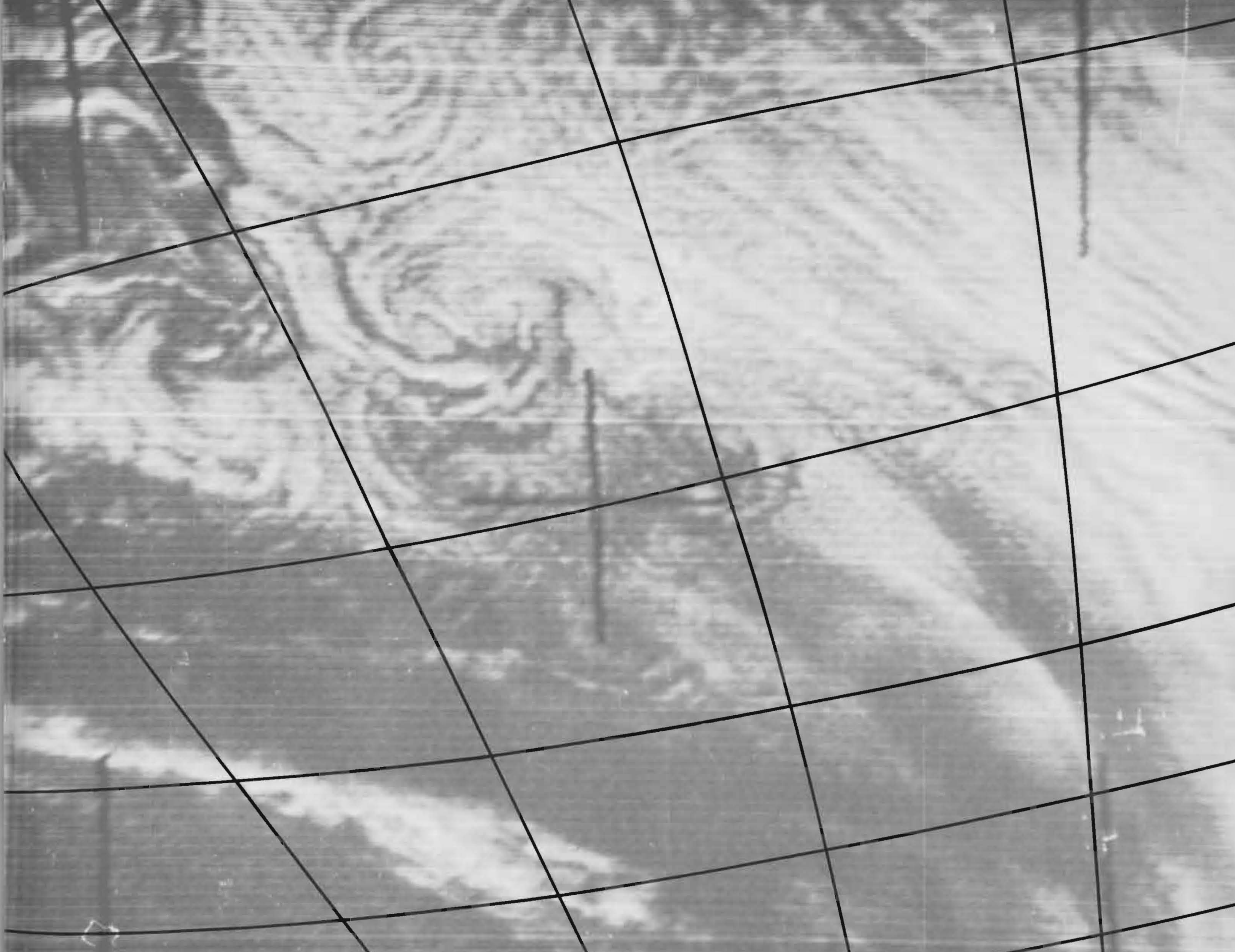
ATMOSPHERIC CHEMISTRY

Understanding of the composition and structure of the atmosphere requires comprehension of the chemical and physical changes taking place in the upper atmosphere. This is particularly true for ionospheric studies, although many of the reaction cross sections needed for an adequate understanding are largely unknown at the present time. The Division, therefore, plans to develop laboratory equipment to investigate cross sections of reactions similar to those believed to be taking place in the upper atmosphere. Theoretical investigations will be pursued simultaneously. Spectrographic study will also be made of the luminescence of atmospheric gases to investigate air glow phenomena known to be associated with atmospheric chemistry reactions occurring at ionospheric heights.

ATMOSPHERIC DYNAMICS



Planetary atmospheres exhibit complicated motions which result in general from the unequal heating of the planetary surface, coupled with the planetary rotation. Although large-scale motions of the lower atmosphere receive careful study in the science of meteorology, it seems certain that these motions must extend to very high levels in the atmosphere, certainly in a seasonal sense, and probably even in connection with storm centers. Consequently such motions would have a profound effect on many aspects of upper atmospheric and ionospheric composition and structure. The possible effects of these atmospheric motions will be studied in the Atmospheric and Space Sciences Division with particular attention being given to the dynamics of the highest levels; this cannot be done independently of a thorough understanding of the motions at lower levels, where most of the energy input to the system occurs.



PENETRATING

All types of energetic particles in space are of direct interest in the program of the Atmospheric and Space Sciences Division. Those with the highest energy (galactic cosmic rays) come from regions outside the solar system. A second type is associated with some solar flares. Energetic particles are also trapped in the Earth's magnetic field to form belts of energetic radiation (the Van Allen belts). Time variations in the intensity of cosmic radiation incident on the Earth and its atmosphere are known to be correlated with solar phenomena and characteristics of the interplanetary medium such as the solar wind and the interplanetary magnetic fields.

The Division's program envisages a major effort of theoretical studies and research investigations to explore all aspects of space radiations. Studies will be undertaken to examine solar system mechanisms which have been shown to modulate incident cosmic radiation on the Earth. Much effort will be made to investigate the correlation of solar flare events and the generation of coincident solar cosmic radiation — a program which has major importance to the safety of manned flights that will be undertaken in deep space during the coming years. Research will be undertaken to determine the spectral intensities of the Van Allen radiation belts and to verify or refine current theories about their characteristics. Causative mechanisms creating auroras will be investigated.

the Earth and of the solar system.

Experimental opportunities for research on the atmospheres of Mars and Venus are likely to be most immediate due to current plans of the National Aeronautics and Space Administration to establish a sustaining program of planetary "fly-by" research probes for these bodies. Consequently, the Atmospheric and Space Sciences Division will, as opportunity affords, propose specific equipment to be carried in these probes. This effort will be supplemented by Division plans to initiate infra-red spectral measurements of water vapor and carbon dioxide in the atmospheres of Mars and Venus from high altitude balloons.

FUTURE PROGRAMS

Preceding sections describe in broad outlines the research program of the Earth and Planetary Sciences Laboratory as it is being developed. In addition, research programs in hydrometeorology and field theory appear to represent valuable extensions to the present effort. Consequently, consideration is being given to establishing scientific groups of distinguished caliber to conduct advanced research in these areas.

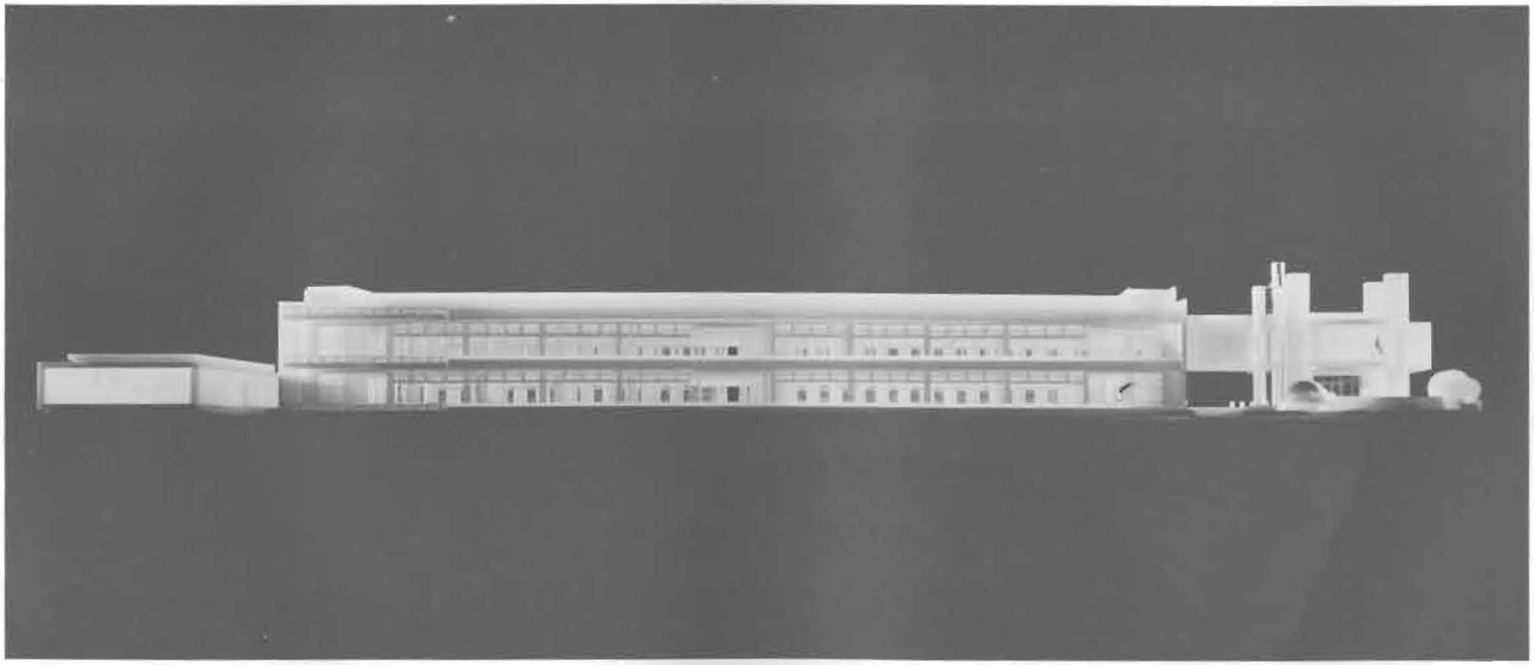
HYDROMETEOROLOGY Basic research in hydrometeorology is concerned with investigations of the complex interrelationships that control the heat and water budget of the Earth. As such, it involves studies of water transport, erosion, physical and chemical transformations, and water storage in the atmosphere, the oceans and on land regions of the Earth; likewise it includes research into the energy mechanisms, primarily solar radiation and heat variations, that bring about these transformations and interchanges. Thus, hydrometeorology embraces basic atmospheric research, physical oceanography, all basic aspects of scientific hydrology, and many facets of geophysics of the Earth's crust. It must also give consideration to the role that all forms of flora and fauna may play in regulating these phenomena. It is clear that both of the present Divisions of the Earth and Planetary Sciences Laboratory have broad interests in hydrometeorological research and that the complement of leading scientists assembled by these Divisions provides a uniquely advantageous base upon which to build a program of fundamental investigations in this field. Moreover, a strong program of hydrometeorological research would be particularly valuable to the

Southwest through the development of basic scientific information directly applicable to problems of water resources and conservation in the region.

FIELD THEORY GROUP In the modern sense, field theory research involves a wide range of disciplines such as hydrodynamics, electromagnetic theory, quantum mechanics, relativity and gravitational theory. Advanced mathematical treatment of these and similar fields is intimately associated with the basic research objectives of the Earth and Planetary Sciences Laboratory. Indeed, it is reasonable to expect that theoretical and experimental investigations of the liquid and solid Earth, its atmospheric sheath or the space environment will raise questions that yield only to advanced mathematical tools. For example, while the interactions of gravitation can be measured, progress in understanding the nature of gravitation depends upon achieving extensions of general relativity theory only partially investigated up to the present time. Hence, mathematical analyses of gravitational waves — or the possible existence of gravitational radiation — suggests one avenue of investigation which certainly will be pursued. Similar examples, related to many other aspects of the Laboratory's program in the earth and planetary sciences, are innumerable; other research programs of the Center, as they are developed, also will require advanced mathematical treatment to assure significant advances. Thus, many reasons for achieving a strong competence in field theory research exist within the Laboratory and careful planning will be devoted to the development of this fundamental asset in the overall program.

EARTH and PLANETARY SCIENCES LABORATORY

The Southwest Center for Advanced Studies has developed a Master Plan for campus development which provides for a prototype major laboratory structure, repeated with variations as the campus grows. The first unit, a model of which is shown, provides laboratories and offices for the Earth and Planetary Sciences Laboratory



and associated administrative and support activities. This is a spacious loft-type building where both laboratories and offices can be arranged in a variety of ways, from small one-man spaces to accommodations for large or unusual programs and equipment. A vertical space frame comprises the center core of the building from which regular and special utilities may be carried vertically and horizontally to each floor in order to serve all space units.

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