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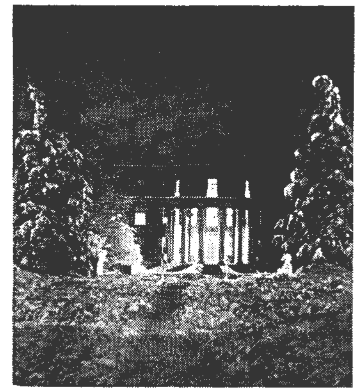
EARTH AND MINERAL SCIENCES



VOLUME 40 NO. 4 JANUARY, 1971

Physicochemical Studies of Lunar Rocks

ARNULF MUAN, *Professor of Mineral Sciences and Head, Department of Geochemistry and Mineralogy*

Introduction

The farthest and most thrilling geological field trips of all times were those carried out by the Apollo astronauts during the past eighteen months. Most of the world was able to share in the excitement of these expeditions through the medium of TV, and scientists at many universities and other research institutions have been given the opportunity to share with NASA's own scientists the excitement of having available for laboratory studies samples of lunar rocks. Some of these "lunatics" are found in the College of Earth and Mineral Sciences at Penn State.

Having extraterrestrial materials available for detailed study in the laboratory is nothing new: Meteorites have been the subject of investigation for more than a hundred years, first by a relatively small number of individuals, commonly considered "eccentrics" by their peers, but more recently by groups of "serious scientists" as well. (For a general background on the status of the mineralogy and petrology of meteorites, the reader is referred to a recent review article in this publication.[1]) However, the fall of meteorites, and the finding of these meteorites, are arbitrary – they cannot be selected in any systematic way, and we do not know where they come from. The Apollo program, by contrast, for the first time in history has made it possible for man to systematically sample an extraterrestrial body. It is this possibility of systematically sampling different parts of the moon and different types of rocks on the moon that makes the Apollo program so valuable geochemically. This careful scientific planning of the Apollo missions has made it very hard for geoscientists to accept the recent decision to reduce the number of remaining Apollo flights at a time when the fulfillment of the scientific objectives of the original program seemed to be attainable.

Why Are Lunar Rocks of Interest to Us?

Aside from man's inherent desire to explore the unknown, there is an additional, more practical impetus for the scientific study of lunar rocks. It is, of course, true, as Edwin Aldrin put it, that the moon is a "magnificently desolate place." However, it is also true that the moon is a magnificently preserved piece of nature. There is no atmosphere on the moon, no clouds, no rain, hence no chemical weathering of the rocks as on the earth. The lunar rocks, therefore, although modified texturally and physically, and to some extent chemically, by meteoritic impacts and solar winds, have remained there relatively unchanged for billions of years. Hence, as distinguished from the earth (see Figure 1), where the early history of the planet is obscured by processes of erosion and sedimentation, the moon is likely to reveal many features from the early stages of its development. Inasmuch as the moon and the earth are parts of the same solar system, it is likely that similar processes and similar conditions were operative in the early stages of the development of the two bodies. Hence, a study of the moon may be expected to shed important light on the early history of the development of our own planet. For a reconstruction of the evolution of our earth and an analysis of the processes involved, the geoscientist usually has to extrapolate *backward* in time over billions of years from very meager and poorly preserved present-day records. The exploration of the moon gives us real hope of being able to attain a starting point from which we can extrapolate *forward* in time. If we succeed in doing this, we have added another dimension to geological sciences and substantially increased our chances of understanding and mastering our own environment.

Present Status of Lunar Research

The initial studies of lunar rocks, particularly those of the Apollo 11 mission, were aimed primarily at *analyzing* and *characterizing* the rocks.[2] In other words, the first investigations represented mainly a *descriptive* approach. This approach is important and necessary, and undoubtedly will be continued also on rocks from future Apollo missions. However, in addition, we have now entered a second stage in lunar studies – the *interpretative* stage. This second stage of lunar investigations is being carried out on synthesized mixtures simulating those collected on the moon, as well as on real lunar samples, and

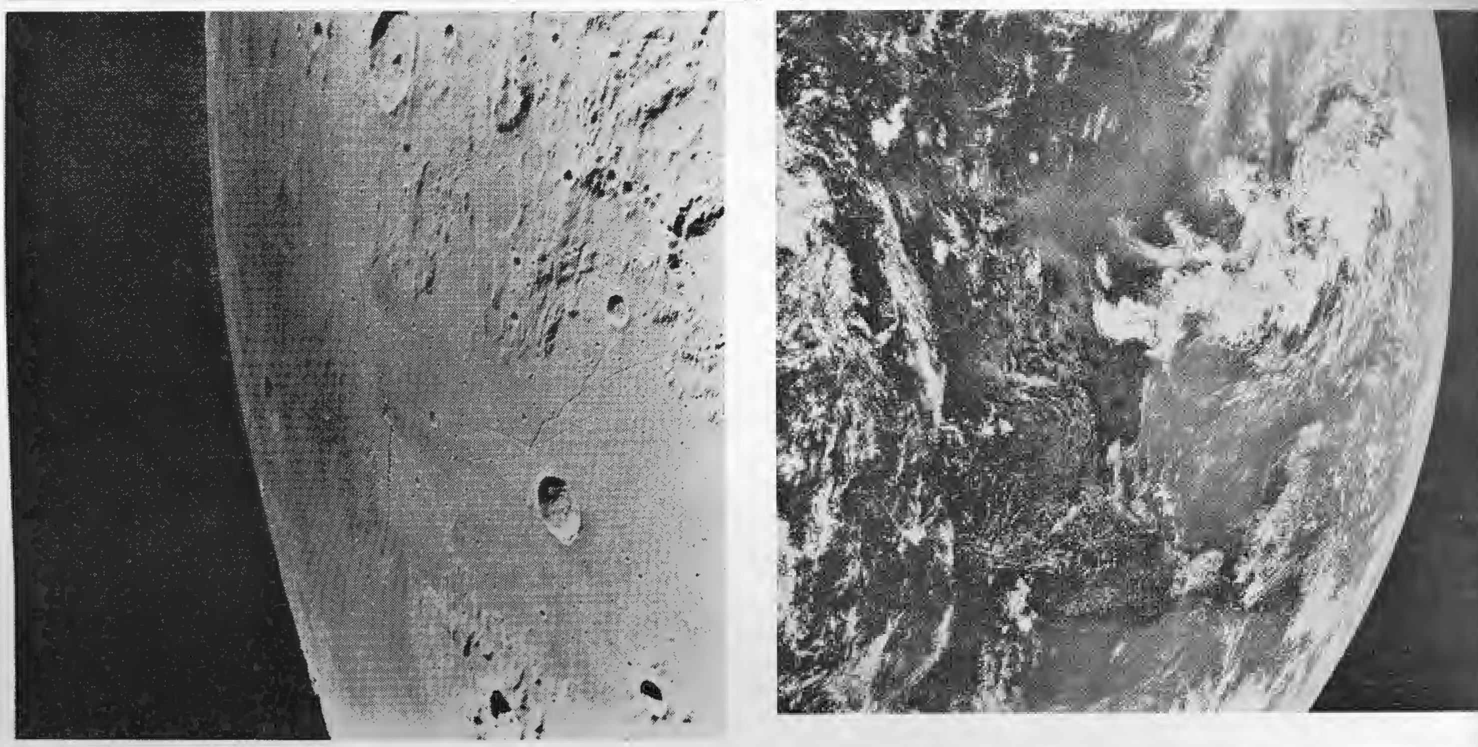


Fig. 1. *Picture showing the contrast between the barren, desolate moon on the left and the earth with its clouds, oceans, and continents on the right.*

it involves in addition a number of theoretical approaches. Hopefully, these various investigations will result in a unified picture of the evolution of the moon and the earth. However, it is clearly too early to expect that such a picture should have emerged by now, less than two years after the Apollo 11 crew returned with the first samples of the moon, and with samples available only from the mare areas. As Preston Cloud put it,[8] "It is as if we were trying to understand North America by examining Plymouth Rock."

EARTH & MINERAL SCIENCES

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The studies of lunar rocks so far have probably raised as many questions as they have provided answers. There is nothing particularly disheartening about this, however. As we travel along new roads, we always see features of the landscape which require further exploration and study. One of the rewards of the scientist is to be able to pass on to the younger generation possible areas of fruitful research for the future. In the lunar studies we are certainly traveling in new territories, and the analysis and interpretation of all the observations will occupy scientists for years to come.

Some Factual Information on Lunar Rocks

Although we have so far, literally and figuratively, merely scratched the surface of the moon, some reasonably well-established facts have emerged from the investigations of Apollo 11 and Apollo 12 samples. Among these facts are some which have influenced research programs within the College of Earth and Mineral Sciences during the past few months and which form the basis for much of the remainder of the present article. Among these facts are the following:

(1) There is overwhelming evidence that at least part of the moon was molten at some stage of its development. Hence, laboratory studies of liquid-solid equilibria are likely to shed light on the evolution of lunar rocks.

(2) There is no free water or hydrous phases in the rocks so far brought back from the moon. Hence, studies of phase relations in dry silicate and oxide systems will play a particularly important role in attempts to understand the genesis of lunar rocks.

(3) Although, by and large, the same types of minerals occur in lunar rocks (see Figure 2) as are found in igneous terrestrial rocks (e.g., olivine, pyroxenes, plagioclase, spinel, ilmenite, etc.), their relative amounts, and sometimes their chemical compositions, are different from those of common terrestrial rocks. This is because the chemistry of the moon is different. It is different with respect to the relative abundances of the various elements, and it is different because the external conditions, particularly the oxygen potential, are different. Typical compositions of lunar rocks are listed in Table 1. Among the most striking characteristics of their chemistry are the high contents of titanium oxide and iron oxide. Clearly, physicochemical data on iron-titanium silicates will have an important bearing on the mineralogy and petrology of lunar rocks.

(4) The oxygen potential of the rocks existing on the lunar surface, as could be predicted, is very low. This is demonstrated by the presence of metallic iron as a phase in lunar rocks. Hence, heating of iron-titanium silicates in contact with metallic iron, under vacu-

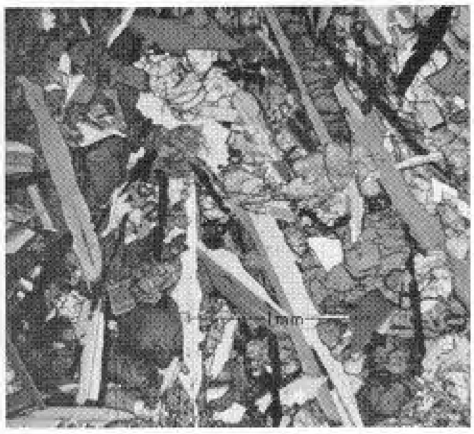

Fig. 2. *Photomicrograph of lunar rock No. 12038 from the Apollo 12 mission, showing crystals of pyroxene, plagioclase, and ilmenite.*

um conditions, will provide experimental conditions closely simulating those which are likely to have been operative during the evolution of lunar rocks.

Equilibrium Studies of Lunar Rocks in the College of Earth and Mineral Sciences

In a joint effort with the Carnegie Institution of Washington, a research program dealing with equilibrium relations in lunar rocks is in progress in the department of geochemistry and mineralogy at Penn State.[4] In this program, we are studying liquid-solid and solid-solid equilibria in lunar materials, using "real" moon samples as well as synthesized mixtures simulating the real ones. For obvious reasons, we try to do as much as possible of our research with the simulated samples, especially in the initial stages of developing and perfecting our experimental techniques. The amounts of the real lunar samples made available to each investigator are, of course, quite limited, often in the milligram but more commonly in the gram range. We feel that our group has been generously treated by NASA, having received from the Apollo 12 mission a total of approximately 22 g of the moon, including rock fragments ("chips"), powdered samples, and polished thin sections of nine different and well-characterized rocks.

One important feature of the lunar program is the very careful documentation of the samples collected, both with regard to their location and orientation on the lunar surface and with regard to the subdivision and cataloging of the samples after their arrival in Houston. The latter aspect of the Lunar Receiving Laboratory's work has not been sufficiently recognized, but it is essential for ensuring maximum amount of information from the limited amounts of rocks available and for ensuring the safe return of the samples and permanent record of the work done. An example of the degree of detail in record-keeping of the samples distributed to the various investigators is shown in Figure 3.

In view of the igneous nature of lunar rocks, it is of paramount importance to ascertain the temperature range over which liquid and crystalline phases may coexist in the lunar samples. Toward this end, we are determining liquidus and solidus temperatures and sequences of appearance of the various crystalline phases under equilibrium conditions, without changing the compositions of the mixtures. This is no easy task, considering the relatively small amounts of samples available and the experimental difficulties involved in the study of iron-titanium silicates at high temperatures. Probably the most perplexing problem in such studies is the tendency of the silicate liquids to react with the crucible materials available. Superimposed on this problem are the necessity of controlling the oxidation state of iron and the tendency for volatile components (e.g., alkalies, sulfur) to boil off to a considerable extent during prolonged heat treatments in an open system at high temperatures. In order to prevent or minimize these difficulties, an experimental technique has been developed which permits equilibrations to be carried out without sample contamination in a closed system under vacuum and under oxygen potentials defined by the contact between the silicate samples and the crucible used. This technique consists of placing small amounts ($\sim$0.04 g) of the lunar samples in iron crucibles, sealing the iron crucibles into silica capsules under vacuum, and then suspending the silica capsules in vertical tube furnaces for equilibration runs at carefully controlled temperatures ($\pm$ 1°C) for various lengths of time, usually 3 to 30 days. Following equilibrations, the samples are quenched rapidly to room temperature, and the phases present are characterized by various analytical techniques, including reflected- and transmitted-light microscopy, X-ray diffraction, and electron microprobe examination.

Our studies have shown that liquidus temperatures (i.e., the highest temperatures of existence of a crystalline phase under equilibrium conditions) are in the range of approximately 1200 to 1300°C, and the solidus temperatures (i.e., the lowest temperatures of existence of a liquid phase under equilibrium conditions) are approximately 1070 to 1100°C, depending on the composition of the individual rocks. The first crystalline phase to appear upon equilibrium cooling of liquids of lunar rock composition is usually olivine or spinel, followed by pyroxene and plagioclase and sometimes by ilmenite.

One phase in lunar rocks which has attracted especial attention is armalcolite. This is a new mineral[5] whose name the alert reader will readily relate to those of the three astronauts of the Apollo 11 mission. Armalcolite, although not known as a mineral in terrestrial rocks, was synthesized in our laboratories, however, before it was found in lunar rocks. This mineral is a member of the solid-solution series between the two end members $FeTi_2O_5$ (ferropseudobrookite) and $MgTi_2O_5$ (magnesium pseudobrookite) in the system MgO-"FeO"-TiO_2. The diagram in Figure 4, as determined in our laboratories,[6] not only shows the composition of armalcolite, but also the distribution of cations (Mg^{2+} and Fe^{2+}) between coexisting pairs of solid-solution phases under equilibrium conditions at the temperature of the diagram (1300°C). Inasmuch as this distribution under equilibrium conditions is not likely to vary very much with temperature, a comparison of these experimentally determined distributions under equilibrium conditions with those found in the lunar rocks provides an

Table 1

Typical Composition (in Weight %) of Lunar Rock from the Apollo 11 and Apollo 12 Missions

	Apollo 11	Apollo 12		
		Rock No. 12018	*Rock No. 12038*	*Rock No. 12065*
SiO_2	42.0	39.0	49.0	39.0
Al_2O_3	13.0	10.0	12.0	12.0
TiO_2	7.0	3.3	3.2	3.8
FeO	17.0	20.5	17.0	22.0
MgO	8.0	17.0	6.5	9.0
CaO	11.5	9.0	11.0	12.8
Na_2O	0.4	0.4	0.6	0.4
K_2O	0.1	0.1	0.1	0.1
MnO	0.3	0.2	0.3	0.4
Cr_2O_3	0.6	0.5	0.3	0.5
ZrO_2	0.1			

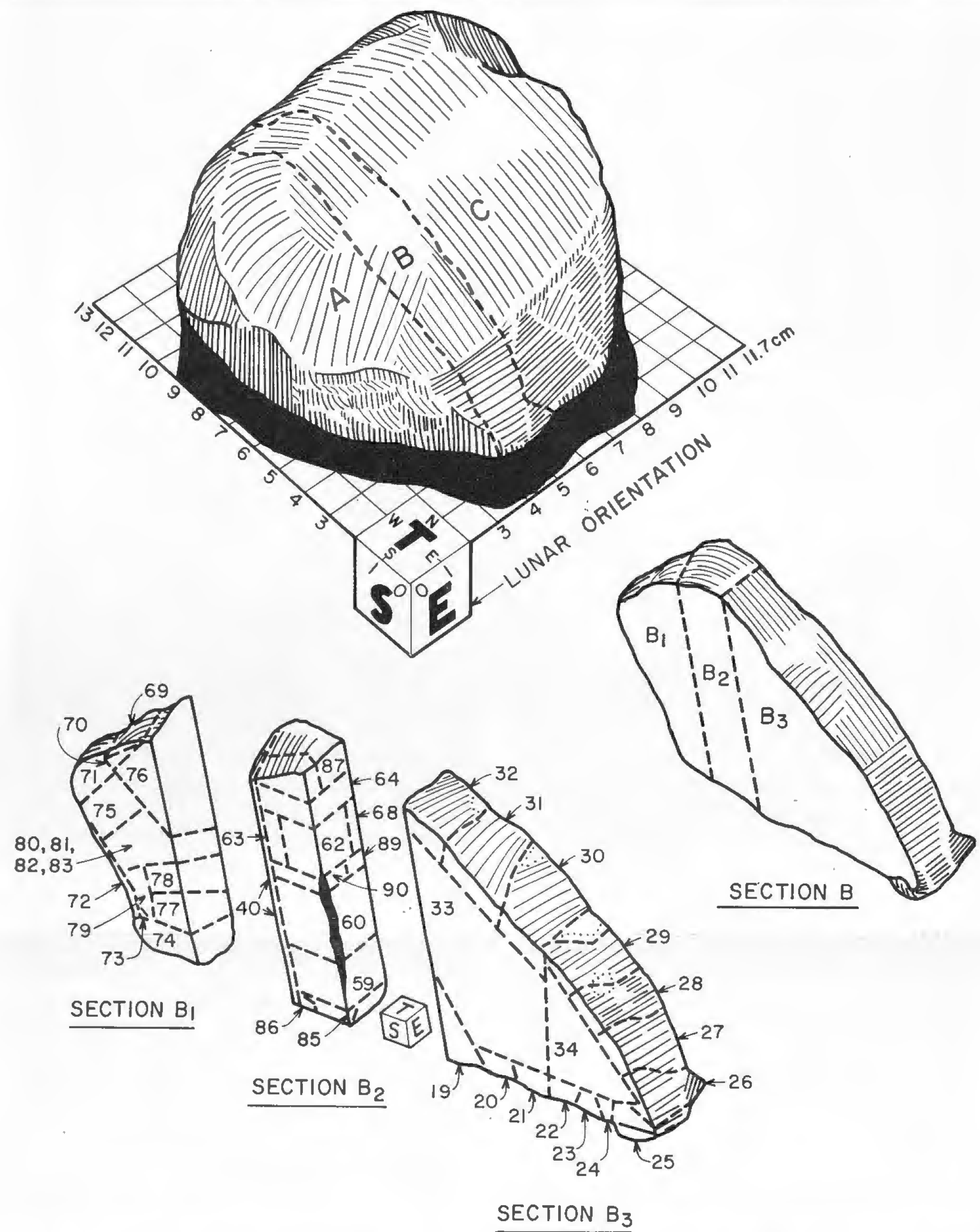

Fig. 3. *Sketch showing subdivision of lunar rock No. 12022 and its orientation on the lunar surface, as recorded at the Lunar Receiving Laboratory of NASA in Houston, Texas.*

important clue to the mechanisms and rates by which the lunar rocks may have crystallized. Analyses have shown that the ilmenite phase in contact with armalcolite in lunar rocks contains only ~3-15% of the $MgTiO_3$ component as compared to an $MgTiO_3$ content of ~50% predicted from the equilibrium data at 1300°C. It appears likely, therefore, that the armalcolite phase now present in the lunar rocks was not formed in equilibrium with ilmenite at high temperatures but rather by some other mechanism. Decomposition of an iron-rich armalcolite phase to magnesium-rich armalcolite and iron-rich ilmenite plus rutile at lower temperatures during cooling of the lunar rocks seems to be a good possibility.

Another phase of the lunar rocks which is attracting especial attention in our investigations is the spinel. Because of the high iron oxide and high titanium oxide contents of the lunar rocks, and because of the strongly reducing conditions prevailing, ulvospinels (idealized composition Fe_2TiO_4) and chromite spinels (idealized composition $FeCr_2O_4$) of unusual compositions are present in lunar rocks. Moreover, indications are that there are two coexisting spinel phases in some of the Apollo 12 samples. It is of considerable interest in lunar petrogenesis to ascertain whether or not two spinel phases of the given compositions can coexist under equilibrium conditions, and if so, under what temperature-pressure-composition conditions such coexistence is possible. As a supplement to these studies of the lunar rocks themselves, we are studying equilibrium relations in a number of simplified spinel systems under carefully controlled laboratory conditions, e.g., FeO-Cr_2O_3-TiO_2, MgO-Cr_2O_3-TiO_2, FeO-Al_2O_3-TiO_2, and MgO-Al_2O_3-TiO_2. We find that the presence of one or two spinel phases is critically dependent on the Al_2O_3/Cr_2O_3 ratios of the samples. Delineation of temperature-composition conditions attending these spinel relations, in conjunction with the armalcolite-ilmenite relations, offers hope that we may be able to place some limits on the temperatures and cooling rates involved in the genesis of lunar rocks.

Conclusions and Future Projections

In the present article, we have given a very brief account of some research on lunar rocks which is being carried out in the department of geochemistry and mineralogy in the College of Earth and Mineral Sciences. Furthermore, we have attempted to place our research into the proper perspective relative to the overall scientific effort in the Apollo program. Clearly, the information obtained and the samples returned so far are too fragmentary to permit a comprehensive description and evaluation of lunar petrology. However, significant steps have been taken toward achieving this goal. Future Apollo flights will be aiming for the lunar highlands, where different types of rocks are likely to be found. Consequently, different synthesized mixtures and simplified systems will be studied in the future in addition to those now being investigated.

This "resonance" between studies of real rocks and the simplified systems in the laboratory is a very important aspect of geochemical research: Excursions into the very complex natural systems are necessary to help us define the problems, but often the best ideas for the solution of the problems are found in the study of simplified laboratory systems where we can better control and sort out the various parameters determining the state of the system. These suggested solutions derived from laboratory studies must then, in turn, be taken into the field for further testing of their soundness and applicability.

A particularly gratifying aspect of the Apollo program has been the spirit of cooperation displayed among a large number of scientists working on the same samples and toward a common goal. Within the span of a short year, these teams of scientists, working in different laboratories in many different parts of the world, have produced, for instance, more first-class analyses of the pyroxenes in lunar rocks than the combined analyses of terrestrial pyrox-

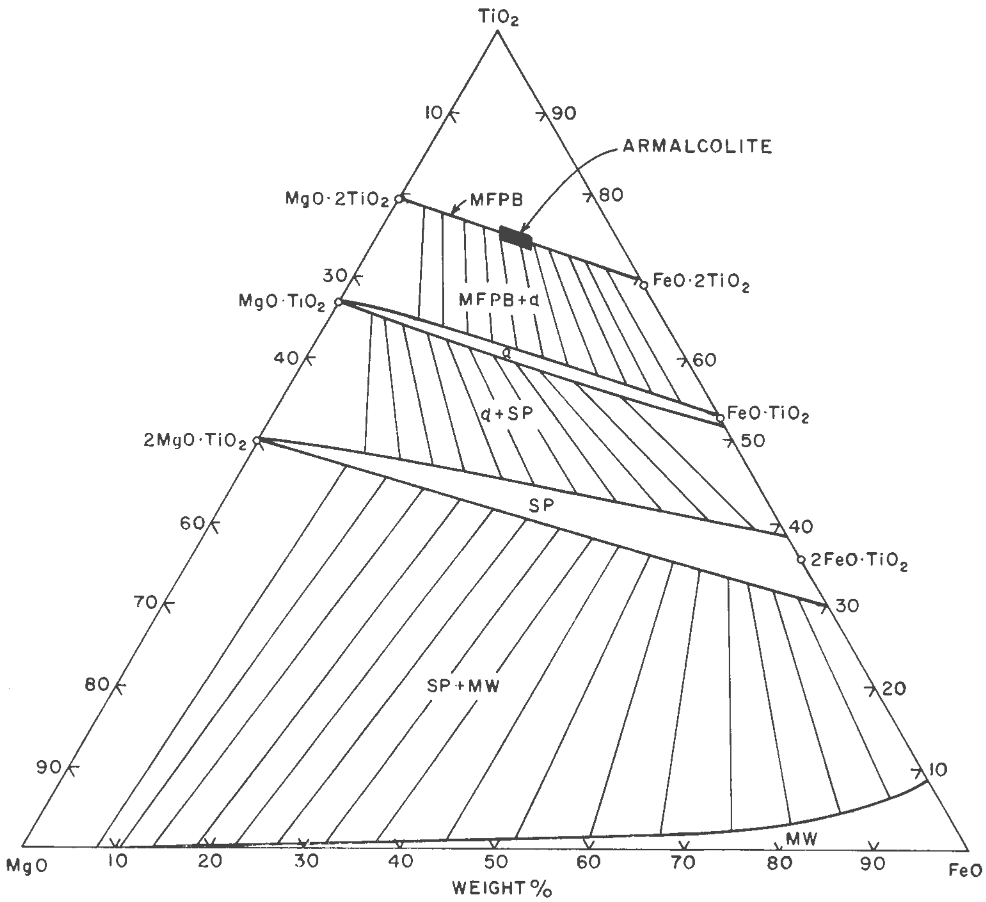

Fig. 4. *Isothermal section of the system MgO-"FeO"-TiO_2 at 1300°, after Johnson, Woermann, and Muan*[6]. *Heavy lines are outlines of the various phase areas, and light lines are conjugation lines between coexisting solid-solution phases. Abbreviations used have the following meanings: MW = magnesiowüstite; SP = spinel; α = rhombohedral solid solutions between Mg-TiO_3 (geikielite) and $FeTiO_3$ (ilmenite); MFPB = magnesium-ferropseudobrookite (armalcolite).*

enes throughout the history of mineralogy. It shows again that even individualistic scientists can work together when there is a sufficiently exciting and unifying theme. Hopefully, the spirit of cooperation and enthusiasm generated by the Apollo 11 and Apollo 12 programs can be transmitted to the study of terrestrial rocks as well. Indeed, efforts are being made by some scientists to promote studies of selected terrestrial rocks by the same teams, in the same degree of detail, and with the same sophisticated equipment as is being used on the lunar rocks. If successful, this would give earth sciences a big boost and maximize the relevancy of the lunar studies. Perhaps the lunar studies in a real, physical sense will eventually help us see the earth as it truly is.

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New Department Established

Dr. Charles L. Hosler, dean of the College of Earth & Mineral Sciences, has announced a number of organizational changes which reflect the direction of future development. These changes have been approved by the Board of Trustees of the University.

Under the direction of Dr. Thomas V. Falkie, associate professor of mining engineering and head of the department of mining since he joined the faculty in 1969, a new department of mineral engineering, encompassing both the departments of petroleum and natural gas and that of mining, has been established. Elements of the existing department of mineral preparation will, under the new organization, become part of mineral engineering and also part of material sciences.

The reorganization will establish two new sections in the department of material sciences: mineral processing and carbon and polymer science. Mineral processing will replace the graduate program administered by the department of mineral preparation, and the B.S. degree in mineral preparation engineering will be discontinued, to be replaced by a mineral processing option in the existing metallurgy baccalaureate program; carbon and polymer science, which represents a new and important step forward in the developing area of teaching and research, will put Penn State among the first to recognize the potential of this area of study.

Chairmen of the new sections in the department of material sciences will be: Dr. Frank F. Aplan – mineral processing, and Dr. Howard B. Palmer – carbon and polymer science. Dr. C. Drew Stahl will continue to head the petroleum and natural gas section in the department of mineral engineering.

College News Notes

Dr. Howard B. Palmer, professor of fuel science, has been granted sabbatical leave for the period January 1 to June 30, 1971. He will serve as visiting professor of chemistry at the University of Pittsburgh, where he will be engaged in experimental research on atomic and molecular reactions in the Space Sciences Laboratory. This work will be directed toward a better understanding of the fundamental process of significance in combustion reactions and atmospheric reactions.

Dr. R. H. Merkel, assistant professor of geophysics, attended a meeting of the Society of Exploration Geophysicists in New Orleans, November 8-12, at which he presented two papers co-authored with D. D. Snyder of Kennecott Exploration, Inc. entitled "The Effect of Secondary Resistivity and Polarization Anomalous Zones in Welling Logging" and "Analytic Models for the Interpretation of Electrical Surveys Using Buried Current Electrodes."

Dr. R. Venkataramani, assistant professor of mining engineering, during his recent visit to India visited the research facilities in the department of mining

(*Continued on page 31*)

Terrae Incognitae Twenty Years After

ROGER DOWNS, *Assistant Professor of Geography*

The title of this article is a restatement of that used by J. K. Wright in 1947. At that time, Wright, a geographer, lamented our lack of understanding of the world as people see it. He argued that we could only offer satisfactory explanations of spatial behavior if we could relate behavior to its correct antecedent environment, the perceived environment. In the following discussion, I would like to expand this argument with some empirical examples and indicate the value of such explanations of spatial behavior.

One of the key arguments in the current ecological furor is that if only the general public knew what some academics know about the environment, the public would be more careful in its interactions with the environment and more receptive to legislation controlling their interactions. At the same time, this is both true *and* ironic – we are being educated to see the former; the latter is the moral of this article. If only academics knew how the general public viewed the environment, it would be easier to both understand patterns of spatial behavior *and* to consciously design and build environments tailored to people's behavioral requirements.

We are faced with a classic case of value transference or cultural relativity, *in reverse.* A fundamental tenet of anthropology requires the observer of an alien culture to consciously *avoid* using his own learned cultural behavior as a yardstick for interpreting the alien culture, thereby preventing naive judgments such as, "This practice (or idea or artefact) is different from our own." Yet academics are behaving in this way toward the general public – that is, they assume that their ways of viewing and classifying the environment are shared by the public at large. As we shall see, nothing could be further from the truth. Also, academics are being inconsistent. Everyone is familiar with the argument that all resources are defined by human perception. (For example, coal outcroppings were of no value until someone found a use for coal.) So the need to understand the perceived environment should not be such a shock to academics, except, of course, to strict behaviorists who consciously avoid this issue. If we are prepared to accept that resources are defined by perception, then we must also accept that the same is true of the rest of the environment, in both its natural and artificial aspects.

However, in our research, we have displayed a singular lack of understanding of how people see and categorize the environment with which they daily interact. Frequently, our assumptions about the nature of the environment, innocuous and seemingly self-evident, have turned out to conflict with the world as others see it, where "others" are the population under discussion. This statement can be substantiated with some examples: Burrill (1968), in a study of an Atlantic coast swamp area, found that "swamp" meant a complex, multi-attribute feature to local residents; to Burrill it was a simple, single attribute feature. Communication, using the same term "swamp," was impossible because of this divergence of viewpoint, academics versus general public. Lucas (1963) found that the spatial extent of a wilderness recreation area in Northeast U.S.A. was defined differently by various subgroups of users and by those who were responsible for its administration.

Turning to the built environment, the same "perception gap" exists. Lee (1964) investigated the familiar planning concept of a neighborhood: Did people see a city as divided into clearly visible neighborhoods with neat spatial boundaries? The answer was no. In my own work (Downs 1970), I blithely assumed that a neighborhood shopping center would be a clearly defined and commonly agreed spatial unit; after all, shops are different from homes or offices. Therefore, the end of the shops defines the end of the shopping center. Again the answer was no because people divided the shopping center into a series of smaller subunits.

Other examples of this perception gap could be presented at will. Having demonstrated the existence of the gap, we must indicate the value of filling it. Let us first question what we mean by "seeing" or "perceiving" the environment. We are trying to ascertain the spatial and cognitive concepts used for coding and storing information. Thus, for example, Lynch (1960) found that city images were composed of five cognitive units: paths, edges, districts, roads, and landmarks. These cognitive concepts can be purely descriptive (or designative) of the environment and its attributes, such as, the neighborhood extends from X to Y *or* it is composed of mixed residential and commercial activities. Cognitive concepts can also be appraisive (or evaluative) of the environment – the neighborhood is well-equipped with recreation facilities *or* is a good area in which to live. It is obvious, then, that these two types of concepts overlap, and, consequently, research design problems in this area are almost overwhelming.

How can we relate such information about the perceived world to human behavior? What is the value of this perceived environment or image to the individual? The image has an *adaptive* function and the underpinning to this argument can be very simply expressed. In order to do something, an individual must know where to do it, that is, where the opportunity to do something exists relative to his current spatial location. The image is vital for attribute location in the environment (the *where* question) and route selection (the *how to get there* question).

The approach outlined has two major implications. First, it can be used to understand existing spatial behavior patterns – thus, the image of the environment has been related to consumer spatial behavior, inter- and intraurban migration, and patterns of industrial location. However, a caveat is necessary lest it appear that we have found the alchemist's touchstone. The image is a *necessary* factor for behavior; *sufficiency* rests in understanding the decision-making process which underlies behavior.

A second implication, which might appeal to one's baser nature, is an answer to the cry for relevance. It is increasingly apparent that human beings should not be viewed as clay in the hands of well-meaning designers and planners. People are not infinitely plastic or malleable or adaptable – they have *human* characteristics which they insist upon asserting. The assertion of these characteristics leads to dysfunction between environment and behavior and between design intentions and behavioral outcomes. The study of the perceived environment can obviously help us to bring behavior and environment into balance and harmony. If, for example, a shopping center is seen as being too far away, it will not be used; if downtown is seen as dangerous, it will not be used; if an inner-city area is seen as declining, people will move out. The areas for research are obvious — for once in our parade of relevancy, we need not appear like Hans Christian Andersen's Emperor. Although the ultimate goal has still not been achieved, some definite progress has been made by exploring Wright's *terrae incognitae,* albeit accidentally in many instances.

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College News Notes

(Continued from page 29)

engineering at the Indian Institute of Technology (Kharaghpur) and the Banaras Hindu University, at which he presented talks on "Systems Engineering and its Application to Mining." He also visited the Neyvelli Lignite Corporation and presented a talk to their technical association on "Operations Research and Computers in Mine Planning."

Dr. Richard Gordon, professor of mineral economics, is the author of a book recently published by Praeger Publishers, New York, in the Praeger Special Studies Series on International Economics and Development entitled *The Evolution of Energy Policy in Western Europe.* Subtitled *The Reluctant Retreat from Coal,* the book sums up 14 years of research into the Western European energy market and shows how policy was long based upon encouraging support of the domestic coal industry.

Dr. H. Reginald Hardy, Jr., professor of mining engineering and Director of the Rock Mechanics Laboratory, is the co-author, with Dr. Y. S. Kim, a Ph.D. graduate of Penn State and now assistant professor of mining and technology at the New Mexico Institute of Mining and Technology, Socorro, N.M., of a paper entitled "Detection of a Low-Level Critical Stress in Geologic Materials Using Ultrasonic Techniques." This paper, which describes research carried out at the Rock Mechanics Laboratory, was presented by Dr. Kim at the 12th Rock Mechanics Symposium held recently at the University of Missouri in Rolla, Mo.

Dr. Arthur W. Rose of the Mineral Conservation Section is the author of a compilation showing a known total of 380 mines and occurrences of zinc, copper, nickel, uranium, chromium, lead, gold and other metals in Pennsylvania. The compilation, which is intended to aid geologists, mining companies, land use planners, and others interested in the distribution and character of natural resources, lists for each of the 380 occurrences the metals present and a classification into one of 23 geologic types, locates each occurrence on a map, lists sources of additional information, and briefly describes 87 of the occurrences from which ore has been mined. Entitled "Metal Mines and Occurrences in Pennsylvania," the compilation has been published as Bulletin M50, "An Atlas of Pennsylvania's Mineral Resources, Part 3," by the Pennsylvania Geological Survey.

Dr. S. M. Farouq Ali, associate professor of petroleum and natural gas engineering, presented a paper co-authored by Abbas A. Alikhan, a Ph.D. candidate who is on the engineering faculty of the Kuwait University, entitled "Oil Recovery by Hydrocarbon Slugs Driven by a Hot Water Bank" at the 7th Eastern Regional Meeting of the Society of Petroleum Engineers held in Pittsburgh November 4-6.

Dr. Farouq Ali has recently been named an honorary member of the graduate faculty of the University of Zulia, Maracaibo, Venezuela.

Dr. H. L. Barnes, professor of geochemistry and Director, Ore Deposits Research Section, and N. G. Lavery, Senior Geologist, Exploration and Minerals Departments of Humble Oil and Refining Company, are the co-authors of a paper entitled "Primary Metal Dispersion as an Indicator of Mineralization" presented at the Fall Meetings of the Society of Mining Engineers of the American Institute of Mining Engineers. The paper describes a method of predicting the size and location of ore bodies using the metal content of nearby, barren host rocks.

Dr. Shelton S. Alexander, associate professor of geophysics, has been elected to a two-year term as vice president of the Seismology Section of the American Geophysical Union. He took office in August 1970. He is also the co-author of a paper entitled "Nuclear Explosions in Pre-Stressed Media and Mechanisms of Tectonic Strain Release" which was presented at the Eastern Section of the Seismological Society of America, which met jointly with the Geological Society of America in Milwaukee, Wis., November 10-14. At that meeting, he also served on the Nominations Committee for new officers of the society. It was announced during the November meeting that Penn State had been selected as the host institution for the 1971 meeting of the Seismological Society's Eastern Section.

Dr. Alexander also visited Argentina and Brazil during the month of October in connection with a study of the crust and mantle structure in South America and its relationship to sea floor spreading. This project is sponsored by the National Science Foundation. In addition, Dr. Alexander attended an International Upper Mantle Project Conference on Solid Earth Problems held in Buenos Aires and participated in several planning seminars for future seismological studies in Latin America.

Dr. Hans A. Panofsky, professor of meteorology, participated in a conference on Wind Loads on Structures held at the California Institute of Technology, Pasadena, Calif., December 18-19, at which he discussed the research on wind characteristics in progress and completed at Penn State. The conference was sponsored by the National Science Foundation.

Dr. Robert H. Essenhigh, professor of fuel science, was the speaker on November 3 in the Fall Seminar Series of the Mechanical Engineering Department of the University of Virginia in Charlottesville. His topic was "The Problem of Smoke Control in Incineration."

Following that talk, Dr. Essenhigh attended the Fall Technical Meeting of the Eastern Section of The Combustion Institute, held in Atlanta, Ga., on November 5-6, at which he presented a paper, co-authored with Dr. Yih-wan Tsai, formerly Research Associate in the fuel science section of the material sciences department and now Research Engineer with P.P.G. Industries in Creighton, Pa., entitled "The Effect of Heat Recovery in Furnace Analysis." Dr. Mehty A. Zeinalov, foreign exchange associate professor from the Soviet Union, also attended the meeting. Dr. Zeinalov is working with Dr. Essenhigh at the Combustion Laboratory this year; he is here on a ten-month International Research and Exchanges Board study program. Dr. Essenhigh is currently serving as Secretary of the Eastern Section of The Combustion Institute.

Dr. Essenhigh is also the author of a paper entitled "Dominant Mechanisms in the Combustion of Coal" which Dr. Robert J. Heinsohn presented on his behalf at the Winter Annual Meeting of the American Society of Mechanical Engineers held in New York, November 30, and the co-author with Mr. Wen-shong Shieh, graduate assistant in fuel science, of a paper entitled "Combustion Behavior in a Test Incinerator" presented at the 4th Mid-Atlantic Industrial Waste Conference at the University of Delaware in Newark, November 18-20. Also attending this conference from the Combustion Laboratory was Mr. Bimal K. Biswas, graduate assistant in fuel science.

Dr. H. Reginald Hardy, Jr., professor of mining engineering and director of the Rock Mechanics Laboratory, attended the second Congress of the International Society for Rock Mechanics held in Belgrade, Yugoslavia, at which he presented two papers: one, co-authored by Natesa Jayaraman, a former mining department graduate student, entitled "An Investigation of Methods for the Determination of the Tensile Strength of Rock," and the other entitled "Model Studies Associated with the Mechanical Stability of Underground Natural Gas Storage Reservoirs."

Dr. Wilbur Zelinsky, professor of geography and head of the geography department, presented a lecture entitled "The Hypothesis of the Mobility Transition" at the University of Nebraska, Lincoln, on November 19.

Dr. Zelinsky is also the author, with Dr. Anthony V. Williams, assistant professor of geography, of a paper entitled "Some Patterns in International Tourist Flows" which appeared in the October issue of *Economic Geography.*

Short Courses Scheduled

Electron Microscopy in the Material Sciences is the title of a short course to be conducted at the University Park Campus from March 29 through April 2.

Lectures will include a review of electron optics and diffraction, basic instruction in specimen preparation techniques, electron scanning microscopy, and electron transmission microscopy in relation to carbon, graphite, and ceramic materials. A Philips EM-300 will be available for research investigations at the laboratory sessions, as well as a Zeiss EM9S for routine work.

More information about the short course may be obtained from Dr. Maurice C. Inman, Department of Material Sciences, The Pennsylvania State University, University Park, Pa. 16802.

From March 24-26, an Advanced Mine Ventilation short course is also scheduled to be held at University Park. This course will deal with practical problems and calculations of mine ventilation projections and modifications. After solutions of various practical problems, the student will have the opportunity to analyze a specific mine problem of his own utilizing a computer program.

Participants are expected to have a working knowledge of U.S. Bureau of Mines Bulletin 589 entitled "Introduction to Mine Ventilating Principles and Practices" by D. S. Kingery. Solutions to problems in the bulletin beginning on page 41 will be dealt with on the first day. At the same time, a handout will be provided containing an illustrative example of how the ventilation system is selected for a new mine projection. This example, solved manually in the handout, will be programmed and solved by computer. The very versatile and flexible mine ventilation computer program developed at Penn State will be studied in detail and applied. Because of the complexity of the circuitry of multiple fan and shaft installations used in mines, it is imperative that better planning of the ventilation system be undertaken, and for this purpose familiarity with the computer program is important. Attendees will have this opportunity.

The course, which is co-sponsored by the Pennsylvania Department of Mines and Mineral Industries, will run three complete days and the registration fee will be $75.00. Further information may be obtained from Dr. Robert Stefanko, Room 110 Mineral Sciences Building, The Pennsylvania State University, University Park, Pa. 16802.

Reprints Available

Recent publications of the College of Earth & Mineral Sciences are listed below. Those desiring reprints should address their requests to the author whose name appears in italics (if there is more than one), 5 Mineral Industries Building, University Park, Pa. 16802.

Title, Author, and Source

The Supposed Meteorite Fall at Orebro in Sweden, 1958. *Frans E. Wickman* and Anna-Greta Uddenberg-Anderson, ARKIV FOR MINERALOGI OCH GEOLOGI Band 4 nr el, December 20, 1968.

Determination of Repose-Period Patterns of Volcanoes from Sequences of Ash Layers. Frans E. Wickman, Mathematical Geology, Vol. 2, No. 3, 1970.

The Chemical History of Some Spring Waters in Carbonate Rocks. Roger L. Jacobson and *Donald Langmuir*, Ground Water, Vol. 8, No. 3, May-June, 1970.

Specific-Ion Electrode Determination of Nitrate in Some Freshwaters and Sewage Effluents. *Donald Langmuir* and Roger L. Jacobson, Science & Technology, October 1970, pp. 834-838.

Study of Sodium Silicate Glasses and Liquids by Infrared Reflectance Spectroscopy. J. R. Sweet and *W. B. White*, Phys. Chem. Glasses, 10:246-251, 1969.

Crystal Chemistry and Properties of Phases in the System SrO-PnO-O. K. L. Keester and *W. B. White*, J. Solid State Chem. 2:68-73, 1970.

Morphology of Etch Pits on Germanium Studied by Optical and Scanning Electron Microscopy. M. F. Ehman, G. R. Jindal, J. W. Faust, and *W. B. White*, J. Appl. Phys. 41:-2824-2827, 1970.

Lithologic Controls on the Development of Solution Porosity in Carbonate Aquifers. H. W. Rauch and *W. B. White*, Water Resources Res. 6:1175-1192, 1970.

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