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EXPLORATION GEOLOGY TO BE ASSISTED BY AIR AND SPACEBORNE REMOTE SENSORS*

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ABSTRACT

The U. S. Geological Survey, working in cooperation with the National Aeronautics and Space Administration, other government agencies, universities and other institutions, have, for a number of years, been studying the field of remote sensing with the objective of determining the feasibility of employing such techniques in spacecraft. A significant part of this effort has been devoted to the study of current and new techniques in aircraft and their applications to exploration geology.

Emphasis of feasibility studies has been placed on the use and applications of color and near infrared photography, as well as infrared and radar imagery. New developments indicate that ultraviolet reflectance and luminescence can be observed from aircraft and possibly from space. Infrared spectrometry, successfully proven on the ground, is now being tested in aircraft and is a potentially powerful tool for the exploration geologist. In addition, investigations of automatic data interpretation and processing methods indicate that a suitable combination of new tools can be developed

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to meet particular problems in exploration geology and assist in the increasingly more difficult task of resource discovery.

An Earth Resources Observation Satellite, being developed by NASA for the Departments of Interior and Agriculture, is the first of a series of satellites designed to attack resources problems.

INTRODUCTION

The preceding speakers have discussed some of the applications of remote sensors to geologic problems that are currently being investigated under Air Force and NASA cooperative programs. As anchor man on the program I would like to mention other sensors that are being studied that have not yet been mentioned today. Most of my remarks will be confined to work being done within the Geological Survey but, where pertinent, I will mention other investigations that appear to be significant to the problems of exploration geology.

First, I will define "exploration geology" in context with air and spacecraft observations. Secondly, I would like to briefly describe the history, objectives, and evolution of the NASA Earth Resources Survey Program and the involvement of the Geological Survey. Then I will discuss some of the feasibility studies that have been completed and are underway in areas of the spectrum not covered by the previous speakers. I will conclude by summarizing results that appear, at this time, to be of most value to exploration geology.

<u>Definition of "exploration geology"</u>: Almost every type of geologic mapping is, in a sense, "exploration geology" because, by definition, geology is the investigation or exploration of the earth. Because of the development of spacecraft and supporting technologies, geologic exploration is extending to the moon and, in the future, will extend to other planets. Some exploration is motivated by scientific curiosity, but most of the frontiers of the world have been pushed back by man's inherent desire to better his environment.

Remote sensor technology is an integral part of this new development, and promises to assist the geoscientist in two ways: 1) by expanding his power of observation beyond that which he can actually see with his own two eyes; and 2) by increasing his mobility or reducing the amount of time he must spend to accomplish his particular objective.

The decision to use air or space derived remote sensor data is determined by the size of the area or scale of the problem that is being studied. In the past, most geologists have used whatever data is available. Most often this data has been obtained for other purposes such as topographic mapping and may not be optimum for his particular need. At the present time aircraft data is most suitable for assisting geologic mapping at scales of 1:100,000 or larger. It is believed that space observations, when obtained both on a routine basis or under special conditions for geologists, will assist mainly those problems being studied at scales of 1:100,000 and smaller. Therefore, these methods of data acquisition will compliment each other.

PRESENT INVESTIGATIONS

Late in 1964, the National Aeronautics and Space Administration began its Earth Resources Survey Program in cooperation with other government agencies, universities, research institutes and industry. The Geological Survey was assigned the task of lead agency in determining the applications of space observation in cartography, geology, hydrology and geography. The Department of Agriculture became lead agency for agriculture and forestry applications and the Naval Oceanographic Office became responsible for space applications to oceanographic problems. Numerous universities, research institutes, and private companies were contracted for instrument development and applications studies.

The prime objective of the Geologic Applications Program is to improve in terms of speed, accuracy and perspective, our geologic mapping and resource evaluation techniques, thereby speeding the task of mapping the geology of the United States, the discovery and appraisal of mineral resources, analyzing and understanding geologic processes. The procedures followed are:

1) To determine what types of geologic problems can be assisted by observations from air and spacecraft.

2) To select and test in aircraft those remote sensing instruments that might best assist solution of those problems.

3) To develop and conduct spaceflight experiments that will lead to operational space systems to assist in assessing and improving man's environment.

Development of the Earth Resources Survey Program has been slow due to the fact that several of the sensors involved were developed for other purposes and had to be modified for earth resource investigations. Data from such instruments was uncalibrated and not familiar to most scientists. Thus, the first years have been spent in developing ability to understand and use remote sensor data and experimenting to determine the optimum conditions for sensor observation. These studies, largely empirical at first, are now becoming more quantitative as we learn what methods and types of ground monitoring are most valuable to data interpretation.

Investigations within the Geological Survey now include 1) empirical studies of data, 2) investigations of sensors, ground monitoring devices and automatic data processing and interpretation systems, 3) theoretical investigations of physical and chemical properties that can be sensed and 4) analysis of the benefits to be derived from space observation and telemetric data relay systems.

Recognizing the potential advantages of space observation to problems in our own country Stewart L. Udall, Secretary of the Interior, announced the Earth Resources Observation Satellite (EROS) Program and requested that each bureau within the Department determine where and how space observations might assist their operations. Ten bureaus are now involved in the program.

The number of scientists involved in the program have grown from a few tens to about 200 throughout the U. S. and more are being added through a cooperative program with Mexico and Brazil. Approximately 30 scientists from Brazil and Mexico are in the United States at this moment receiving training in remote sensing at NASA's Manned Spacecraft Center in Houston. Extension of this program to Latin America and other parts of the world is important to making optimum use of data that will be collected on a world-wide basis.

FEASIBILITY STUDIES

Feasibility studies conducted in the early stages of this program focused on existing satellite and spacecraft data of the earth. These have come primarily from the Gemini and Nimbus programs. They have demonstrated some of the advantages of acquiring synoptic views of large areas under uniform lighting conditions. The contrast between space photography and mosaics of aircraft photography taken of the same areas at conventional altitudes is remarkable. The angle of illumination of the earth surface by the sun is also important to geologic interpretation. From space large structural features, such as major faults and fold belts are seen in their regional context and their relationships to intrusive masses and to known mineral belts can be better understood. The value of space photography as a planning tool for geologic exploration, especially in remote areas of the world where maps are either poor or non-existent, should be great. The value of space photography as a teaching aid should not be overlooked. Many of you in the teaching profession are now using Gemini photography on a routine basis in some of your courses.

Subsequent studies have been conducted using other less well known remote sensors in aircraft. Of primary interest to geologists are the infrared and side-looking radar scanning systems. The latter have already been discussed.

1) An experiment to detect ultraviolet absorption and luminescence from air and spacecraft is being conducted by William R. Hemphill of the Geological Survey. An ancient infrared scanner known as AAS-5 was modified with a photomultiplier tube and filters to provide data from the UV portion of the spectrum -- but has never worked properly. A multichannel optical

mechanical scanner developed by the University of Michigan, on the other hand, has provided some useful UV data. Because it records on magnetic tape and can be automatically processed and enhanced, some UV data has been obtained which indicates that certain rock types (evaporites, limestone, phosphates) can be enhanced in this portion of the spectrum. Automatic computer print out of a single rock type was successfully completed within the last month.

To reduce atmospheric interference in this portion of the spectrum a device known as a Fraunhofer Line Discriminator has been designed and constructed by the Perkin Elmer Corporation for NASA. It is undergoing acceptance tests at the present time and will be used to detect small concentrations of luminescent materials such as Rhodamine-B dye, used by hydrologists to trace the flow and dispersion of rivers and other water bodies. It may have application to the search for fish oils on the ocean surface and, possibly, to the search for phosphate rock and tar sands.

2) Experiments in color photography applications to geologic mapping and mineral resources are being conducted by Survey geologists in Arizona, Utah, and Nevada. Optimum film, filter and camera combinations have been selected which provide accurate display of rock and soil colors. Geologic mapping using Kodak aeroneg (SO-151) color ektachrome photography is underway and appears especially applicable to studies of metallic mineral deposits.

Color infrared and multispectral photography are also under investigation to determine their use in geologic mapping of mining districts where soil chemistry may affect vegetative cover.

Results to date indicate that color photography will provide the most useful information under average mapping conditions.

3) Infrared imagery has been obtained by aircraft over flying many types of geologic terrain ranging from volcanoes and hot springs to fault zones, offshore springs, river effluents and coal mine fires. Because infrared scanners sense small variations in surface temperatures, soil moisture, topography, weather, time of day, composition, density and other factors, all affect the sensor record. Ground monitoring during infrared scanning is, therefore, important to determine not only what is recorded in the scene of the airborne scanner but to provide quantitative information to calibrate the observation.

Instrumentation for ground monitoring of geologic features is being developed by R. M. Moxham, G. W. Greene and others of the U. S. Geological Survey Infrared Laboratory by modifying and adapting existing equipment. Automatic recording systems with multiple probes to provide coverage of areas equal to or greater than resolution elements of space borne sensors have been designed and operated successfully in the field.

Repetitive infrared scanner coverage at different times of day indicate that rock types having high thermal inertia can best be sensed shortly after sun down. Materials such as shales and sandstones having high moisture content show greatest contrast in daylight imagery. Infrared scanning of hot springs, coal mine fires and other small thermal features stand out best when surrounding materials reach equilibrium in the pre-dawn period.

Wallace and Moxham, in Professional Paper 575-D, reported on extensive infrared surveys of the Carrizo Plains area of the San Andreas Fault zone, indicating that such imagery may reveal 1) soil moisture and possible ground water entrapment in areas where the fault is covered by alluvium, 2) soil moisture or cool air in land depressions associated with landslides in the fault zone and 3) thermal differences in compact and loose rock and soil materials through the duirnal cycle. Morris, in a report in preparation, has found that welded tuffs have high thermal inertia and stand out as a very bright image on early evening imagery. Similar response can be expected from outcrops in areas where glacial debris and vegetation make bedrock mapping extremely difficult.

An infrared spectrometer has been developed and is now being flight tested by Professor R. J. P. Lyon of Stanford University, to determine gross rock composition by remote means. A library of spectra of common rock types measured in the laboratory has been computerized and is used in comparison with spectra of unknown rocks in the field. Measurements made at ground levels from distances of over 2000 feet have been successful. Initial aircraft tests have been promising.

Passive microwave imaging radiometers are under development but have not yet been intensively studied under this program.

In summary, remote sensors in air and spacecraft offer exploration geologists the opportunity to map features they might not otherwise observe. Space observations will make it possible to map features on a broad regional or world-wide basis. Not only will sensors broaden his perceptive ability but can, if properly utilized, speed his mapping capability. In order to take advantage of these new opportunities, the geologist must learn 1) how to utilize the data; and 2) how to obtain optimum results from the sensors for his particular problem. He must insist on using the best data possible and be able to specify his needs to contractors, as well as be able to judge and accept the products.