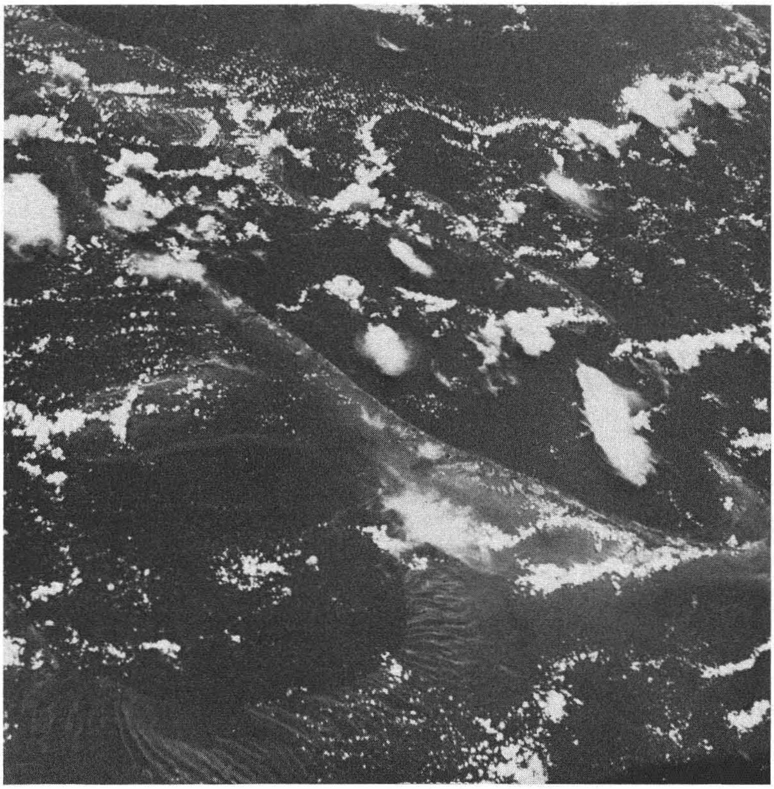

FRONTISPIECE. Satellite view of Great Bahama Banks. Note detail of ocean bottom information. Small islands of Great Exuma, Cat and Long are only land areas along the reef. Depth of water on bank is about 30 feet while in the tongue of the ocean (in lower left) it is over one mile deep. Photography taken from Gemini V on 22 August 1965 on the 19th orbit. Altitude is approximately 120 nautical miles. Camera: Hasselblad, Model 500-C (NASA modified). Lens: Zeiss Planar, 80 mm. Film: Kodak, S O 217 (MS Ektachrome), 70 mm. width. (See page 782)

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Orbital Remote Sensing and Natural Resources

Unique advantages of space systems can aid studies in forestry, geology, geography, and oceanography.

* Presented at the Annual Convention of the American Society of Photogrammetry, Washington, D. C., March 1966, under the title "Unique Advantages of Orbital Remote Sensing for the Study of Natural Resources."

Introduction and Objectives of NASA's Natural and Cultural Resources Program

Natural resources are defined as those naturally occurring materials, such as mineral deposits, timberstands, and fresh water, which are of value to mankind. Cultural resources are defined as those items of value to man which result from his own activities. As such they encompass all the beneficial works of man and as so defined include man himself. Cultural resources are in general derived from the natural resources.

Since World War I the natural and cultural features of the Earth have been extensively "mapped" by photographic means and to a much lesser extent by radar and infrared sensors. Historically, the development and use of such techniques has been fostered by the military, but in recent years there have been widespread applications beyond the military field. During the past three decades civil and commercial interests have used airborne imaging devices extensively. Gravity, magnetic, and radioactive measuring instruments have also been applied to the search for mineral and petroleum deposits. In the past few years imaging sensors in unmanned and manned spacecraft have been employed to provide the first true synoptic coverage of the lithosphere, hydrosphere and atmosphere.

The following list of overall program objectives are divided into two phases of data-gathering capability. These are the initial or feasibility and research phases, currently in progress, and the ultimate operational phase.

Feasibility and Research Phase:

1. To determine those natural and cultural resource data which can be acquired best from spacecraft for the benefit of mankind.
2. To test and develop the best combination of observational procedures, instruments, subsystems, and interpretive techniques for the acquisition and study of terrestrial, lunar, and planetary natural and cultural resource data from spacecraft.
3. To determine how the increased frequency and synoptic coverage uniquely afforded by spacecraft observations can aid the study of time variant and relatively unchanging phenomena on the surface of the Earth.
4. To develop improved methods of displaying and disseminating space-acquired natural and cultural resource data on a global basis suitable for utilization by scientific, technical, and commercial interests.
5. To determine which natural and cultural resource data can be most effectively and economically obtained by manned spacecraft, unmanned satellites, interrogation of surface sensors, or the means currently being used.
6. To discover, by virtue of trained scientists in spacecraft, what unforeseen natural and cultural resources or geoscience phenomena may be observable from the overview available at orbital altitudes.

Operational Phase:

To gather natural and cultural resource data with spaceborne instruments in an operational repetitive manner for use by

Abstract: *A Natural Resources Program has been initiated in the National Aeronautics and Space Administration (NASA) for utilizing remote sensors in space for the discovery, inventory, evaluation, development, and conservation of natural and cultural resources. Resources which can be studied in this manner include mineral districts, soils, crops, timber, water, housing, transportation networks, and human resources. These instruments in Earth-orbital spacecraft possess a number of unique advantages, some of which are: rapidity and continuity of observations, greater freedom from weather disturbances, synoptic views for regional syntheses, reduced data acquisition times, reduced costs, and better quality data of several types.*

Dr. Peter C. Badgley

	TOPOGRAPHY	TIMBERLINE	WATERLINE	SNOWLINE	DESERTLINE	GRASSLAND-BRUSHLAND INTERFACE	BRUSHLAND-TIMBERLAND INTERFACE	GRASSLAND-TIMBERLAND INTERFACE	SOIL SERIES	VEGETATION DENSITY	TREE COUNT AND IDENTIFICATION	TREE CROWN DIAMETER	CROP SPECIES	IRRIGATION WATER (SNOW PACK)	STRESS (DISEASE) EVAPOTRANSPIRATION	PLANT VIGOR	FIELDS, LESS THAN ONE ACRE	FIELDS, ONE TO TEN ACRES	FIELDS, GREATER THAN TEN ACRES	SOIL MOISTURE	SOIL TEMPERATURE	FIRE DETECTION (PREDICTION)	DAMAGE ASSESSMENT (FLOOD)	LIVESTOCK CENSUS (ECOLOGY)
1. METRIC MAPPING CAMERA	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			X	X
2. PANORAMIC CAMERA	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			X	X
3. ULTRA-HIGH RES. CAMERA	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X			X			X	X
4. MULTIBAND SYNOPTIC CAMERA	X	X	X	X	X	X	X	X		X				X			X	X	X				X	X
5. LASER ALTIMETER	X																							
6. RADAR IMAGER	X	X	X	X	X	X	X	X	X	X				X			X					X	X	
7. OPTICAL-MECHANICAL SCANNER (.32 - 16.0 MICRONS)	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
8. INFRARED RADIOMETER		X	X	X						X			X		X		X	X	X	X	X	X	X	
9. MICROWAVE IMAGER	X													X						X			X	
10. MICROWAVE RADIOMETER	X													X						X	X	X	X	
11. VIEW FINDER																						X	X	
ON THE GROUND																								
12. THERMOMETER AND HYDROMETER															X					X	X			
13. ANEMOMETER															X							X	X	
14. WEIR STREAM GAUGE														X									X	
15. FATHOMETER														X									X	
16. SNOW PACK INTEGRATOR														X										
17. XEROMETER																						X		
18. PARTICLE SIZE ANALYZER														X	X									

COMPILED BY THE U.S. DEPARTMENT OF AGRICULTURE

FIG. 1. Anticipated Agriculture and Forestry Applications of Remote Sensors.

scientific, technical and commercial interests.

A large number of potential users having interests in a variety of geoscientific problems and applications have been identified. Among the various fields of application which will be actively served by the Natural Resources Program of NASA are the following:

1. Agriculture and Forestry Resources,
2. Geography/Cultural Resources,
3. Geology/Hydrology (Mineral and Water Resources),
4. Oceanography (Marine Resources).

Possible Phenomena which may be Observed and Recorded Advantageously from Spacecraft

Figures 1–5 indicate the types of phenomena which may be "mapped" from space. The word "mapped" is used here to mean that certain natural and cultural phenomena are observed from space and recorded on photographs, images, tapes, or other data storage media. After these raw data are recovered and analyzed, the pertinent information is plotted on appropriate bases which become thematic maps. These thematic maps, together with written reports, constitute one of the principal end-products expected of the Natural Resources Program. Figures 1–5 also indicate the types of sensors that may be used based on the state-of-the-art. As new or better sensors are developed, the listings of observable phenomena will undoubtedly grow.

Accomplishments to Date

With the assistance of disciplinary groups in several Federal agencies and institutions, program definition activities have been initiated in the four disciplinary areas.

Many of the phenomena which each natural resource discipline wishes to observe and record from space have been identified (Figures 1–5). The instruments needed to gather these data and their frequencies have also been identified as closely as possible (Figures 1–5).

The resolutions needed to observe each phenomena are currently being identified. It should be pointed out strongly, however, that one of the main objectives of this program is to determine the best combination of instruments and the best resolutions for observing natural resource phenomena. Until several generations of instruments have been flown in space and the data analyzed, it will be impossible to be completely precise on the subject of resolutions.

To develop the best analytical procedures for each discipline, the various remote sensing instruments recommended by the disciplinary groups are being flown over carefully selected test sites with aircraft. Examples of data obtained to date are shown in Figures 6–9 and the Frontispiece. New ground data at these sites (soil moisture, surface roughness, compositional data, etc.) are being acquired as needed. Certain companion laboratory analyses of rocks and soils, etc., are also underway.

A data facility to handle the raw aircraft-acquired data has been established. The data

	LAND USE	URBAN STUDIES	TRANSPORTATION AND LINKAGES	SETTLE & POPULA. MOVEMENTS	RESOURCES UTILIZATION	VEGETATION COVER & SOILS	CLIMATIC CONDITIONS	ENERGY BUDGET (INC. WATER)	GEOMORPHOLOGY	GLACIOLOGY AND PERMAFROST	TOPOGRAPHIC & THEMATIC MAP.
1. METRIC CAMERA	X	X	X	X	X	X	X	X	X	X	X
2. PANORAMIC CAMERA	X	X	X	X	X	X	X	X	X	X	X
3. ULTRA-HIGH RES. CAMERA	X	X	X	X	X	X			X		X
4. MULTIBAND SYNOPTIC CAMERA	X	X	X	X	X	X	X	X	X	X	X
5. RADAR IMAGER	X	X	X		X		?		X	X	X
6. RADAR SCATTEROMETER		?	?								
7. INFRARED IMAGER	X	X	X								
8. IR RADIOMETER/SPECTROMETER	X	X	X								
9. MICROWAVE IMAGER	X	X	?			X				X	
10. MICROWAVE RADIOMETER		?	?								
11. LASER ALTIMETER											X
12. MAGNETOMETER					X						
13. GRAVITY GRADIOMETER											
14. ABSORPTION SPECTROSCOPY											
15. RADIO FREQUENCY REFLEC.											
16. VIEWFINDER			X		X		X				X

COMPILED BY THE U. S. GEOLOGICAL SURVEY

FIG. 2. Anticipated Geographic Applications of Remote Sensors.

from such test site overflights are being scrutinized by the disciplinary and instrument scientists under contract to this program. Appropriate changes in the data-gathering procedures are being recommended periodically.

Albums of imagery acquired by this aircraft program together with spacecraft-acquired imagery (from Gemini, Nimbus, etc.) of value to natural resource scientists are being compiled. An atlas which analyzes the potential of this data for natural resource scientists is in preparation.

The costs and times required to build the

	COMPOSITION				STRUCTURE			STRATIGRAPHY SEDIMENTATION					MINERAL DEPOSITS					ENGINEERING					CRUSTAL / MANTLESTUDIES								OTHERS	
	ROCK TYPES (GROSS)	LITHOLOGY	POROSITY	PERMEABILITY	FABRIC (GROSS)	FAULTS, FOLDS	SALT DOMES	CORAL REEFS	RIVER EFFLUENTS	NEAR SHORE & BEACH DEPOSITS	DUNES	STREAM, LAKE, BAY DEPOSITS FANS	FAULTS, FOLDS	ALTERATION, CONTACT ZONES	INTRUSIVE ROCKS	METALLOGENIC PROVINCES	OIL SHALE	SURFACE ROUGHNESS	SOIL MOISTURE DIST.	PERMAFROST	SLOPE STABILITY	COMPACTION	EARTHQUAKE ZONES	VOLCANOS, THERMAL WATERS	HEAT BALANCE, VARIATIONS	MAGNETIC FIELDS	GRAVITY GRADIENTS	INTERNAL CONSTITUTION	ISOSTASY	CONTINENTAL DRIFT	GLACIATION (CONTINENTAL, VALLEY)	
1. METRIC CAMERA	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X				X	X	X	
2. PANORAMIC CAMERA	X	X		X	X	X	X	X	X		X	X	X			X	X	X					X	X	X					X	X	
3. ULTRA-HIGH RES. CAMERA	X	X	X	X		X	X		X	X			X	X	X	X	X	X			X	X	X	X	X						X	
4. MULTIBAND SYNOPTIC CAMERA	X	X	X	X	X	X	X	X	X		X	X			X	X	X	X				X	X	X	X						X	
5. RADAR IMAGER	X		X	X	X	X	X			X	X	X	X		X	X		X				X										
6. RADAR SCATTEROMETER	?			?												X		X				X										
7. INFRARED IMAGER	X		X	X	X	X	X	X	X	X	X	X	X	X		X	X		X	X				X	X			X				
8. IR RADIOMETER/SPECTROMETER	X	X	X					X	X		X	X			X	X	X		X	X				X	X			X				
9. MICROWAVE IMAGER	X				X			X	X		X	?						?	?	?					X						X	
10. MICROWAVE RADIOMETER	?	?	X	X							X							?	?	?					X						X	
11. LASER ALTIMETER						X	X	X					X			X		X											X	X	X	
12. MAGNETOMETER															X	X										X		X	X	X		
13. GRAVITY GRADIOMETER						?									X												X	X	X	X		
14. ABSORPTION SPECTROSCOPY		X																X	X			X										
15. RADIO FREQUENCY REFLEC.	?																														X	
16. ULTRAVIOLET	X	X	?	?		?	?	X	X	X	X	X	?	X	X	X	X					X			?							
17. VIEW FINDER								X	X			X												X							X	

COMPILED BY THE U. S. GEOLOGICAL SURVEY

FIG. 3. Anticipated Geologic Applications of Remote Sensors.

	EVAPOTRANSPIRATION	WATER SURFACE ROUGHNESS	RAIN DISTRIBUTION AND INFILTRATION	GROUND WATER DISCHARGE	IDENTIFICATION OF SUB-AQUEOUS FEATURES	SALT CONTENT AND LIGHT ABSORPTION OF WATER	WATER POLLUTION	RESERVOIR SEDIMENTATION	EFFLUENTS OF MAJOR RIVERS	RUNOFF & WATER RETENTION IN GLACIERS	WATER REGIMEN OF VALLEY GLACIERS	MONITORING OF LAKE AND RESERVOIR LEVELS	SNOW SURVEYING	EROSION & SEDIMENTATION RATES
1. METRIC CAMERA		X	X		X			X		X	X		X	X
2. PANORAMIC CAMERA			X	X	X		X	X	X	X	X	X	X	X
3. ULTRA-HIGH RES. CAMERA		X	X	X	X	X	X	X	X	X	X	X	X	X
4. MULTIBAND SYNOPTIC CAMERA	X		X	X	X	X	X	X	X	X				X
5. RADAR IMAGER	X		X	X			X		X	X			X	X
6. RADAR SCATTEROMETER			X							X			X	
7. INFRARED IMAGER	X		X	X			X		X	X	X		X	
8. IR RADIOMETER/SPECTROMETER	X	X					X			X	X		X	
9. MICROWAVE IMAGER			X	X			X			X	X		X	X
10. MICROWAVE RADIOMETER	X		X				X			X	X		X	
11. LASER ALTIMETER												X		
12. MAGNETOMETER														
13. GRAVITY GRADIOMETER														
14. ABSORPTION SPECTROSCOPY														
15. RADIO FREQUENCY REFLEC.	X		X							X				
16. VIEWFINDER			X				X					X		
17. TELEMETERING BUOYS														

COMPILED BY THE U. S. GEOLOGICAL SURVEY

FIG. 4. Anticipated Hydrologic Applications of Remote Sensors.

highest priority instruments have been studied in a preliminary manner.

Exploration and Mapping Requirements

The economic status of any nation is a direct function of the use its people make of its natural and cultural resources. Expansion in effective use of all resources depends on enlarged knowledge of their distribution and character.

Just to maintain the United States and world economies at their present levels requires continued discovery and development of new resources. The supply problem is compounding with growth in population and rise in per capita consumption of raw materials and energy. The U. S., for example, will double its present consumption of most minerals within 15 to 25 years.

As a result, it is particularly important that we develop better techniques for discovery of new deposits, especially for those that elude detection by current search instruments and techniques. In the past, new techniques of data acquisition for natural resources have resulted in a simultaneous increase in production. It appears that the capabilities of remote sensors in Earth orbit can make significant contributions relative to these exploration tasks.

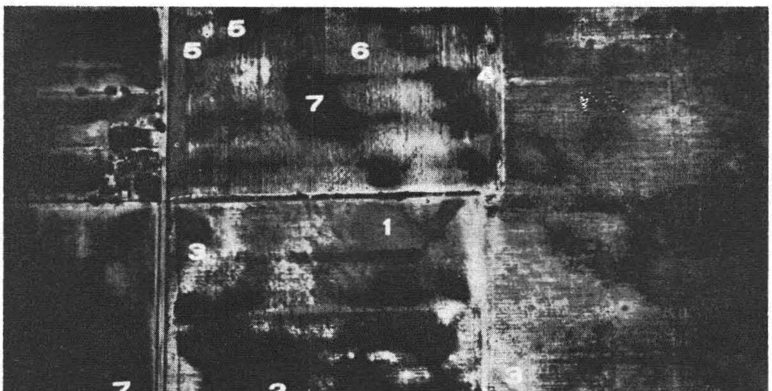
The current domestic surplus of agriculture products is likewise transitory and even now

FIG. 6. Identification of Soil and Crop Types by Diagnostic Color Signatures Using Aerial Ektachrome Film (Visible Infrared). Photography taken in several wavelength bands simultaneously yields signatures which when combined will provide positive identifications. Legend: (1) Healthy cotton 48 inches high, salinity: 1 MMHO/cm; (2) Unhealthy cotton 12–16 inches high, salinity: 7–10 MMHOS/cm.; (3) Bare soil, salinity > 12 MMHOS/cm.; (4) Pig weeds in wet area, minor sorghum; (5) Pig weeds above short sorghum; (6) Dry topsoil between rows of sorghum; and (7) Bare soil between rows of sorghum, high moisture content.

	SEA SURFACE THERMAL MAPPING	OCEAN WAVES	SHOALS & COASTAL MAPPING	CURRENTS	ICE SURVEILLANCE	COASTAL MARINE PROCESSES	BIOLOGICAL PHENOMENA	AIR/SEA INTERACTIONS	SEA LEVEL AND SEA SLOPE	WATER COLOR ANALYSIS	VOLCANIC ACTIVITY	SUBSURFACE STRUCTURE
1. METRIC CAMERA		X	X	X	X	X	X	X		X		
2. PANORAMIC CAMERA		X	X	X	X	X	X	X		X		
3. MULTIBAND SYNOPTIC CAMERA	X			X	X	X	X			X	X	
4. RADAR IMAGER		X	X		X	X	X	X				
5. RADAR SCATTEROMETER		X			X		X	X	X			
6. INFRARED IMAGER	X		X	X	X	X	X	X		X	X	
7. IR RADIOMETER/SPECTROMETER	X			X	X	X	X	X		X	X	
8. MICROWAVE IMAGER	X		X	X	X	X		X			X	
9. MICROWAVE RADIOMETER		X			X	X		X			X	
10. LASER ALTIMETER		X	X		X			X	X			
11. MAGNETOMETER			X								X	X
12. GRAVITY GRADIOMETER			X	X		X	X				X	X
13. ABSORPTION SPECTROSCOPY								X				
14. RADIO FREQUENCY REFLEC.	X				X		X					
15. VIEWFINDER			X		X							
16. TELEMETERING BUOYS	X	X	X	X				X	X			

COMPILED BY U.S. NAVAL OCEANOGRAPHIC OFFICE

FIG. 5. Anticipated Oceanographic Applications of Remote Sensors.



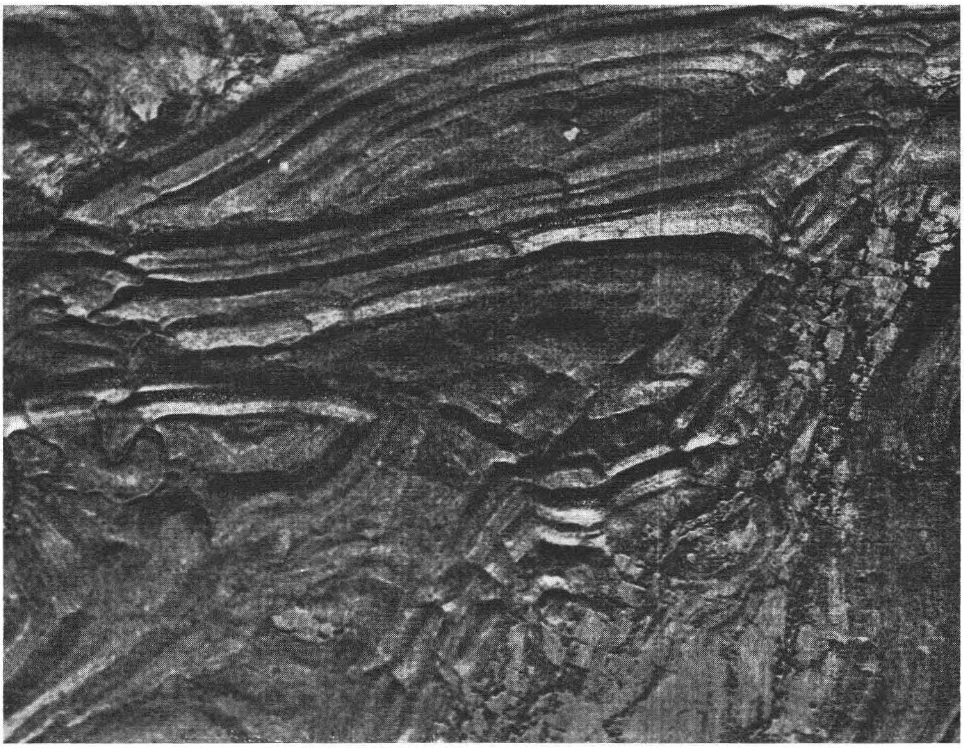


FIG. 7. Radar Image of Folded and Faulted Geologic Structures.

will not adequately supply the entire needs of mankind, New sources of foods, such as tapping the abundant fish supply of the oceans, are required to adequately feed the present population, and in the future the need will be all the more urgent.

The principal methods of recording and analyzing natural and cultural resources is through the use of thematic (topical) maps. The determination of types, scales and area coverage of required base-maps for each resource application is one of the initial fields of investigation of the program. Table 1 indicates the current status of availability of basic map coverage of the world.

The remarks in the above tabulation indicate that base maps not only must be precisely compiled, but must also be revised periodically. The need for revision varies greatly. Coastal charts often require revision annually; urban area maps at least every five years; and others in proportion to the natural and cultural alterations involved.

ECONOMIC BENEFITS

Base and thematic mapping by conventional aerial surveys is an extremely costly operation. It has been estimated that over $1 billion is spent annually to obtain the aircraft-acquired data from which such maps are made, and yet only a very small percentage of the Earth's resources are so covered in any one year. The Earth's surface consists of 510 million square kilometers, of which 150 million is land areas. Table 2 gives an idea of the costs involved to cover the land and adjacent shallow sea areas (150 million square kilometers) once by aircraft.

If the remaining ocean areas were covered only in a synoptic manner using magnetic-gravity, infrared, microwave, and selective photography at an estimated cost of $10 per square kilometer, this would add $3.5 billion to the land coverage figure. Thus, a one-time aerial survey of the Earth and its force fields would cost about $5.5 billion. However, many of the phenomena affecting resources are time variant and repeated coverage is needed. Even if repetitive annual coverage were limited to about 20 per cent of the world (100 million square kilometers) and if only synoptic sensing totaling $10 per square kilometer were performed, the program maintenance cost would be $1 billion annually. These figures cover only the cost of data acquisition. Data reduction and dissemination would involve costs exceeding those of the acquisition phase.

The cost of mounting an operational real-source-sensing space program cannot be accurately determined at this time. Parameters, such as the payload, power, mode (manned or unmanned), have not been fully defined. However, if one assumes that these parameters will be compatible with one or more of the space vehicles being developed, then the costs attributed to the Natural Resources Program would be reasonable.

Comparing the cost of a space program to one of conventional aerial surveys does not provide the total answer. Many aircraft surveys will still be required and some types of anticipated surveys might not prove practical by either aircraft or spacecraft. However, indications are that, where coverage of a global repetitive nature is required and obtainable by both modes, a space system has unquestionable economic advantages. It appears that the cost will be on the order of a magnitude less for the space mode. The potential economic advantages of utilizing space for resource analysis is not limited to the acquisition phase, but is also important in the data reduction phases. Since space-acquired data will be of a uniform and systematic nature, its conversion into maps and statistics will be enormously simplified when compared to conventional methods.

The question of whether the program is worth the cost of a spaceborne data gathering system must be considered on the basis of future demands for natural resources. Current indications strongly support the need for new revolutionary means, such as orbiting spacecraft, to meet rapidly increasing demands for natural resources. The data of scientific value

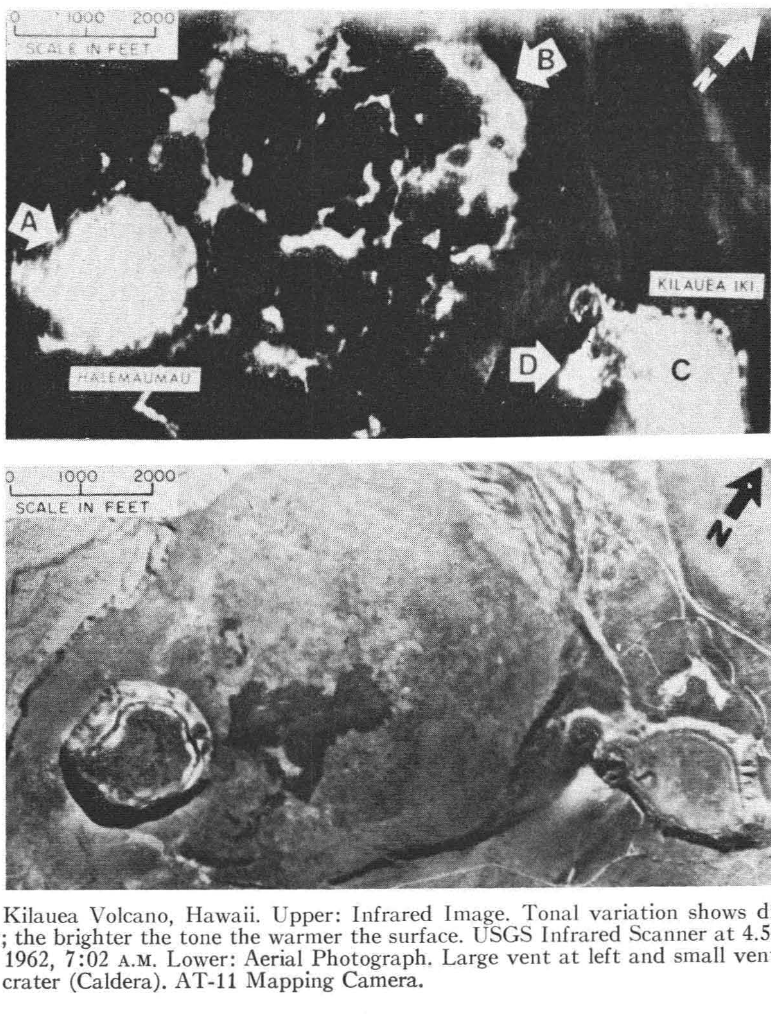


FIG. 8. Kilauea Volcano, Hawaii. Upper: Infrared Image. Tonal variation shows distribution of radiant heat; the brighter the tone the warmer the surface. USGS Infrared Scanner at 4.5–5.5 microns, January 28, 1962, 7:02 A.M. Lower: Aerial Photograph. Large vent at left and small vent at right are within large crater (Caldera). AT-11 Mapping Camera.

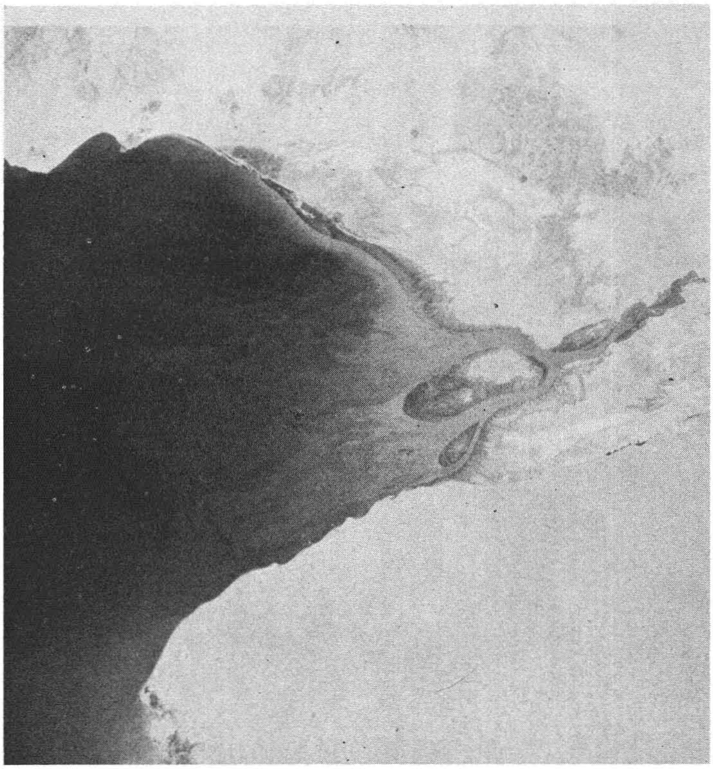


FIG. 9. View of the Mouth of the Colorado River. Taken from Gemini 4 in June 1965 with a Hasselblad 500 C, altitude of 110–120 N. Mi. The Sonora Desert of Mexico occupies the lower right hand part of the photo.

from such a program will also be enormous, but unfortunately cannot have a price tag put on it at this time. The full extent of the economic benefits to accrue from this program can be properly evaluated only by the scientists and economists associated with the various natural and cultural resources. This evaluation has been initiated as an integral part of this program, and there are indications that the potential benefits will greatly exceed the cost of the program. However, realistic experiments and additional research must be conducted before any specific dollar values can be placed on these benefits.

Future Program

Milestones and instrument development plans have been set up for this program. The actual timing of these activities depends on funding, flight programs, and authorization

TABLE 1

WORLD MAP AND CHART COVERAGE

Scale	*Per Cent of Land Area Covered*	*Remarks*
1:5,000,000	100	Ocean areas also
1:1,000,000	85	Generally well maintained
1:250,000	40	50 per cent needs revision
1:100,000 and larger	20	Over 50 per cent needs revision
1:25,000 and larger	8	Over 50 per cent needs revision

TABLE 2

ESTIMATED COST OF AERIAL SURVEYS

Types of Surveys	*Cost/km²*	*Cost to Cover Land and Adjacent Areas*
A. Small Scale Mapping and Supplementary Photography and Infrared	\$6.00	\$ 900,000,000
B. Magnetic-Gravity	5.00	750,000,000
C. Side-Looking Radar	1.00	150,000,000
		\$1,800,000,000

relative to the various stages of the program. Ideally, the program should proceed through the following phases:

FEASIBILITY

This phase, which is currently underway, is basically one of experimentation from aircraft and precursor spacecraft flights, during which phenomena signatures will be determined. During this phase, carefully selected and controlled test sites will be utilized with the subsequent correlation and evaluation of each sensor with respect to the phenomena in question being made. As instrumental value is established, design and procurement of space hardware will be initiated. Facilities for data handling and reduction are also being established during this stage. Aircraft testing of sensors is expected to be a continuing activity, which will continue beyond this phase, as it will be desirable to receive data from both aircraft and spacecraft simultaneously during the spaceflight testing phase.

SPACECRAFT TESTING

During the 1968–1972 period the first flights with the primary purpose of sensing the Earth's resources are planned. These are expected to include flights of the Apollo Applications Program, where manned spacecraft will carry a sizeable number of sensors which can observe various parts of the Earth simultaneously. On these initial spaceflights, coverage will be concentrated over areas such as the United States where ground controls will be used to verify the conclusions derived during the feasibility stage. Arctic, tropical, and other representative test sites are planned also. As a result of these flights, it is expected that sufficient information will be available to determine the optimum parameters and factors for the sensing of natural resources from space relative to the following:

1. Mode—unmanned, manned, or man-serviced;
2. Orbital configuration and flight duration;
3. Extent and variety of sensors:
4. Mode of data recording and their return to Earth;
5. Methods of data reduction and dissemination.

During this stage, the basic economics of resource sensing from space must be determined. This will involve weighing of the benefits as opposed to the costs of the program entering into an operational stage. Although not an operational phase, it is expected that considerable data of economic importance will be obtained in addition to a large amount of scientific information.

OPERATIONAL

The existence and extent of this stage will depend on the economic analysis made during the previous stage. Indications are that it will be multidiscipline in nature, global in extent and more or less continuous since many of the important phenomena associated with resources are time variant. Operational flights may well begin while the orbital testing stage is still in progress—perhaps during 1971 or 1972. By 1972 it is expected that testing and operational spaceflights will be combined.

SUMMARY OF UNIQUE ADVANTAGES

There are many advantages to obtaining imagery of the entire Earth or major parts of it by means of orbiting geoscience sensing systems. These systems encompass a number of instruments and techniques applicable to many disciplines, both cultural and natural, and of use to scientific and applications users. These systems have the unique utility of complementing one another in their results, hence their broad applications.

For sizeable areas within the field of view of the sensor, spacecraft coverage is truly synoptic. This is of great advantage to research work in the Earth sciences and in natural resources, which have been hampered by the time and space scales that arise in the measurement of the variable under investigation.

Further, there is information in the whole pattern of an integrated structure which can neither be derived from elements of the whole nor considered simply as the sum of the elements.

An important advantage of satellite photography is the aspect of real-time data acquisition. With this characteristic remote areas of special significance could be canvassed on short notice, thus providing information on impending disasters such as tsunamis, and forest fires, and studying disaster areas which result from storms, earthquakes, etc.

For complete aerial photographic coverage over large areas many technical problems pertaining to data reduction exist, for example, the assembling of broad-scale mosaics. Here the photos must be matched, and corrections in density, scale, or color reproduction be made, and finally the joining lines must be reduced as much as possible. Using space photography would reduce these tasks to a minimum since one space photograph, depending on scale, will cover many times the area as most aerial photographs.

The long duration of spaceflights and all-weather operations are highly advantageous aspects of remote sensing from space. There are many regions of the Earth that are covered with clouds for long periods of time. The cloud cover not only absorbs and reflects a large part of the radiation from the Sun to the Earth, but also absorbs radiation from the Earth out into space. In a manned orbiting satellite the problem can be partially overcome since the scientist on board the craft will be able to see when an area is clear enough to make observations and to also employ those sensors which can penetrate certain types of overcast. A less obvious but highly significant advantage results from the clearer images possible when the observation is made from far above the turbulent refracting and diffusing layer which often seriously degrades aerial observations.

With orbital sensing, it appears that the costs will be considerably less than even a single synoptic global coverage with aircraft. This is true because of the great amount of data that can be rapidly acquired, of the more complete coverage, and of the superior quality of some of the data which greatly reduces the effort needed for processing and analyzing.

Low-altitude photography applied to natural resource surveys and exploration has proven to be of great value. However, up-to-date and comprehensive data require frequent overflights and near-blanket coverage; thus extensive aircraft acquisition is prohibitively costly. Since the resolving power of remote-imaging instruments from satellite altitudes will be sufficient to permit identification of many different parameters of Earth resources, a potential means of economically acquiring such data on a world basis is offered.

A further advantage of orbital sensing is that global coverage can be obtained by uniform types of equipment and methods of calibration and measurements. This will insure that data will be collected under controlled conditions and will not be subjected to these uncertainties. Obvious technical and operational advantages result from the precise regularity of spacecraft motion, from the lack of vibration, and from the high rate of speed.

The Earth-orbital missions are also of great value for the experience gained and the testing of sensors and techniques prior to the conducting of lunar planetary orbital missions.

World-wide resource management through the use of operational spacecraft will provide a combination of scientific, sociological, political, and economic benefits. Through resource management, man is able to monitor the total resource availability, make efficient use of existing resources, protect existing resources against damage or loss, and uncover new resources. To be effective, action must be taken well in advance of the depletion of available resources. Thus accurate data on current inventory and rate of depletion furnishes the basic information required to anticipate forthcoming pressures on resources and to indicate appropriate steps to be taken.