



FIG. 1. Gemini XI photograph of the sub-continent of India and a portion of Ceylon. Note cloud line offshore from India and polygonal cells of cumulus clouds. Photo data: September 14, 1966 (1255 hours, Local Time); India-Ceylon, Laccadive Islands, Bay of Bengal; astronauts: Cdr. Charles Conrad, Jr. and Lt. Cdr. Richard F. Gordon, Jr. NASA/msc Photo No. S66-54676.

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Satellite Imagery of the Earth

The potential applications of spacecraft imagery are practically boundless.

INTRODUCTION

IN THIS DECADE, a significant amount of imagery of the Earth has been obtained from tellites. Numerous applications have been

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found for this photography, principally in the Earth and atmospheric sciences. Future space programs promise much additional imagery of the Earth. This paper describes recent studies of satellite imagery, being performed by scientists of several disciplines, which will form the basis for proper utilization of future hyper-altitude imagery. These studies endeavor to answer the following questions: What are the scientific and economic benefits of satellite

imagery? What systems should be employed in future missions? And, how can interpretations be made more quantitative and reliable?

SPACE PHOTOGRAPHY FOR EARTH RESOURCES APPLICATION*

THE SUPERB PHOTOGRAPHS obtained during Gemini and Apollo orbital flights have wide application to many scientific disciplines including geology, cartography, geography, meteorology, sedimentation, forestry and oceanography. Several intriguing developments as shown by the interpretation of five photographs from Gemini V, XI, and XII, and Apollo 6, serve to illustrate the utility of space photography to oceanography, meteorology and marine climatology, and in the location of fisheries.

As useful as space photography has proven to be, fundamental questions remain to be answered regarding what should be photo-

graphed of Earth or human resources, that can be observed best from space. It is not sensible to orbit a spacecraft to evaluate a problem which can be done better and far more economically from an airplane or from the ground. Photography from space is most applicable to those problems which require (1) magnitude, (2) repetition, and (3) which can only be viewed from a vantage point of several hundred miles above the Earth's surface.

The merits of manned and unmanned space photography are a serious consideration. Use of unmanned vehicles provides savings in weight as well as overcoming the problem of astronaut safety, complicated life-support systems, and the substitution of astronauts if the vehicle is to have a long life. Proponents of manned vehicles for space photography believe that the capability of an ingenious crew member far outweighs the disadvantages cited. Selectivity by the photographer permits

ABSTRACT: Photography of the Earth from spacecraft has application to both atmospheric and Earth sciences. Gemini and Apollo photographs have furnished information on sea surface roughness, areas of potential upwelling and oceanic current systems. Regional geologic structures and geomorphologic features are also recorded in orbital photographs. Infrared satellite imagery provides meteorological and hydrological data and is potentially useful for locating fresh water springs along coastal areas, sources of geothermal power and volcanic activity. Ground and airborne surveys are being undertaken to create a basis for the interpretation of data obtained from future satellite systems.

graphed, whether or not the photography should be acquired from manned or unmanned vehicles and what portions of the Earth should be photographed during the early stages of the program. These questions about acquisition of space photography will be examined first, then some of the inherent problems in interpretation of orbital photography and the adjustments required of the interpreter, and finally specific applications as shown by the photographs.

Perhaps the most common question asked about space photography is, "What can be photographed from space?" The answer to this is *anything*, if one is willing to orbit a camera with sufficient focal length. A more pertinent question is, "What should be photographed from space?" To this, the answer is that space photography is best applied to those features of the Earth, or those problems

acquisition of photos of unexpected or unusual occurrences as well as avoiding photographs of completely cloud covered areas or of uninteresting or obscure regions.

It has been proposed that space photography should be utilized to obtain prints of those portions of the Earth that cannot otherwise be easily photographed. Thus there is strong argument for an automatic polar orbit. Yet, because there are large areas of the Earth about which little is known, especially on the scale of space photographs, it would appear that the ice caps should wait. In the early stages of the program of Earth photography the greatest effort might best be concentrated in regions where the most benefits can be gained, that is, within 40° to 50° of the equator.

A CONSIDERABLE number of space photographs have been taken with standard camera sizes (9×9-inch photograph format, 6-inch focal length lens or longer) from various types of orbiting vehicles, such as the now surplus Air Force "Percheron", which lend them-

* Contributed by R. E. Stevenson, Bureau of Commercial Fisheries, Galveston, Texas (Laboratory Contribution #285), and R. O. Stone, University of Southern California, Los Angeles, California.

selves to standard interpretation techniques. Scales of these photographs are not much more than the order of 1:500,000 or perhaps 1:1,000,000. Although these scales are an order of magnitude smaller than those with which most photo interpreters are familiar, they are not at such a magnitude to present an image alien to the previous experience of the interpreter. Such photographs, however, are all classified and generally not available.

Gemini and Apollo photographs that may be obtained for study were taken with short focal-length lenses (38 mm. to 80 mm.) and a 70-mm. format camera. The scale of these photographs is small, of the order of 1:2,000,000 or smaller, and the interpretable area covered by a single photograph may be as much as 15,000 square miles. Interpretation of photos at these scales must be considerably different from that of photographs of two orders of magnitude smaller and existing photo-interpretation keys are of small value. The interpreter is observing features which are on the scale of maps or charts, rather than the scale of the usual aerial photograph, 1:2,500 to 1:100,000.

Even though resolution of space photographs is rather good (under certain conditions highways, canals and railroads can be distinguished), the cities of Miami and Miami Beach, Florida together still cover only about 0.1 inch on a typical space photograph obtained with a 38-mm. lens. The interpreter must undergo mental reorientation in terms of magnitude and gross aspect of features. On space photographs he may observe linear dune fields 200 feet in height and several hundred miles in length, entire mountain chains, vast dust storms or extensive cloud masses. The interpreter will view entire drainage systems rather than the bank of one small river or the length of a minor tributary; he will observe a coastline over a distance of 200 or 300 miles and not an individual sand spit; and he may be concerned with large faults (the San Andreas Fault of western California, for example, can be seen almost in its entirety on a single space photograph) and not with minor displacements. The scale of space photography dictates that the interpreter must be a knowledgeable Earth scientist and ideally have a working knowledge of more than a single Earth-science discipline.

THE INTERPRETER OF space photographs must deal with the problem of clouds. Most photo interpreters have never viewed a cloud from above, as most are not fliers and usually

aerial photographs are taken under cloud-free conditions. Even individuals who have flown have rarely seen clouds from any appreciable height. One of the rather interesting developments regarding space photographs is that many observers simply do not recognize clouds when they are viewed from above.

In the case of the geologist, cloud cover will not make him especially happy, but for the meteorologist, clouds are extremely useful. For the oceanographer, clouds may or may not be of interest depending on the type of data he is seeking. Nevertheless, the interpreter must become accustomed to viewing the Earth through and around the inevitable clouds. He must be able to recognize cloud patterns and their implications. He should know if the cloud pattern is indicative of a convergence, a front, fog, convection, a storm, or orographic development over a mountain.

PHOTOGRAPHS FROM orbiting vehicles have rarely been vertical. On none of the Gemini or manned Apollo flights was fuel budgeted for positioning the spacecraft for photography, although on Gemini IV, Lt. Colonel James A. McDivitt held the spacecraft in a vertical position to enable Lt. Colonel Edward H. White to obtain a remarkable sequence of eight vertical photographs of the region between Ensenada, Baja California and Nogales, Mexico. For the most part, the spacecrafts were in tumbling flight so that the photographs obtained were always either high or low obliques. In many cases, the scene was so spectacular to the astronaut that the horizon was included in the photo. Consequently, the high oblique might have the particular feature of interest at such great distance from the observer that it precluded usual interpreting techniques. On the other hand, certain conditions lend themselves to oblique photographs and, in some cases, even to high obliques. This is true, for example, in the interpretation of clouds over the sea where one is interested in as great a view of the total cloud pattern as possible. Such interpretation could not be gleaned from either vertical or low-oblique photography.

In the few vertical photographs from Gemini and the near vertical photography from Apollo 6, the great amount of information that can be obtained is apparent. In future experiments as the Apollo Application Series and Manned Orbiting Laboratories, there will be provision for acquiring vertical photographs under ideal lighting conditions.

The great amount of information that can be gained from vertical photography, and

more especially from stereo pairs, was demonstrated by analyses of the photographs taken during the unmanned flight of Apollo 6, April 4, 1968. An automatic Maurer camera was mounted in the hatch window and was activated just before the beginning of the second orbit. The camera operated continuously, with an 8.54-second exposure interval, through part of the third orbit. This continuous operation provided 754 photographs with from 40 to 72 percent overlap of the frames. Of these 754 photographs, 319 were exposed on the "dark side" of the Earth and produced no identifiable images. Of the remaining 435 frames, 370 were suitable for the interpretation of oceanic, atmospheric, and land features.

The Apollo 6 spacecraft was oriented so that the camera was vertical throughout the orbit. Even though the scales varied from 1:2,300,000 to 1:3,900,000, the vertical nature of the photography and the capability of stereoscopic viewing produced the most technically usable photographs yet available from the National Aeronautics and Space Administration space flights.

THE CAMERA USED for all Gemini missions was a Hasselblad, Model 500-C, modified by NASA. Eastman Kodak Ektachrome MS (S.O. 217) film was used, with the emulsion on a base one-sixth the thickness of normal Eastman Ektachrome. Three lenses were used, a (1) Zeiss Biogon, 38-mm. focal length, $f:4.5$, (2) Zeiss Planar, 80-mm. focal length, $f:2.8$, and (3) Zeiss Sonnar, 250-mm. focal length, $f:4.5$. The latter lens was used only on Gemini VII.

On Apollo 6, a 220G Maurer, 70-mm. camera was mounted with a 76-mm. Kodak Ektar, $f:2.8$ lens. The film was Kodak Ektachrome, SO 121. That film, plus a 2E Wratten filter, and the "red" coating of the Apollo window, produced the reddish-tinted photographs with excellent resolution and a reduction of "haze effects" that are of extreme utility.

Photography (Figure 1) of the Indian subcontinent and the surrounding portions of the Indian Ocean was taken during the flight of Gemini XI from an altitude of 620 nautical miles. The lens on the Hasselblad camera was a 38-mm. Biogon, wide-angle lens.

The cloudless skies along the entire coast of India are probably the result of subsiding air, as would occur during the daytime sea breeze. The weather map of 1,200 hours GCT, five hours after the photograph was taken, depicts the winds blowing toward the shore

along all coasts. There was a calm in the center of India and a slight low pressure system over the northern part of the subcontinent. Coastal air temperatures were about 81.5°F and inland areas were 7° to 9°F warmer. Conditions were typical of a sea breeze day.

The ability to view such a system in its entirety is tremendously significant. Not only can the seaward extent of the sea breeze, for the first time, be measured, but sea-surface wind drift, areas of potential upwelling, and convergences can be plotted for an entire coast, synoptically. Were such a view available daily, the value to fisheries, shipping, and meteorologists would be incalculable.

Seaward of the sea-breeze zone, the even distribution of water temperatures and the lack of surface winds is noted from the occurrence of polygonal, Bénard cells of cumulus clouds.

AS THE APOLLO 6 spacecraft passed over the northern coast of the Gulf of Guinea, it obtained a fine series of photographs of a portion of the coast of Ghana, and all the coasts of Togo and Dahomey. At the time, a sea breeze was blowing. The seaward and landward lines of cumulus clouds parallel to the shore marked the extent of this local wind system (Figure 2).

There are no wind data for April 4. Nonetheless, the existence of the seabreeze system is quite clear. There is the typical absence of low-level clouds over the coastal waters and land. The high cirrus clouds were well above the sea breeze. Inland, mainly in Dahomey, smoke can be seen rising from fires amongst the trees. The smoke trails toward the north-northeast and at speeds no greater than 6 miles per hour.

This photograph, and the stereo pairs with it, allows the first precise measurement of the landward and seaward extent of a sea-breeze system anywhere along the coasts of the world. The photographs of India were high obliques, precluding, therefore, any capability of precisely measuring the width of the sea-breeze zone.

The significance of being able to see and measure the width of a sea-breeze system is considerable. From a knowledge of the prevailing sea breeze, one can determine the influence of coastal winds on the coastal currents. In this photograph (Figure 2), the nearshore drift of water to the east, in response to the sea breeze, can be noted from the sediment plume about midway along the coast of Togo.

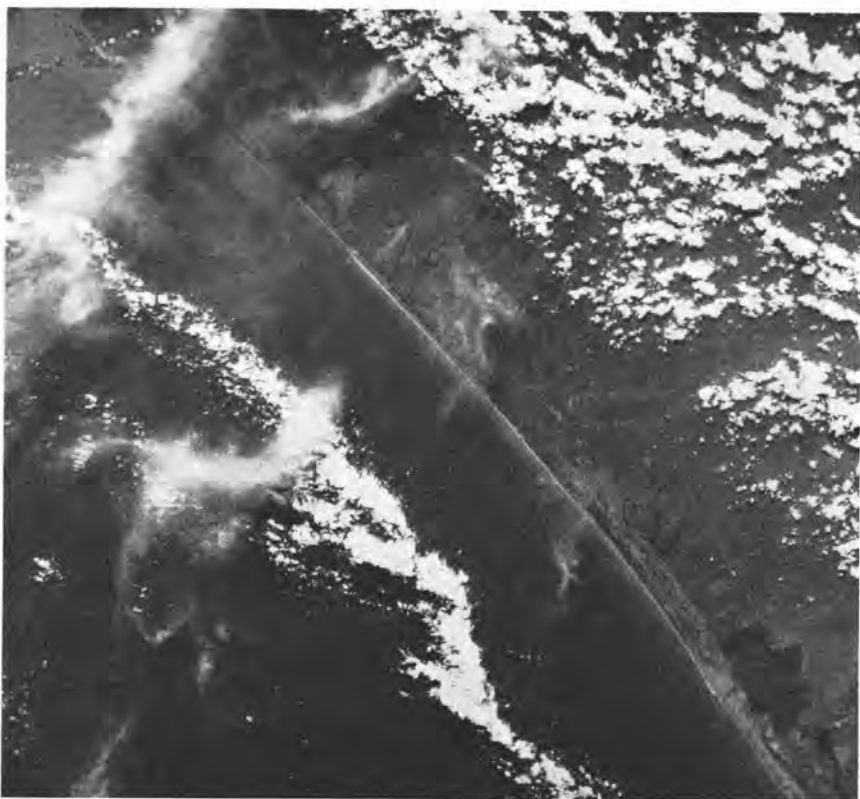


FIG. 2. Apollo 6 photograph of the northern Gulf of Guinea. Photo data: April 4, 1968, southern coast of Ghana, Togo and Dahomey. NASA/MSC Photo No. AS6-2-973.

The major benefit along this particular part of the African coast is to the coastal fisheries. For the most part, fishing in Dahomey and Togo are by local individuals. There is no large, organized fishing group, as yet. Most of the fishing is done from dug-out canoes. Under such conditions, it is clear that any correlative information is significant to their fishing efforts.

A PORTION OF east Africa and the Arabian peninsula is shown on the next photograph (Figure 3) which was taken during the flight of Gemini XI, from an altitude of 480 nautical miles. A 38-mm. Biogon, wide-angle lens was used on the Hasselblad camera.

The sun is reflecting from the land area of French Somaliland, so that just the edge of the reflection extends over the western waters of the Gulf of Aden. The variation in the reflection from the water is caused by differences in the roughness of the sea surface. Any water movement with the wind results in a smoother surface than areas of no motion, or a

movement into the wind. The winds of September 14 were blowing at about 5 miles per hour from the west at the time this photograph was taken.

In September, the water level in the Red Sea recovers from the great loss by evaporation that occurs each winter. The warm (90°F), highly saline (39 to 40 percent) waters begin to pour over the 350-foot-deep sill of the Strait of Bab al Mandab into the western Gulf of Aden. These Red Sea waters are more saline, and thus denser, than those of the surface layers in the Gulf of Aden (about 36 percent), so that they sink to a depth of 1,200 feet and then flow through the Gulf of Aden to join the intermediate (2,100 feet) waters of the western Indian Ocean.

The eddy system in the sun glitter of this photograph is the surface flow and turbulence set up by Red Sea waters flowing into and beneath the Gulf of Aden surface layers. Areas of divergence and convergence can be delineated, and it is clear that by use of a lens with a longer focal length, turbulent eddies 1/2 to 15 miles in diameter could be mapped.

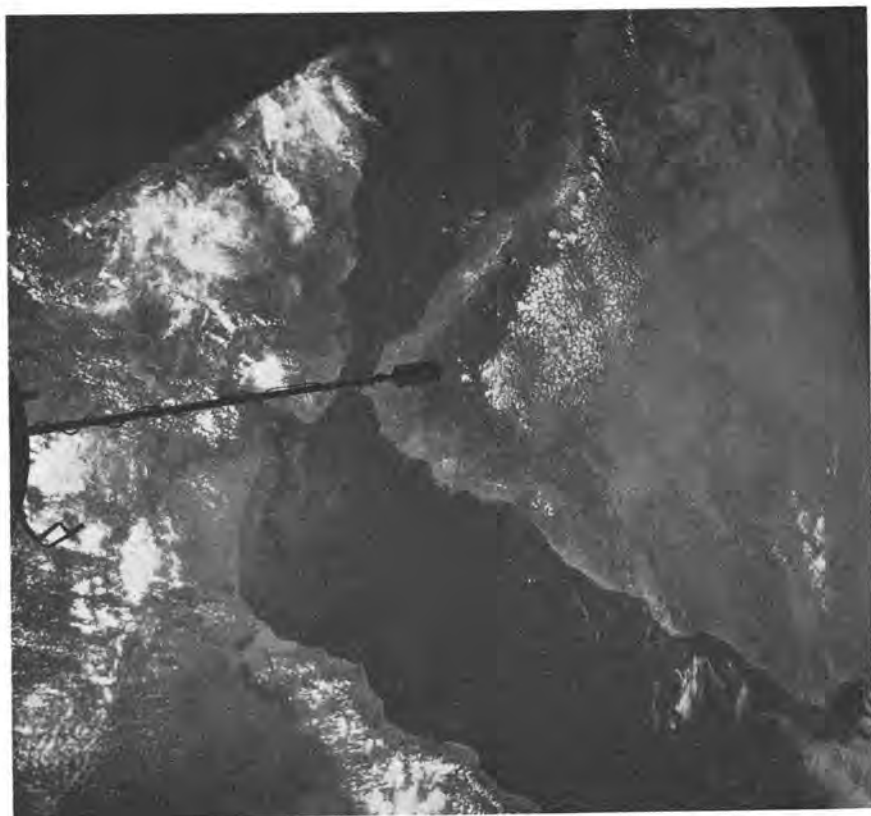


FIG. 3. Gemini XI photograph from an altitude of 450 miles of a portion of east Africa and the Arabian Peninsula. Photo data: September 14, 1966; Ethiopia, Aden, Hadramat, Somali, French Somaliland, Saudi Arabia, Yeman, South Arabia, Red Sea, Gulf of Aden; astronauts: Cdr. Charles Conrad, Jr. and Lt. Cdr. Richard F. Gordon, Jr. NASA/MSC Photo No. S66-54537.

THE PORTION OF the eddy visible in this photograph is 170 miles long and 80 miles in diameter. The next photograph (Figure 4), taken seconds later, outlined the extension of the system along the Somali Coast, so that the two together give an instantaneous view of a current system 300 miles in length. Such current systems may confine significant fisheries, especially in the Gulf of Aden where large populations of pelagic fish are known to exist.

From an altitude of 200 miles this photograph (Figure 4) was taken with a 38-mm., Biogon, wide-angle lens on the Hasselblad camera. The view is to the southeast, across the southern Persian Gulf and along the length of the Gulf of Oman.

The lagoonal complexes of the Trucial States are clearly defined, especially those near the city of Dubai. The apparently submerged point of Ra's Musandam stands out in contrast to the depositional coast to the west and across the strait. Most spectacular

is the anticlinorium, in the foreground, of the Persian Gulf coast of Iran.

The large island of Qeshm, 70 miles long, and the smaller islands in the Persian Gulf are apparent segments of the major structural features. The clear change in the geology of coastal Iran, along the Gulf of Oman, although predictable, is exciting in its magnitude.

For the sedimentologist, the sand bars and turbid water around Qeshm and along the coast readily depict gross movements and patterns. Repetitive photographs would provide data of transport in response to tides, currents and wave action.

Although the high cirrus clouds present little problem to the interpreter in this photograph, note should be made of the cloud shadow that angles across the anticlines immediately in front of the spacecraft. It is seemingly innocuous, but it blends so well with the topography that an unwary observer might mistake it for a topographic expression.

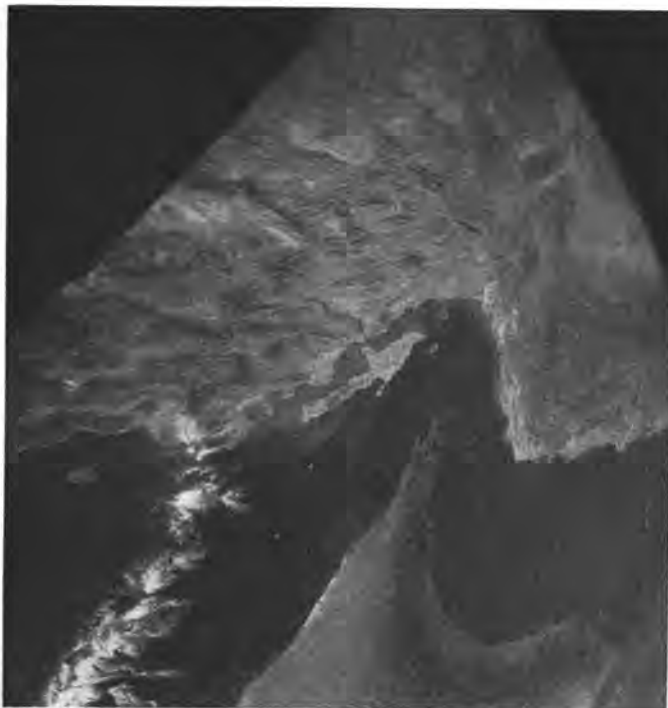


FIG. 4. Gemini XII photograph viewing to the southeast across the southern Persian Gulf and along the length of the Gulf of Oman taken from an altitude of 210 miles. Note particularly sediment discoloration in the sea in the vicinity of the island of Qeshm. Photo data: November 15, 1966; Iran, Persian Gulf, Gulf of Oman, Trucial Oman, Muscat and Oman, Zagros Mountains, Qeshm Island; astronauts: Capt. James A. Lovell, Jr. and Maj. Edwin E. Aldrin, Jr. NASA/MSC Photo No. S66-63082.

The ocean waters of the coasts of California and Baja California are cool in response to the major north to south circulation in the eastern Pacific Ocean. Over the cool waters, stratus and stratocumulus clouds form and are nearly constant features of the overlying marine atmosphere.

Normal atmospheric circulation over this portion of the Pacific Ocean is also north to south, with variations responding to seasonal modifications in the Hawaiian High Pressure System and local conditions usual to any coast.

A TYPICAL LOW LAYER of stratocumulus clouds moving by Guadalupe Island at 8 to 14 miles per hour was photographed from an altitude of 140 nautical miles during the flight of Gemini V (Figure 5). The Island has peaks to 4,500 feet which project through, and interfere with, such a cloud layer. A *shock*, or *bow* wave spreads from the north end of the island in much the manner of similar waves formed by a ship moving through water. Downstream, south of the island, turbulent von Karman eddies, rotating to the right and to

the left, formed as a turbulent *island wake*.

These cloud features, waves, and eddies have been photographed during four Gemini missions. They must be considered, therefore, climatic features of the Guadalupe Island marine atmosphere. Similar waves and eddies appear in the water around islands, and it is clear that the details of these fluid motions will permit more lucid understanding of atmospheric and oceanic flows.

SATELLITE MONITORING OF LAKEBED SURFACES*

DRY LAKEBEDS, situated in all of the world's deserts, are useful as emergency aircraft landing sites and as indicators of the hydrologic environment. A factor that has limited their use is the inability to monitor continuously the surface changes that occur as a result of rain. A partial solution in monitoring them is through the use of satellite photography. Reflectance changes that indicate soil moisture variation (which in turn affect

* Contributed by J. T. Neal, J. Cronin and R. S. Williams, Jr., Air Force Cambridge Research Laboratories, Bedford, Massachusetts.

trafficability) have been observed on Gemini color photographs and Nimbus AVCS (Advanced Vidicon Camera System) imagery.

Figure 6, an AVCS image taken over northwestern Nevada, shows a variety of lakebed surface conditions ranging from hard, dry clay crusts (locations 2, 3, 6, 7, 16-19) to soft, dry, friable surfaces (locations 5, 8, 10, 14, 15). The latter frequently contain moist surfaces with accumulations of salt (see for example the central portion of Humboldt Salt Marsh—#15). Without prior knowledge of surface conditions, it would be difficult to predict the type of surface present on these lakebeds. For example, the gray-level of the hard, dry clay crust at Smith Creek Valley (#19) is the same as the central salt-core of the Humboldt Salt Marsh (#15). However, it is known that these two lakebeds change little from year to year, so that any pronounced change in the reflectance level would probably indicate a change in moisture, or surface flooding.

Figure 7 is an enlarged segment of a Gemini IV 70 mm color transparency (printed here in black and white) showing Willcox Lake (playa), Arizona. The dark sinuous feature (arrow) had disappeared three months later and was not visible on the Gemini V photographs even though contrast was generally

greater. The change can be explained by the presence and subsequent evaporation of soil moisture in which a 20 percent reflectance difference occurs.

These studies have shown that both types of data have value in lakebed studies, especially when they can be used together. Future systems with improved resolution are certain to provide more detailed information to our knowledge of planetary environments.

GEOLOGIC INFORMATION FROM SATELLITE INFRARED IMAGERY*

THE PRESENTLY AVAILABLE infrared imagery is that acquired by NASA from the Nimbus I and II satellites in the 3.4 to 4.2-micron band of the spectrum. The system used in both satellites was the High Resolution Infrared Radiometer (HRIR), that was designed primarily to determine cloud distribution, a function that was performed admirably. Its ground resolution was 2.1 to 4.7 miles, depending on altitude. Another system

* Contributed by S. J. Gawarecki, U. S. Geological Survey, Washington, D.C.; J. T. Neal, J. Cronin and R. S. Williams, Jr., Air Force Cambridge Research Laboratories, Bedford, Massachusetts.

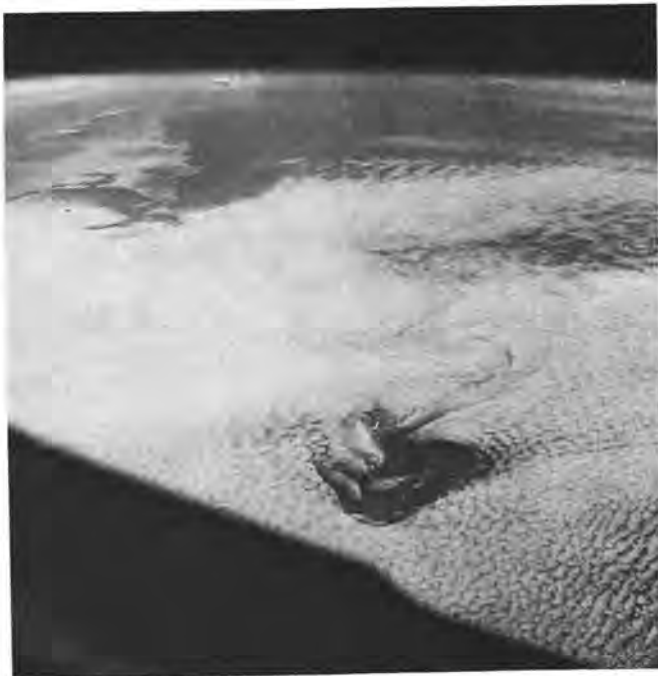


FIG. 5. Gemini V photograph showing low layer of strato-cumulus clouds in the vicinity of Vizcaino Bay and Guadalupe Island, Baja California. Well-defined von Kármán eddies have formed to the lee of Guadalupe Island. Photo data: August 21, 1965; Guadalupe Island and Vizcaino Bay, Baja California, Mexico; astronauts: Lt. Col. L. G. Cooper and Cdr. Charles Conrad, Jr. NASA/msc Photo No. S65-45697.

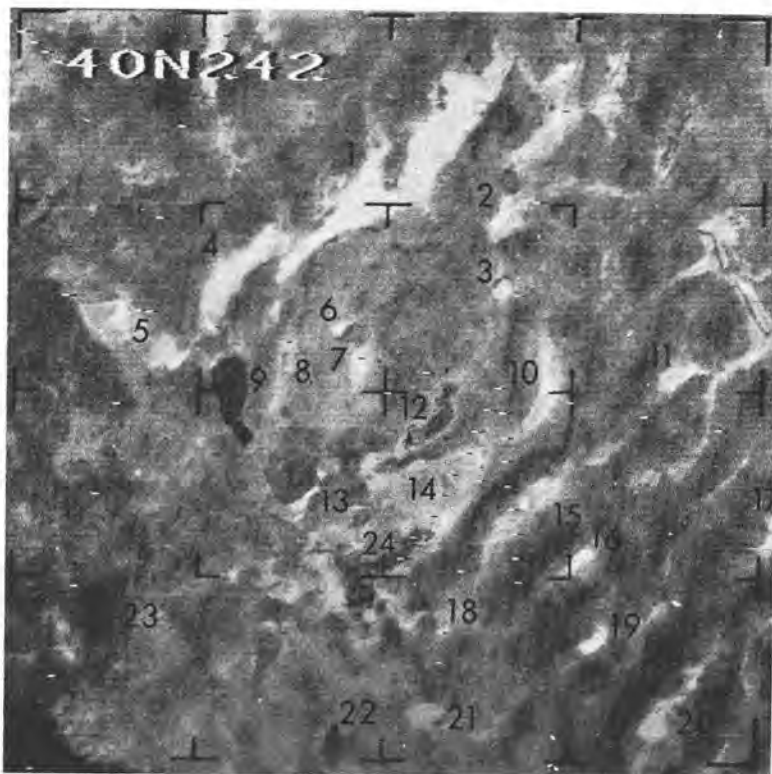


FIG. 6. Nimbus AVCS image, northwestern Nevada, 17 September 1964, Orbit 285, time 19-04-43. Good contrast separation between lakebeds (white and light gray), alluvium (intermediate gray), forested mountains (dark gray), and lakes (black) is apparent. Principal playas and lakes are listed below and keyed to numbers on the photo. NASA photo.

- | | |
|--------------------------------------|--------------------------------|
| 1-Black Rock Desert (playa) | 13-Brady Playa |
| 2-Jungo Flats (playa) | 14-Carson Sink (playa) |
| 3-Pit-Taylor Reservoir (playa) | 15-Humboldt Salt Marsh (playa) |
| 4-Smoke Creek Desert (playa) | 16-Edwards Creek Playa |
| 5-Honey Lake Valley (2 playas) | 17-Grass Playa |
| 6-Bluewing Playa | 18-Labou Flat (playa) |
| 7-Adobe Flat (playa) | 19-Smith Creek Playa |
| 8-Winnemucca Lake (playa) | 20-Big Smoky Playa |
| 9-Pyramid Lake | 21-Gabbs Playa |
| 10-Buena Vista Playa | 22-Walker Lake |
| 11-Buffalo Playa | 23-Lake Tahoe |
| 12-Farmlands in lacustrine sediments | 24-Marshland (dark gray area) |

used on Nimbus II, the Medium Resolution Infrared Radiometer (MRIR) had a ground resolution of 35 miles, which was too coarse to provide anything but a distinction of continental margins. None of these systems are presently in operation.

The spectral band used in the HRIR system was more favorable for temperatures between 680 and 840°K than the average ambient Earth temperature of about 300°K. As a result, and despite a relatively large instantaneous field of view (7.9 mr), the system was able to detect some volcanic activity from orbit. Kilauea and Mauna Loa volcanoes on the island of Hawaii (Gawarecki, Lyon, and

Nordberg, 1965) and Mount Etna volcano in the Mediterranean were detected on Nimbus I imagery. From Nimbus II the same system was able to detect Surtsey volcano during one of its eruptions.

The Terrestrial Sciences Laboratory of Air Force Cambridge Research Laboratories in conjunction with the U.S. Geological Survey has undertaken a long-term investigation of Icelandic and other geothermal and volcanic areas. The most important study to date has involved the Iceland volcano, Surtsey.

Infrared emission from the effusive basalt fissure eruption on Surtsey, between 19 August and 3 October 1966, was recorded con-



FIG. 7. Wilcox Lake (playa), Arizona, photographed from Gemini IV with 70 mm. MS Ektachrome. This black and white copy is enlarged about 4 times and is a segment of the original photograph. Note moist zone (arrow) on this hard silty clay surface. NASA Photo.

currently by an airborne scanning radiometer and the HRIR system of the Nimbus II meteorological satellite. An MIAI thermal infrared scanner, with a detection capability in the 3 to 5.5-micron wavelength region was used in the airborne surveys.

Airborne infrared imagery revealed a complex pattern of thermal anomalies outside the 1966 eruptive area. The most intense anomalies were related to venting fumaroles, fissures, and fractured areas. The positive thermal anomaly detected on HRIR imagery appeared as a small black spot. Energy calculations have shown that the anomaly on the HRIR imagery is caused principally by the energy released by the effusive volcanic eruption with its attendant maximum temperature of 1150°C. Calculations based on the geologic and thermal data have further established that the Surtsey thermal anomaly noted on satellite infrared imagery during August through October 1966 was recorded with an efficiency ratio of less than 5 percent largely because of convection and conductive heat loss to the atmosphere, ocean, and solid substructure of Surtsey.

Detection of the Surtsey anomaly on Nimbus HRIR imagery demonstrates that effusive volcanic events of this magnitude, involving

major convective heat loss, can undoubtedly be detected and monitored from Earth or extra-terrestrial orbit by infrared scanning radiometry, and that the efficiency ratio of detection may be characteristic of this type of volcanic event.

Other geoscience features recognized on the available imagery include the distribution of ice and open water in the polar regions and identification of major lineaments as a result of large scale topographic relief (Gawarecki, Lyon and Nordberg, 1965).

Given better ground and thermal resolution and optimum filtered and unfiltered imagery in the far infrared spectrum (i.e., 8 to 14 micron band), it is not unlikely that many other geological features may be detected from space. These would include smaller and/or cooler targets such as craters of active or semiactive andesitic and acidic volcanoes, hot springs, and other thermal areas. Data from TIROS broad-response radiometers which measure radiation in the water vapor window (8 to 13 μ) have been shown to depend strongly not only on the surface temperature and intervening atmosphere, but also on the surface emissivity (Buettner, Kern, and Cronin, 1965). A method has been developed which measures

the emissivity of terrestrial surfaces *in situ*. The method employs an emissivity box and an infrared interferometer from which data taken measures the spectral emissivity of lithologic materials. Results obtained in the study of igneous and sedimentary rocks show that at satellite altitudes it is possible to distinguish these two types of rocks and map their areal distribution, particularly of desert regions such as North Africa. These data are particularly meaningful when used in conjunction with satellite photography.

Extrapolation of results from suborbital altitude infrared surveys suggests that it will be possible to:

1. Differentiate bedrock from unconsolidated materials, and in some cases, different types of bedrock.
2. Determine the distribution and types of playas.
3. Delimit paludal environments.
4. Locate fresh water springs along and off coastal areas.
5. Locate areas of hydrothermal activity such as hot springs, fumaroles, mud volcanoes and large low level geothermal activity.
6. Determine structural features, primarily on the basis of moist drainage alignments, and, to a lesser extent, on the basis of bedrock type distribution. A synoptic study of fault systems in the world with the aid of infrared imagery is a logical approach to the prediction of earthquakes and to the search for ore deposits.
7. Infrared spectrometric data of rocks and minerals currently being obtained may lead to scanner multiband and filtering techniques, enabling better identification of terrain materials from space. Alteration due to ore mineralization, in most cases, will not be visible in satellite imagery because of small size and generally low contrast. The heat of oxidation of sulphide ores has not as yet been detected with IR scanners from suborbital altitudes. However, the effect of this oxidation in regions of permafrost is reported to have caused warm windows in the frozen ground. If the resolution is small enough, these features may be detected from orbit.

METEOROLOGIC AND HYDROLOGIC INFORMATION FROM SATELLITE IMAGERY*

FIGURE 8 IS AN example of Nimbus II HRIR data recorded over the eastern United States and Gulf of Mexico. This picture was taken near midnight (local time) on October 1, 1966. At this time water bodies were warm relative to adjacent land areas and appear dark. Clouds, being colder than either the land or water, appear lighter in color with the highest clouds (coldest) being the whitest.

The dark areas near the center at the top



FIG. 8. Nimbus II infrared image of the eastern United States and Gulf of Mexico, October 1, 1966, Orbit 1299. NASA photo.

of the picture are the Great Lakes. To the right is the east coast of the United States. Large geographical areas such as Long Island, Delaware Bay, and the Chesapeake Bay are clearly visible. Just east of the Delaware Bay, about halfway between the shore and the clouds, a slightly blacker area is visible. The boundary between this black area and the dark grey area near shore is the northern boundary of the warm Gulf Stream. A close inspection of the southeastern section of the United States reveals many smaller lakes and rivers.

A cold front is visible as a white band near the right side of the picture; behind the band is an area of broken light grey. This light grey area is caused by low level clouds. The circular white area near the bottom is hurricane Inez. Its counter-clockwise rotation is evident from the spiral cloud bands reaching out from the center of the storm. The intense

* Contributed by L. L. Foshee, Goddard Space Flight Center, NASA, Greenbelt, Maryland.

white spots are the tops of cumulonimbus clouds associated with the hurricane.

Figure 9 is a mosaic prepared from Nimbus II HRIR data selected to show geographical detail. In this presentation the warmer areas appear dark and colder areas white. These images were taken near local midnight when bodies of water were warmer, and thus darker than the surrounding land. The white-black dots and partial numbers are part of a grid system computer produced on the photograph. The grid system may contain errors up to two degrees and individual swaths are distorted near the edges so the grids do not always appear straight when geographical areas are matched in adjacent orbits.

A close inspection of this mosaic of the United States will reveal many lakes and rivers such as Lake Okeechobee in Florida, The Lake of the Woods in Minnesota, the St. Lawrence River and the Colorado River in the southwestern U.S. Perhaps less apparent to a casual observer is the San Joaquin Valley shown as a dark grey area surrounded by black in the western U.S., near 120°W and 40°N, and the Sierra Nevada Range shown as the light area to the east of the valley.

The gridded picture in Figure 10 is a typical

presentation of a photograph taken by the ATS-B suomi Camera. The 20-degree grid spacing seen here was added in such a manner so as to obscure as little data as possible yet include reference lines to allow one to locate a particular locale. The description below indicates, in a general way, what can be seen in the photographs.

In the Northern Hemisphere (at approximately 10°N) the Intertropical Convergence Zone (ITC) can be readily identified. A dissipating cyclone (33°N-145°W) with a cold front trailing to the south-southwest into the ITC and the warm front to the east can be recognized. At approximately 50°N-180°W, another low pressure cell can be depicted with an occlusion having its triple point at about 45°N-160°W with the elongated cold front extending to the southwest to the edge of the picture. The warm front oriented to the east becomes a cold front going into a vortex along the coast of British Columbia. Canada and parts of the United States are cloud covered due to the cyclones and associated frontal systems. Baja California and much of Mexico are cloud free as usual. The Hawaiian Islands are discernible by the clouds that envelop them.



FIG. 9. Mosaic of Nimbus II infrared data (HRIR) of the eastern United States. The Great Lakes are in the upper center. NASA photo.

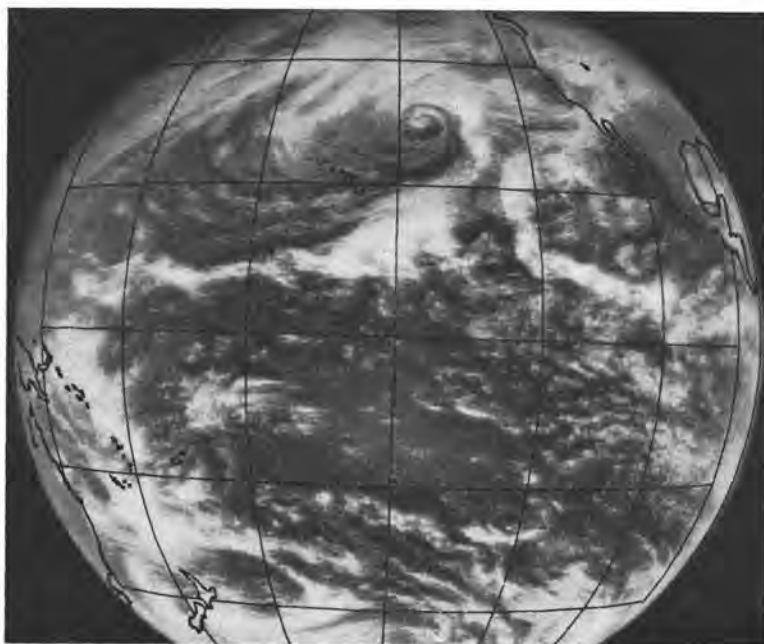


FIG. 10. Nimbus II APT picture of the Pacific Ocean. NASA photo.

In the Southern Hemisphere the usual field of cumuliform clouds are to the west of South America. Along the bottom of the picture several vortices with associated frontal systems can be seen. North Island (39°S - 176°E) of New Zealand can be identified but unfortunately South Island is obscured by clouds. The east coast of Australia is visible. To the east and north of Australia, a perturbed area can be recognized.

The montage of Nimbus II APT pictures in Figure 11 was recorded by one station on one pass on 16 May 1966 between 1045 and 1056 E.S.T. Thus, within 11 minutes the eastern portion of the U.S. and Canada was photographically displayed for meteorological and terrestrial analysis.

Shown in the lower left of the bottom picture is Cuba, Haiti and the Dominican Republic with Florida in the upper left corner.

The entire east coast is visible in the second photograph. Cape Hatteras, Chesapeake Bay, Delaware Bay, Long Island and Cape Cod stand out prominently.

In the third photograph, at the left of the picture, can be seen Lake Michigan with the western tip of Lake Superior extending beyond the cloud band. Ice covered James Bay in the top center is clearly outlined. The dark triangle in the Bay just south of Akimiski Island is shallow water first to melt in the Bay. To the right of the Bay is Quebec with its heavily forested areas still covered with

snow. In the lower right of the picture can be seen the dark lines of rivers and valleys extending down to the St. Lawrence River.

The last picture shows ice covered Hudson Bay, the northern portion of Quebec still heavily snow covered and the southwest portion of Baffin Island. In several places along the north and western shores of the Bay and along the shore of Baffin Island, large leads appear as the ice is beginning to melt and break up. Outlined by these leads are snow covered Southampton, Coats, Mansel and several smaller islands.

PROBLEMS AND POTENTIAL OF SPACECRAFT IMAGERY

SPACECRAFT IMAGERY obtained to date does not satisfy the needs of all potential users. Improved resolution, for example, would be desirable for most applications. Larger camera systems will undoubtedly be utilized in future projects. Information from a greater part of the electromagnetic spectrum is also desirable, viz., several bands in the visible and near infrared as well as the far infrared and microwave regions (radar and microwave radiometry).

As is well known to photo interpreters, stereoscopy greatly improves interpretability. But relief features are small in comparison with satellite altitudes. At the sacrifice of coverage, long focal-length cameras are required to obtain the necessary vertical resolu-



FIG. 11. Montage of Nimbus II APT pictures of the eastern United States and Canada. Lake Michigan is in the left center. NASA photo.

tion. Use of a single camera reduces the photo base to the point where the proper parallax cannot be achieved unless huge film formats are employed. Perhaps the answer lies in the use of panoramic cameras or two cameras tilted fore and aft of the spacecraft.

Improved attitude control is desirable so that essentially vertical imagery is obtained. Moreover, improved attitude sensing would facilitate the location and rectification of the imagery. Owing to the predictability of satellite orbits, and utilizing advanced attitude sensing devices, it will be possible to determine the location and orientation of a sensor with high precision at the time each image is obtained.

An improved library of knowledge on the spectral signatures of natural surfaces is another important objective. This would allow the interpreter to quantize his data and further increase his confidence in identification. Finally, considerable progress in automatic imagery reduction is necessary to aid the interpreter in the task of handling large volumes of information.

The potential applications of spacecraft imagery are practically boundless. The satellite is clearly an expedient means of gathering information about the surface of the Earth. Earth-orbiting satellites will contribute significantly to the development and management of Earth resources. Satellite imagery has the advantage of large areal coverage per image, rapid coverage of the entire surface of a planetary body, rapid repetition of coverage, wide choice of scales, and conceivably, lower cost than aerial surveys with a multi-mission satellite. In agriculture, satellite surveys could lead to increased yield and quantity of lands under cultivation and decreased losses from infestation and fires. In geology, satellite imagery on a global basis would provide new insight into the distribution, relationships and origin of mineralogic and petroleum provinces. In addition, it would provide more expedient means of assessing earthquake damage and monitoring volcanic eruptions.

Less than 50 percent of the Earth is adequately mapped. Unmapped areas, as well as areas where revised maps are needed, could be rapidly surveyed from satellites. Up-to-date maps and the imagery from which they were constructed would greatly promote studies of urban development, land use, forest and range management, water and air pollution, water resources and recreational sites. The utility of satellite imagery has already proved invaluable in weather prediction; weather satellites are today a permanent meteorological data-gathering tool. Oceanographic information, such as the state of the sea and the movement of icebergs and schools of fish, can also be gathered from satellites. The applications cover such a

variety of scientific and social disciplines that it is difficult at this time to assess the full potential of satellite imagery.

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