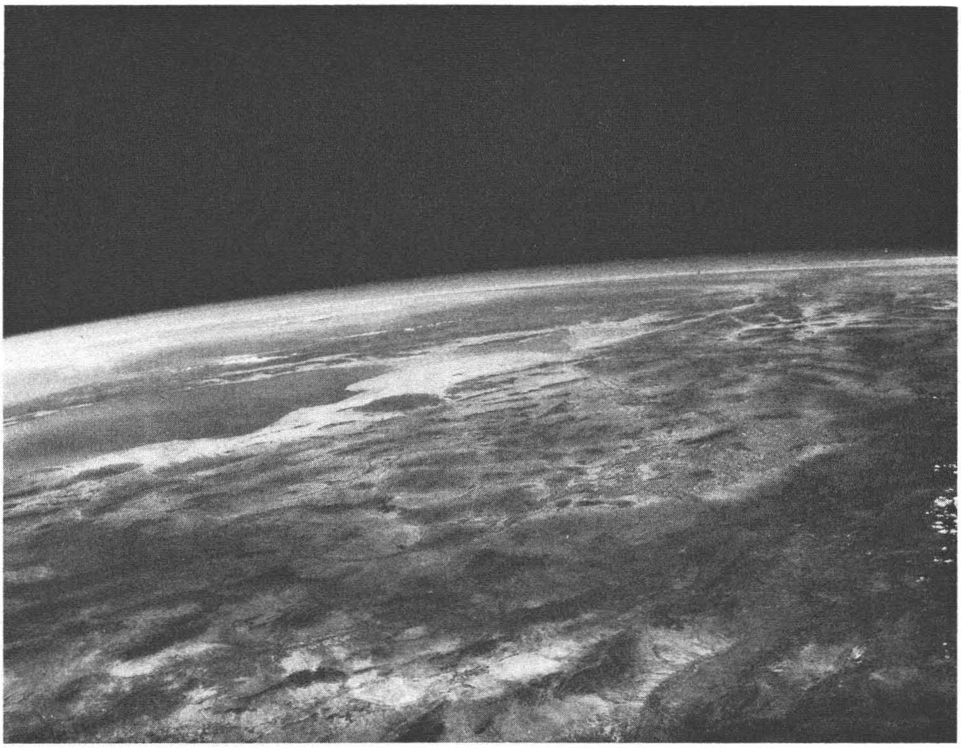

FIG. 1. Viking 12 photo of southwest U.S.A. from about 140 miles altitude. View to southwest.

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Space Photography—A Review

In addition to their meteorological uses, photographs taken of the earth from satellites have applications for numerous other geophysical studies.

Introduction

Since the development of large rockets in World War II, thousands of photographs of the earth have been taken from altitudes of 50 miles or higher, i.e., from space. The purpose of this paper is to review briefly the history, present status, and unique capabilities of what may be called "space photography," or "hyperaltitude photography." In addition, its potential applications will be reviewed.

Stress will be on pictures of the earth's surface rather than on those of cloud patterns, since such photography is of interest primarily to meteorologists. Military space photography is excluded from the scope of this paper.

Abstract: *This paper reviews the history, present status, and unique capabilities of photography of the earth from space, and presents representative space photographs. Space photography has the following main advantages over conventional aerial photography: wider perspective, potential world-wide coverage, greater speed, and rapid repetition of coverage. In addition, it can partially duplicate aerial photography in producing large scale pictures by the use of long focal-length cameras. Potential applications of space photography based on these characteristics lie in geologic reconnaissance, topographic mapping, oceanography, and several other fields.*

History of Space Photography

Although photographs were reportedly taken from rockets before World War I (Katz, 1963), space photography began in earnest with the use of small cameras carried by V-2 rockets fired from White Sands Proving Ground after World War II. Since that time, numerous flights which obtained photographs have been made by a variety of sounding rockets, ballistic missiles, satellites, and manned spacecraft; these are listed in Table I. Representative pictures taken during these flights are presented in Figures 1, 2, 3, 4, 5, 6, and 7. It should be kept in mind, in judging the quality of these pictures, that nearly all of these flights were made for purposes other than photography, which was usually an auxiliary experiment.

Useful references on certain aspects of space photography include papers by Katz (1963), Merifield (1964), Bird and Morrison (1964), Rochlin (1962), and Lowman (1964).

Current Projects

Topics which will be discussed under this heading include interpretation of existing space photographs, planning of space photography for presently approved programs, and long-range planning and investigations for possible future space missions.

In the area of interpretation, current or recently-completed efforts include studies of the MA-4 photos of North Africa by Morrison, *et al.* (in press), of the Viking, Tiros, and certain MA-4 photos by Merifield (1964), and of Tiros pictures of the United States by Cronin (1963). Although not yet published, efforts are being made at Goddard Space Flight Center and elsewhere to extract the maximum amount of non-meteorological information from the 27,000 images transmitted by the Nimbus I during its brief but productive lifetime. Other interpretive research by specialists is in progress; an interesting example is the recent comparison of Martian surface features with seif dunes in North Africa photographed by the MA-4 camera (Gifford, 1964).

The only currently approved manned spaceflight program involving photography of the earth is Project Gemini. Although primarily an operational and engineering test program, several of the Gemini earth-orbital flights will have provision for scientific experiments, including synoptic terrain and weather photography (Gill and Gerathewohl, in press). The terrain photography is being planned to secure pictures of the United States, for which ground truth and large scale air photos are available. Pictures thus obtained can be used as a base of experience for interpretation of space photographs of remote parts of the earth.

Several possible future space programs may involve space photography. Foremost among these is the Manned Orbiting Research Laboratory (MORL) (Badgley and Lyon, in press); to aid in mission planning, NASA hopes to make calibration test flights over selected parts of the United States with

TABLE I

SUMMARY OF SUCCESSFUL SPACE PHOTOGRAPHY FLIGHTS

Vehicle	Date	Cameras	Film (Filter)*	Area	Altitude (mi.)	Reference
V-2	1946	35 mm. Motion Picture	Super XX (25A)	SW U.S.A.	76	Holliday, 1954
V-2	1947	K-25 Aircraft	Infrared Reconnaissance Base (25A)	SW U.S.A.	100	Bergstrahl, 1947
Aerobee and V-2	1946–50	K-25 Aircraft	Aerographic Super XX (25A)	SW U.S.A.	60–80	Holliday, 1954; Newell, 1953; Newell, 1959
		35 mm. Motion Picture	Eastman IN Spectroscopic (29A)	SW U.S.A.		
		16 mm. Gunsight	Kodachrome	SW U.S.A.		
Vikings 11 and 12	1954–55	K-25 Aircraft	Eastman Hi-Speed Infrared	SW U.S.A.	Up to 158	Baumann and Winkler, 1955; Baumann and Winkler, 1959
Atlas	1959	16 mm. Time-Lapse	Recordak Fine-gr. Panchromatic	Atlantic Ocean SE of Atlantic Missile Range	Up to 230	Lathrop and Rush 1959
Aerobee	1960	Maurer 220 70 mm. Aerial	Kodak IR Aerographic (88A); Kodak Experimental Ektachrome (8778); Kodak High-Definition Negative (3)	North-Central Canada, Hudson Bay	47–140	Evans, Baumann, and Andryshak, 1962
Mercury Flight MR-1†	December 1960	Maurer 220G 70 mm.	Super Anscochrome	Florida, Bahama Islands	Maximum over 130	
Mercury Flight MA-3	April 1961	Maurer 220G 70 mm.	Super Anscochrome	Not Known	Low Altitude Abort Flight	
Mercury Flight MR-3	May 1961	Maurer 220G 70 mm.	Super Anscochrome	Florida, Bahama Islands, Mainly Cloud Covered		
Mercury Flight MA-4 (1961αα1)	September 1961	Maurer 220 G 70 mm.	Super Anscochrome	First Orbit Flight Path: Atlantic Ocean, North and Central Africa	86–123	
Mercury Flight MA-5 (1961α~1)	November 1961	Maurer 220G 70 mm.; Milliken DBM7, 16 mm. (periscope observer camera)	Super Anscochrome; Kodachrome EK Type II	SE U.S.A., West Coast of Mexico North Africa	86–128	
Mercury Flight MA-6 (1962γ1)	February 1962	Ansco Autoset, 35 mm	Eastman Color Negative	Florida, North Africa	87–141	Glenn, 1962
Mercury Flight MA-7 (1962 τ 1)	May 1962	Robot Recorder, 35 mm.	Eastman Color Negative	West Africa, Atlantic Ocean, and other areas	87–145	Carpenter, 1962
Mercury Flight MA-8 (1962 βδ 1)	October 1962	Hasselblad 500C, Modified 70 mm.	Anscochrome 200	Western U.S.A., Mexican Gulf Coast, South Atlantic Ocean	87–145	Schirra, 1962
Mercury Flight MA-9 (1963 15A)	May 1963	Hasselblad 500C, Modified 70 mm.	Anscochrome 200	South-Central Asia, Philippine Islands, Pacific Ocean, Middle East, North Africa	87-144	Cooper, 1963

* Wratten filter numbers.

† MR refers to suborbital flights with a Redstone launch vehicle; MA to flights with an Atlas launch vehicle. The MR-2 flight carried the chimpanzee Ham; MR-3, A. Shepard; MR-4, V. Grissom; MA-4, a simulated man; MA-5, the chimpanzee Enos; MA-6, J. Glenn; MA-7, M. Carpenter; MA-8, W. Schirra; MA-9, L. Cooper.

FIG. 2. Viking II photo of El Paso and Rio Grande Riva from about 158 miles altitude. North of top left.

an aircraft equipped with a variety of sensors, including cameras. Another program under consideration is the Lunar Orbital Survey System (LOSS), which would use modified Apollo spacecraft in circumlunar orbits to map the moon with cameras and a variety of non-visual sensors such as infrared, ultraviolet, and gamma-ray detectors. The results of planning and experimentation for possible MORL and LOSS missions will, of course, be applicable to flyby probes of the planets by manned and unmanned spacecraft, such as the forthcoming Mars Mariner flights. A detailed discussion of planetary exploration from orbiting vehicles is presented by Badgley and Lyon (in press).

Unique Capabilities of Space Photography

It is apparent, from the examples presented here, that the scale numbers and coverage per picture of available space photographs are orders of magnitude greater than those of conventional air photos. We now ask what space photography can offer which aerial photography cannot. Before discussing this question, however, it must be pointed out that space photography can duplicate, to an unknown but probably high degree, the functions of aerial photography in producing large-scale, high resolution pictures of the ground. Katz (1963), for example, points out that a ground resolution of 2.4 feet should be obtainable from 150 miles altitude on a photograph with resolution of 100 lines/millimeter, using a 120-inch focal length camera. Neglecting this possible duplication of aerial photography, however, we see that space photography from orbiting vehicles offers the following unique advantages:

1. Greater perspective
2. Wider coverage
3. Greater speed
4. Rapid repetition of coverage.

The *perspective* afforded by the great altitude of orbiting spacecraft is, of course, the most striking characteristic of space photographs, permitting one to see entire orogenic belts, drainage basins, and wrench fault sys-

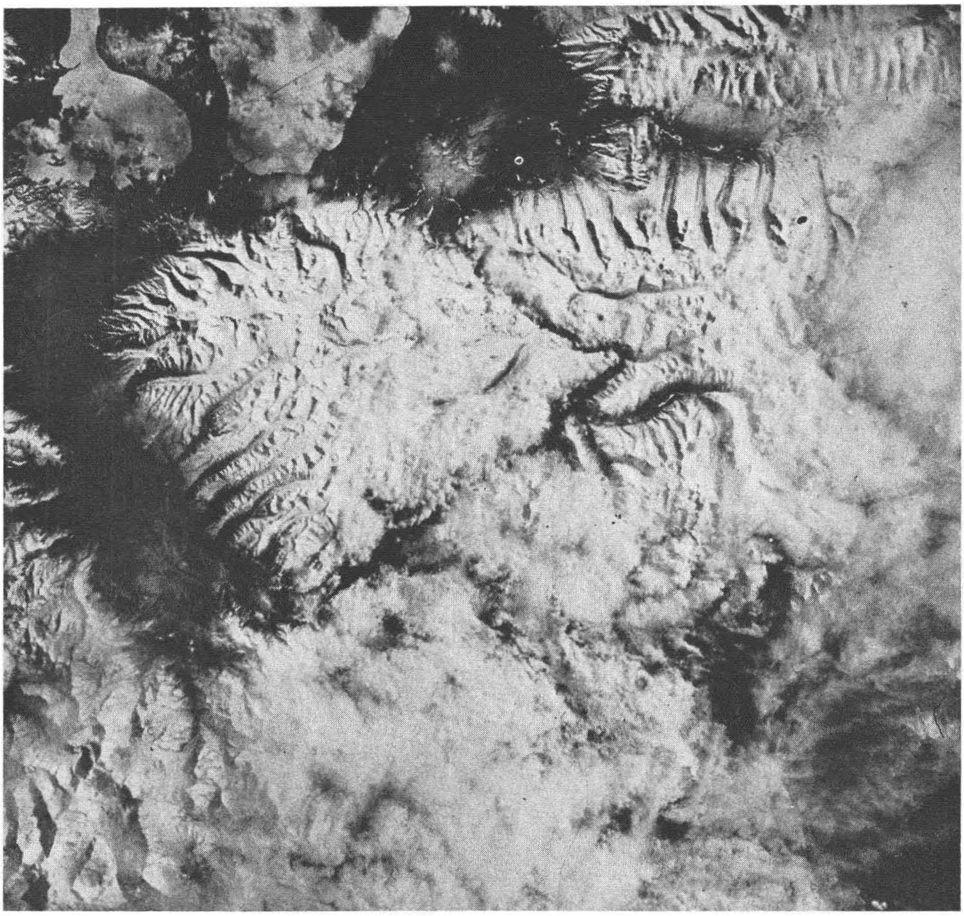

FIG. 3. Black and white print of a 70 mm. color transparency taken by L. G. Cooper during MA-9 flight, showing southwest Tibet. Lakes in upper left of photo are Rakas Tal (left; about 10 miles in east-west width) and Manasarowar (right); snow-covered mountain in upper left center of photo is Gurla Mandhata (25,335′). North at top.

tems at a glance. This perspective affords a continuity of observation which might permit, for example, the detection of large geologic structures unnoticed on large scale air photos. In Figures 1 and 4, many lineaments scores of miles long are easily seen. The value of small scale photographs has, of course, been recognized before (Hemphill, 1958; Cameron, 1961), and is demonstrated by the wide use of mosaics. Space photographs, however, have an advantage over mosaics in showing the terrain as it is, without the necessity for dodging, which must destroy many of the tonal clues to structure (Miller, 1961). This advantage may be especially useful in delineating structure in heavily vegetated areas, where interpretation must depend largely on subtle tone or color differences.

World-wide coverage can be provided for space photography by high-inclination or polar orbits. The importance of this advantage for photography of the polar regions is obvious, but it may be pointed out that camera-carrying satellites will also cover large areas, such as the central Pacific, which would be very difficult and expensive to photograph from aircraft. A related characteristic of space photography from orbiting vehicles is the *speed* of areal coverage which is possible. Rochlin (1962) points out that one satellite at a 300 mile altitude in polar orbit could photograph the entire surface of the earth in about $4\frac{1}{2}$ days. This extremely rapid coverage will also permit, if the satellite stays up for a few weeks or months, *rapid repetition of coverage* which would be very difficult to achieve with aircraft. This would permit the repeated photography of cloud-covered areas and detection of seasonal changes in features such as vegetation, snow fields, and ocean currents.

Potential Applications of Space Photography

The unique benefits offered by space photography, coupled with the possibility of duplicating conventional aerial photography with long focal length cameras, suggests applications in many areas, such as the following.

Geologic Reconnaissance

The most obvious application of space photography to geology is the photomapping of remote areas not previously mapped, such as parts of the interior of Antarctica. An even more interesting possibility is that of photographing previously mapped areas to show large geologic structures unnoticed on conventional air photos (Figure 4 is of interest in this connection). For example, the existence of transcontinental fracture zones, such as the Clipperton-Vema lineament crossing Venezuela (Fuller, 1964), might be investigated by space photography. Other geologic applications are suggested by the fact that color film adds a negligible amount to the cost of space photography; the spectacular pictures taken by Cooper during the MA-9 flight demonstrated the practicability of color space photography (Lowman, 1964).

Topographic Mapping

The Army Map Service study previously referred to (Spoocer, 1959) concluded tentatively that 1:1,000,000 scale topographic mapping might be done with satellite photography with good accuracy, and that somewhat larger scales might be possible with lower accuracy. The requirements for attitude and altitude control of a cartographic satellite are considerably more stringent than those for

Fig. 4. Black and white print of a 70 mm. color transparency taken by L. G. Cooper during MA-9 flight, showing central Tibet. North at top.

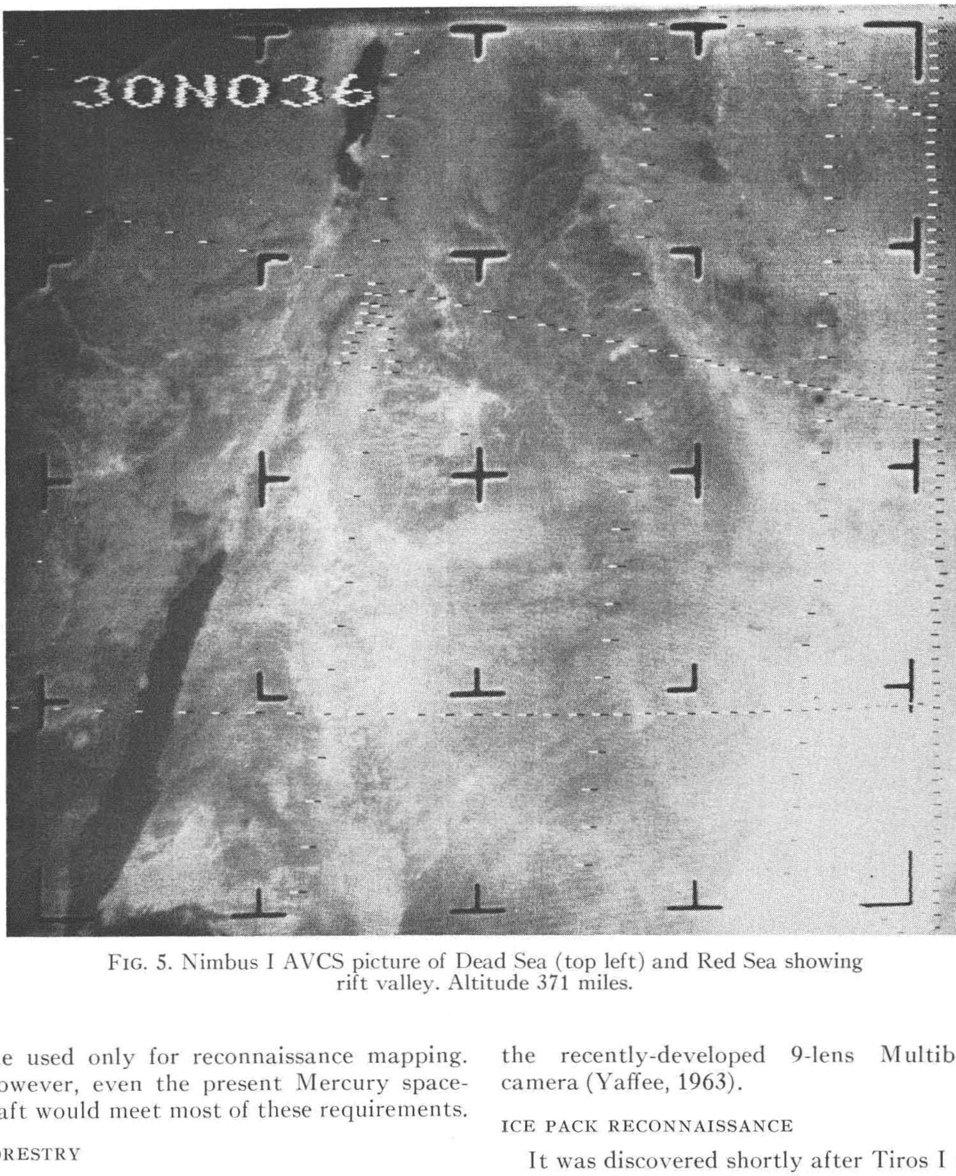

FIG. 5. Nimbus I AVCS picture of Dead Sea (top left) and Red Sea showing rift valley. Altitude 371 miles.

one used only for reconnaissance mapping. However, even the present Mercury spacecraft would meet most of these requirements.

FORESTRY

The fact that aerial photography has become a nearly indispensable tool of the modern forester makes it seem likely that space photography will have application in this field. The scale and resolution possible with small cameras would prevent the use of space photographs for detailed studies such as crown counts, but reconnaissance forest mapping might be possible. The use of color film for space photography would increase its value in forestry. The great potential value of multispectral photography (Colwell, 1961) in detecting changes in vegetation suggests that it would be useful to carry out such photography from space using instruments such as the recently-developed 9-lens Multiband camera (Yaffee, 1963).

ICE PACK RECONNAISSANCE

It was discovered shortly after Tiros I was put into orbit that sea and river ice could be seen on the telemetered images despite their relatively low resolution. This led rapidly to the joint Canadian-American Project Tirec to investigate the application of weather satellites to ice reconnaissance. Using Tiros photographs in conjunction with aircraft photography and ground observations the project demonstrated that satellite ice reconnaissance in areas such as the Gulf of St. Lawrence was clearly feasible and of great potential value (Balites and Neiss); Singer and Popham (1963) report that as much as $1,700,000 might have been saved in 1961 by the United States and Canada through ice observations from a Nimbus satellite had one been in orbit. It may be pointed out that a figure of this sort is misleadingly conservative; an operational Nimbus satellite could provide similar ice reconnaissance over the approaches to western Europe, Russia, and Antarctica at very little extra cost.

Film photography would have the advantage of greater resolution than television. But in day-to-day ice pack monitoring, methods of rapid image retrieval would have to be utilized, such as facsimile transmission of films developed in flight. It seems safe to say that both television and photography from orbiting vehicles promise to be immensely useful in ice studies.

HYDROLOGY

Although relatively little application has been made of space photography to hydrology, it might be useful in several ways. One of these is the measurement, over large areas, of snow cover; the National Weather Satellite Center and other agencies in the United States and Canada are currently investigating the use of Tiros pictures for this purpose. As shown by the MA-9 photographs, deep snow, light snow, and valley glaciers can be distinguished easily, indicating that methods involving film recovery should also be valuable because of the high resolution of the film.

The fact that entire drainage basins of major rivers can be photographed quickly from satellites suggests that many other hydrologic applications can be found for space photography.

SUPPLEMENTAL WEATHER PHOTOGRAPHY

The greater resolution obtainable with film-recovery methods of space photography

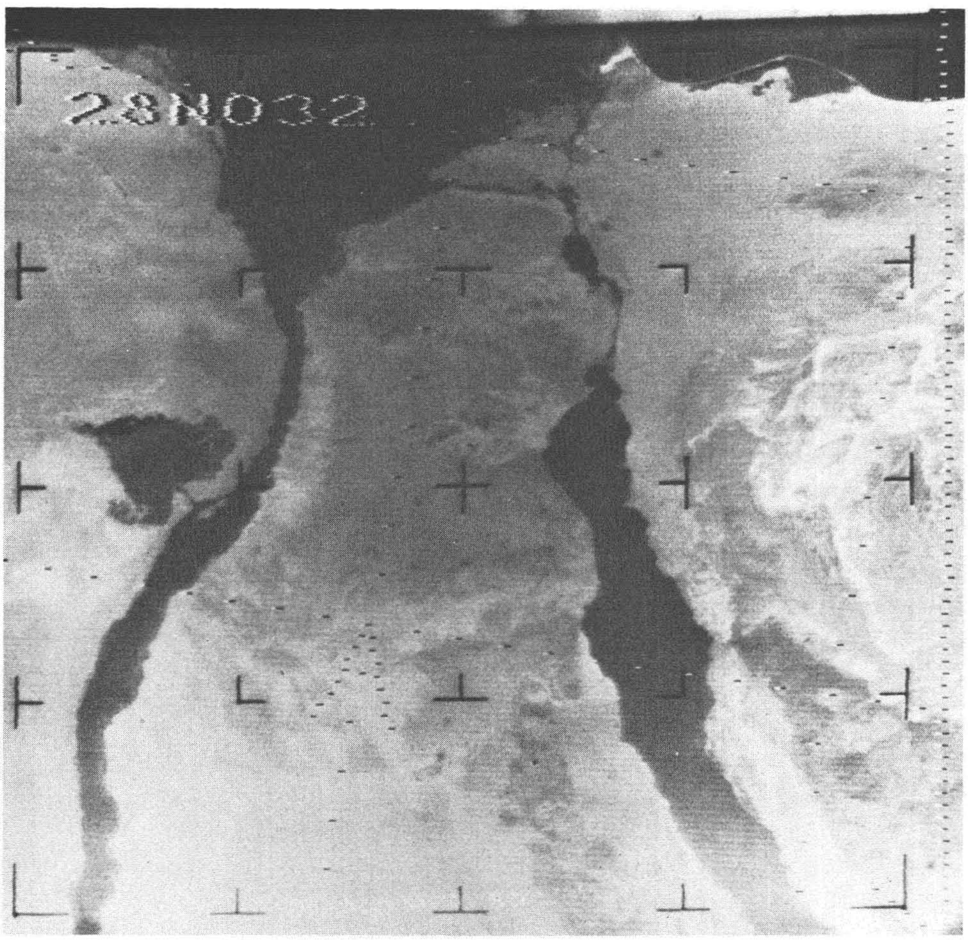

FIG. 6. Nimbus I AVCS picture showing Gulf of Suez, Suez Canal, and Nile River. Altitude 371 miles.

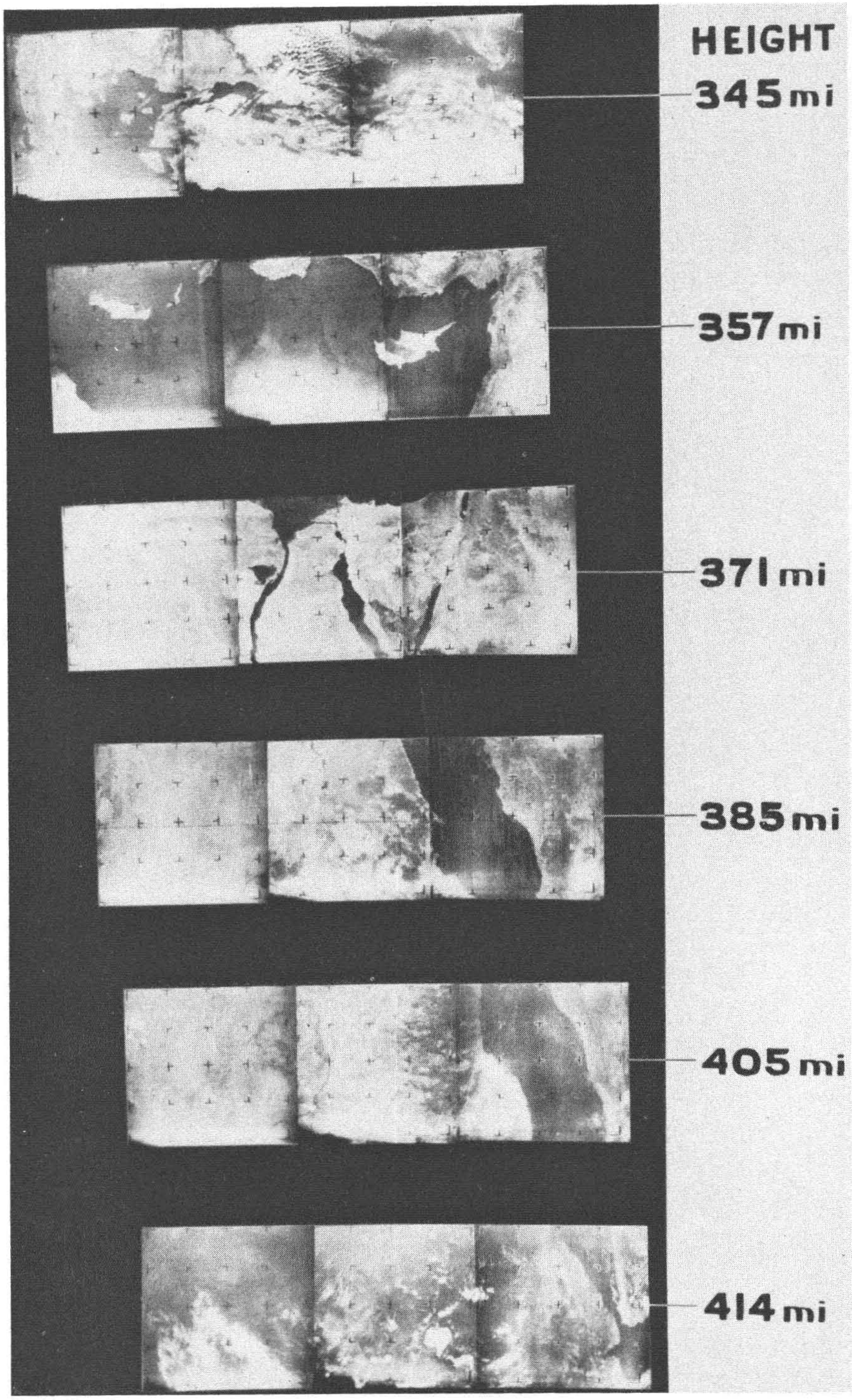

FIG. 7. Mosaic of Nimbus I pictures including areas shown in Figures 5 and 6.

makes space photographs valuable for synoptic studies of the fine structure of cloud systems (S. Soules and K. Nagler, personal communication), similar to those already conducted from aircraft (Malkus, 1963). The Arctic Meteorology Photo Probe (Evans, Baumann, and Andryshak, 1962) further demonstrated the usefulness of rocket photography in supplementing and supporting meteorological satellites.

These applications would not be considered photogrammetry in the usual sense, but are worth mentioning because a surprisingly large part of the earth's surface is covered with clouds at any one time. This will obviously hamper terrain photography, but the pictures of the cloud cover itself will be of value.

OCEANOGRAPHY

The ability to take individual photographs covering scores of thousands of square miles should prove invaluable in oceanographic studies. In addition to the obvious benefits of weather observations over remote oceanic areas, the following applications may be possible:

1. Multispectral photography covering the near infrared, visible, and ultraviolet can show the distribution of currents and possibly of areas with differing salinity. That such photography is possible even from space vehicles was suggested by Glenn's ability to see the Gulf Stream during the MA-6 flight (Glenn, 1962). A knowledge of the structure of such major near-surface currents would obviously be of value to the fishing and shipping industries, and from a broader viewpoint to nations whose climate is strongly influenced by these currents, such as Iceland, England, and Chile.
2. The discovery by Cameron (1952, 1962) that water currents in oceans, bays, and rivers could be mapped by pseudo-stereoscopic time-lapse air photography opens another possible application of space photography. Small areas can, of course, be mapped with low altitude photography, but to map large currents, such as those in the Bay of Fundy, Cameron found it necessary to use photographs with scales of 1:85,000. He suggests extension of the method to major currents such as the Gulf Stream (and to large physiographic features) by the use of 1:270,000 photographs taken from altitudes of 80,000 ft. or higher, or by the use of satellite photography.
3. L. G. Cooper, during the MA-9 flight, noticed striking color differences in the water around islands in the Bahamas, which he attributed, presumably correctly, to water depth. Conventional air photos have been used to study this, and it is interesting to note the possibility raised by Cooper's observation that space photographs can also be used to map bottom topography.

EXTRATERRESTRIAL PHOTOINTERPRETATION

The most immediate extraterrestrial use for space photography of the earth is its application to the study of pictures of other planetary surfaces, that of Mars in particular. It is interesting to note that nearly all the efforts to interpret the thousands of available pictures have been made in essentially complete ignorance of what the earth would look like under similar conditions. The problem of deducing the nature of the Martian surface is complicated by the fact that experience gained by the study of lunar features cannot be applied reliably to Mars, because the existence of a Martian atmosphere and an intermittent hydrosphere may have produced physiography more nearly terrestrial than lunar. An interesting example of the use of space photography in the study of Mars is presented by Gifford (1964).

SUMMARY

It is, of course, obvious that photography from orbital distances cannot replace aerial photography, especially for applications requiring extremely large scales. Nevertheless, it seems clear that the uniquely great coverage and perspective possible with space photography will make it an invaluable tool for many purposes, and may uncover broad features of the earth's structure whose existence has been only conjectured.

ACKNOWLEDGEMENTS

Numerous people and organizations generously contributed material and advice for this paper and for the writer's earlier review. In addition to those acknowledged in the earlier paper, I am indebted to Dr. W. Nordberg and Mr. W. Harbour for access to pictures transmitted by Nimbus I.

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