EROS # 104

MAPPING THE EARTH FROM SPACE

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INTRODUCTION

The Department of the Interior's Earth Resources Observation Systems (EROS) program, directed by the U.S. Geological Survey (USGS), is dedicated to applying remote sensing to the survey of the earth's resources and eventually to their management. The EROS program is closely allied with similar programs in other Departments, such as Agriculture and Commerce, and the programs of all the interrelated disciplines are monitored and supported by the Earth Resources Survey Program of the National Aeronautics and Space Administration (NASA). NASA provides the vehicles (satellites and aircraft), the remote-sensing systems, and the auxiliary equipment for obtaining imagery and other data for the earth-resources studies.

FOUR MODES

In the EROS program, four remote-sensing modes for viewing the earth have been defined, as shown in table 1. Although routine aerial photography has been a standard sensing process for many years, the use of different sensors and flights at higher altitudes is continually increasing the capabilities of the airborne mode.

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Table 1.--Basic modes for remote sensing of the earth

- AIRBORNE. Aircraft, ballon, or similar platform within the atmosphere-- generally film return (MSC aircraft).*

- SPACE, DATA TRANSMISSION, GLOBAL. Sun synchronous, long lived, 300-900 km altitude (ERTS, A&B).*

- SPACE, FILM RETURN, GLOBAL. Sun synchronous, short lived, 150-300 km altitude (ERTS, C&D).*

- SPACE, DATA TRANSMISSION, GEOSYNCHRONOUS. Near geostationary, long lived, 36,000 km altitude (advanced technology satellite, ATS).*

* Designation of NASA programs that exemplify the mode.

Photographs taken from high-flying airplanes with various camera-film-filter combinations are being studied for applications in earth-resources surveys. For example an experiment is being conducted to produce a color photomap by photographically color separating three bands of imagery from color infrared photographs taken at 18.3-km (60,000 ft) flight height with a camera of 12-inch focal length (fig. 1). Other experiments are underway to evaluate the usefulness of high-altitude photographs for both line mapping and photomapping. A sample of the input for these experiments is shown in figure 2--a photograph taken at about 20-km (70,000 ft) flight height from a U-2 airplane with a standard mapping camera of 6-inch focal length.

In this paper, the primary topic is the first of the three space modes, which is represented by the first Earth Resource Technology Satellite, ERTS-A. The two other space modes are mentioned briefly below.

Resource surveys can be made from geostationary (geosynchronous) satellites, but because of the high cost and research involved, they are probably 5 to 10 years off. However, the USGS has defined an earth-sensing geosynchronous experiment* in which the sensors would be tracking telescopes, each hovering over a portion of the earth at 36,000-km altitude. Figure 3 is an image from the small spin-scan camera in the Advanced Technology Satellite (ATS), which is geosynchronous. This is about the best shot of the earth we now have from the 36,000-km altitude, but the imagery from the experiment proposed by USGS would be of much larger scale and higher quality.

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*Colvocoresses, Alden P., Surveying the Earth from 20,000 Miles, Image Technology, v. 12, no. 1, 1970, p. 13-18.

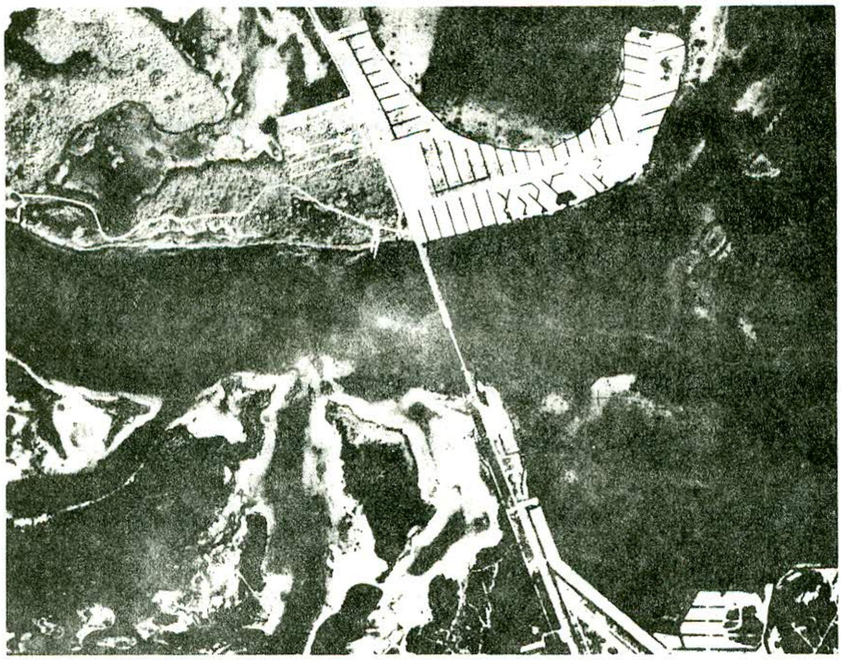


Figure 1.--Copy of a color IR photograph; flight-height, 18.3 km (60,000 ft); camera focal length, 12-inches; Florida Keys area. NASA photo.

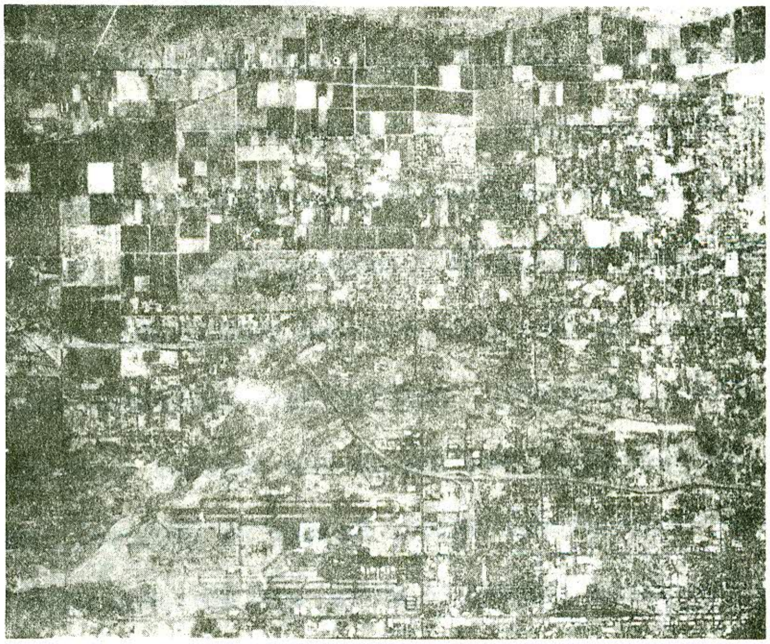


Figure 2.--Portion of a B&W photograph of Phoenix, Ariz., area; 20-km flight height (70,000 ft); U-2 airplane; 6-inch mapping camera.

Figure 3.--Portion of an image from the small spin-scan camera on the geostationary ATS spacecraft. NASA photo.

The film-return mode has been demonstrated, in a small way, on NASA's Mercury, Gemini, and Apollo flights, and Skylab will provide considerably more photographic coverage. In regard to the film-return mode, the USGS has proposed dedicated unmanned flights for obtaining earth-resources data and has recommended the use of a mapping camera of 12-inch focal length. Table 2 indicates the tradeoffs between 6-inch and 12-inch film cameras at nominal 200-km altitudes. Studies have indicated that such space flights are economically feasible if the desired resolution can be obtained and an area as large as the United States is covered. Figure 4 shows the number of stereomodels needed to cover a given area with spacecraft and aircraft photographs.

Table 2.--Camera system capability at 200-km altitude.

Relative Mapping	6-inch camera	12-inch camera
Content for map scale of:	1:500,000	1:250,000
Position accuracy for map scale of:	1: 25,000	1: 25,000
Elevation accuracy for contour interval of:	50 m	15 m
Absolute Mapping		
Content for map scale of:	1:500,000	1:250,000
Position accuracy for map scale of:	1:100,000	1: 50,000
Elevation accuracy for contour interval of:	200 m	50 m

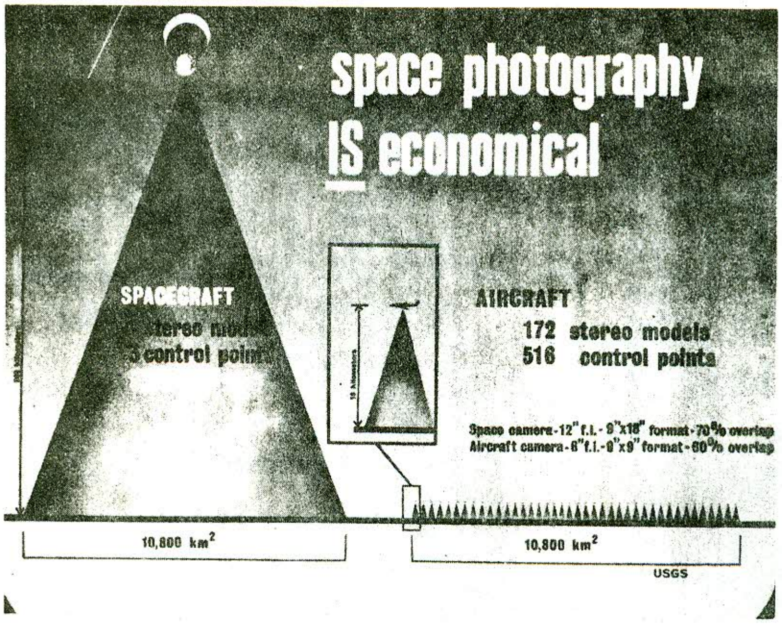


Figure 4.--Comparison of coverage of space and aircraft mapping photography.

SKYLAB is a manned NASA spaceflight scheduled for 1973 at a nominal 435-km (235 N.M.) altitude on an orbit of 50° inclination to the Equator. Thus all of Latin America except the southern tip of Argentina and Chile will be within the range of SKYLAB (fig. 5). The areas for which remote-sensor coverage will be obtained will, of course, depend on the proposals received and approved by NASA. Formal proposals for using either ERTS or SKYLAB images of areas outside the United States should be processed through diplomatic channels. An important reason for this procedure is that ground control information must be submitted to NASA before the images can be precision processed for cartographic use.

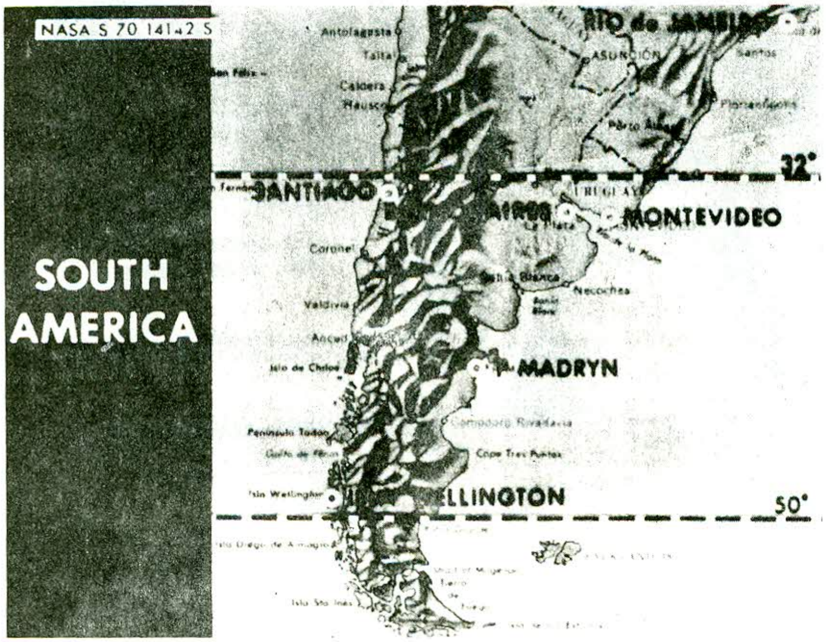


Figure 5.--SKYLAB will fly over all but the southern tip of South America; the area in addition to that covered by GEMINI/APOLLO flights is shown between the dashed lines.

The remote sensors on SKYLAB for obtaining earth-resources data are listed below.

- S190 Multispectral Photographic Facility
- S191 Infrared Spectrometer
- S192 Multispectral Scanner
- S193 Microwave System
    - A - Radiometer/Scatterometer (K-Band)
    - B - Altimeter (K-Band)
    - C - Radiometer (L-Band)

A drawing of the S190 multispectral photographic sensor is shown in figure 6. The cameras have a focal length of 150 mm, an aperture of f/2.8, and use 70-mm roll film. They will record imagery in the following spectral bands:

- 0.5 to 0.6 μm
- 0.6 to 0.7 μm
- 0.7 to 0.8 μm
- 0.8 to 0.9 μm
- color
- color infrared

The imagery from experiment S190 should have about three times the resolution of ERTS, perhaps twice that of Apollo, and be ideal for planimetric mapping at 1:250,000 scale. A document describing SKYLAB as well as instructions for preparation of proposals are available from NASA.

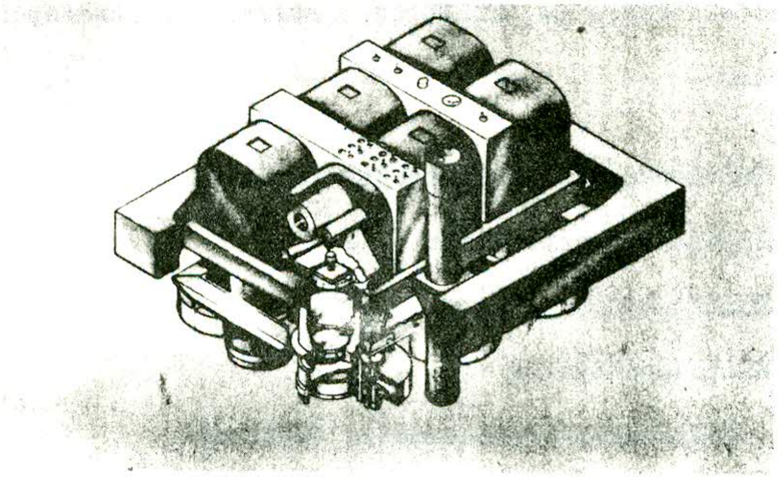


Figure 6.--S190 Multispectral Photographic Facility

ERTS SYSTEM

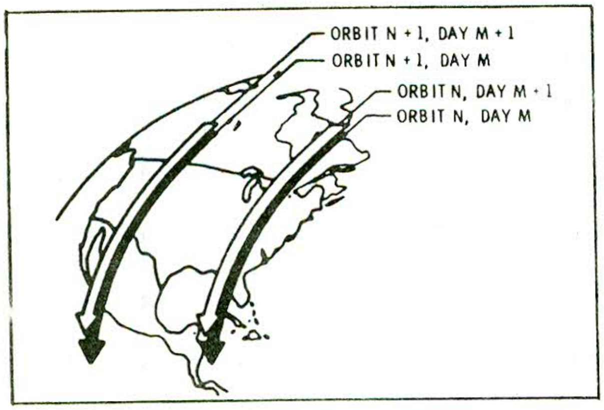
The remainder of this paper is devoted to the mode represented by ERTS. A year from now it is expected that the first Earth Resource Technology Satellite, ERTS-A, will be in orbit, to be followed a year later by ERTS-B. Table 3 briefly describes the system and characteristics of the sensors. Note two types of sensors on ERTS, the return beam vidicons (RBV) and the multispectral scanners (MSS). We can now only predict what an image from ERTS will look like, but imagery obtained in experiment S065 from Apollo 9 in March 1969 in many respects simulates ERTS (RBV) imagery. Many of the following illustrations were made from S065 images.

The formats of ERTS are illustrated in figure 7. The bulk imagery is not truly rectified and is referenced to the ground only to within about 5 km. On the other hand, the precision-processed imagery will be suitable for photomap bases. It will be rectified and fitted to the Universal Transverse Mercator grid. To do this, it will be necessary to have ground control points that are identifiable on the imagery. River junctions, coast-line points, and even major cultural features are suitable points, but they should be defined with respect to controlled maps of 1:250,000 scale or larger.

With suitable control points available, the precision-processed images should have positional accuracy that exceeds the requirements of the U.S. National Map Accuracy Standards, which permit positional errors of up to 500 meters (for 90% of the points tested) at 1:1,000,000 scale. The scale of 1:1,000,000 is considered optimum for handling ERTS imagery in photographic form, but it can be enlarged or reduced for various purposes.

Table 3.--Orbit parameters and multispectral sensor characteristics for ERTS-A

Parameters



Orbit Parameter	Nominal Orbit
Altitude	492.35 nm
Inclination	99.088 deg
Period	6196.015 sec
Eccentricity	0
Time at Ascending Node	2130 hrs
Coverage Cycle Duration	18 days (251 revs)
Distance Between Adjacent Ground Tracks at Equator	86.06 nm

Sensor Characteristics

RBV Camera Subsystem

Characteristic	Camera No. 1	Camera No. 2	Camera No. 3
Spectral Bandwidth (nanometers)	475-575	580-680	690-830
Resolution (at maximum scene highlight contrast)	4500 TVL	4500 TVL	3400 TVL
Edge Resolution (percentage of center)	80	80	80
Signal-to-Noise Ratio (at 10 TVL)	33 dB	33 dB	25 dB
Dynamic Range	50:1	50:1	50:1
Gray Scale ($\sqrt{2}$ transmission steps)	10	10	8
Horizontal Scan Rate (lines/sec)	1250	1250	1250
Number of Scan Lines	4200	4200	4200
Readout Time (seconds)	3.5	3.5	3.5
Video Bandwidth (MHz)	3.5	3.5	3.5
Time Between Picture Sets (seconds)	25	25	25
Exposure Time (milliseconds)	8, 12 or 16	8, 12 or 16	8, 12 or 16
Image Distortion (maximum)	1%	1%	1%
Deflection Skew (maximum)	+0.5%	+0.5%	+0.5%
Size and Centering Shift (maximum)	± 2%	± 2%	± 2%

Multispectral Scanner Subsystem

Spectral Bandwidth (microns)	Channel 1	0.5 to 0.6
	Channel 2	0.6 to 0.7
	Channel 3	0.7 to 0.8
	Channel 4	0.8 to 1.1
	Channel 5	10.4 to 12.6 (ERTS B only)
Scanning	Object Plane	
Scan Rate	13.6 Hz	
Scan Efficiency	50%	
Detectors/Band/Scan (Channels 1 thru 4)	6	
Instantaneous Field of View	260 ft x 260 ft	
Multiplexer Output	15 Mbps PCM	

From NASA publication, "Earth Resources Technology Satellite," 1970

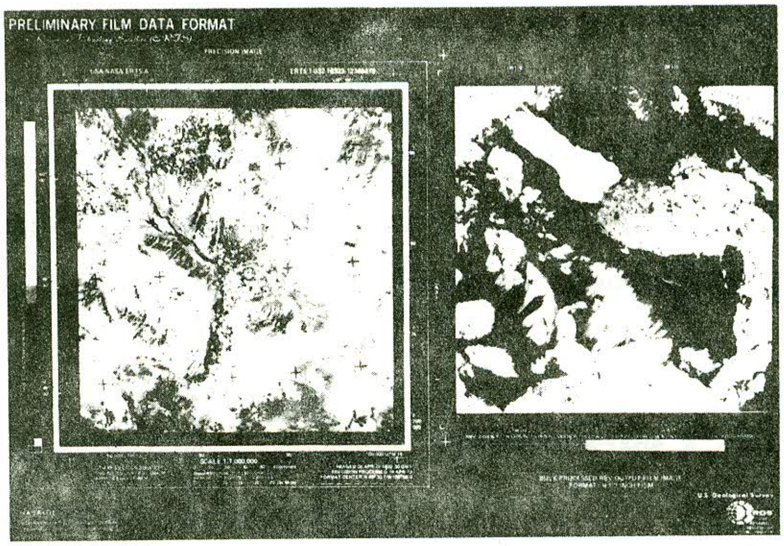


Figure 7.--Formats of ERTS imagery--precision-processed (left) and bulk (right).

You may have seen maps made from Apollo imagery at both 1:250,000 and 1:500,000 scales. However the resolution of ERTS imagery is expected to be somewhat poorer than that of Apollo. One should not expect to find much cultural detail on ERTS imagery, however major highways and other sizeable cleared areas will show up where there is background of good contrast. The following illustrations, derived from S065 imagery, indicate the uses and types of products we expect to develop from ERTS imagery.

Base Photomaps

Figure 8 shows a space photomap originally prepared at 1:250,000 scale and the equivalent line map. Content and currency of the base map are certainly improved by the addition of the space imagery. Of course the line map was not made from the space images, nor could it be. Similar results were obtained at 1:500,000 and 1:1,000,000 scales. The 1:250,000-scale space photomap is on public sale by the USGS.

Map Accuracy

When the space imagery was applied to the Phoenix, Ariz., 1:250,000-scale map, some discrepancies became obvious, as shown in figure 9. The position of the imagery was found to be correct, and the line detail on the map was adjusted accordingly. The space photographs were taken from an altitude of 236 km with a Hasselblad camera of 80-mm focal length. It is not a calibrated mapping camera and does not even have a film-flattening system, but because of the relatively narrow angle, the image

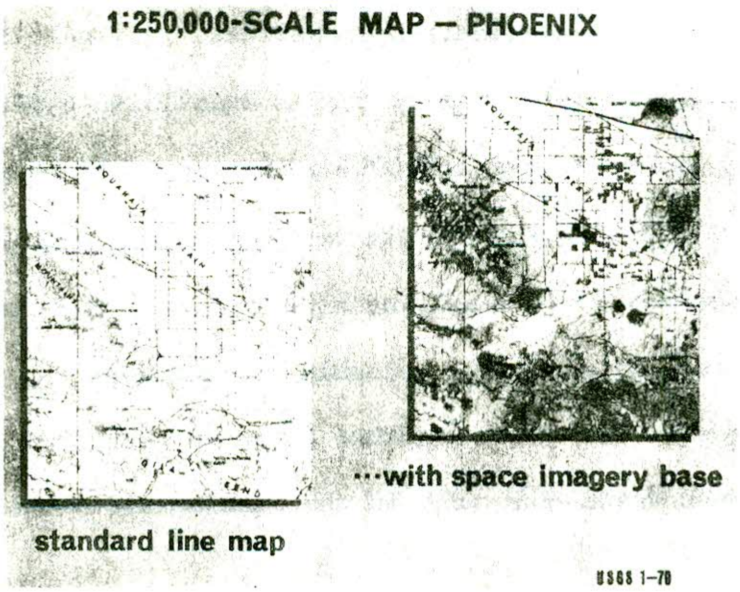


Figure 8.--Comparison of a topographic map with and without space imagery added.

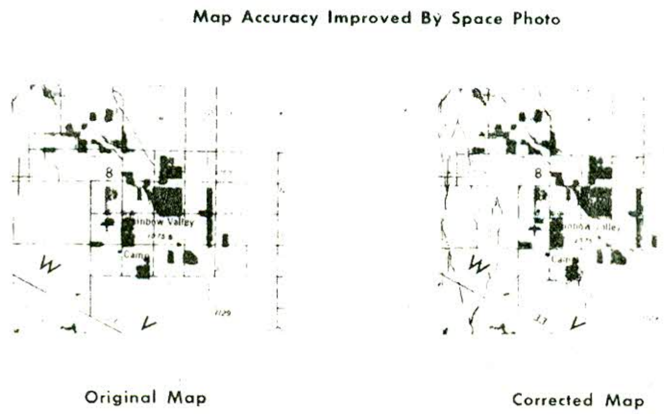


Figure 9.--Map detail (planimetry) was moved about 1 mm (0.04") on this 1:250,000-scale map (Phoenix) to conform with the detail on the space photo (Apollo 9). The photo was found to be correct.

produced has rather amazing planimetric properties. (If a 1:250,000-scale map can be corrected with imagery from a Hasselblad camera, then it is reasonable to assume that a 1:50,000-scale map could be corrected or horizontally controlled with space photographs from a good 12-inch mapping camera.) Because it is nearly orthophotographic and covers such a large area, ERTS imagery should be valuable for checking the accuracy of smaller scale maps or for tying together isolated groups of larger scale maps on a common datum--but only in the planimetric sense.

THEMATIC MAPPING

Traditionally, engineers and earth scientists have used topographic or planimetric maps which depict mostly fixed earth features. But there is a growing need for maps which portray time-variant phenomena such as snow, surface water, and crop coverage. Those who manage natural resources need such maps in a timely basis and accurate form so that the information can be applied to decision-making in a wide variety of disciplines. With space systems that transmit the pertinent information in near real time, we believe that the capability for meaningful thematic mapping exists. We define a thematic map as one which portrays a particular earth surface or condition (theme) in a definitive binary form. In other words the theme is differentiated from all other features and can be portrayed in black and white or, where several themes are involved, as a multicolor product. Following are some examples of the thematic map approach as applied to Apollo 9 (S065) space images.

Figure 10 portrays snow coverage classified roughly according to depth. This was done by the photographic process of density slicing, and ground inspection has indicated that this thematic map is basically correct.

Figure 11 portrays vegetation which has a strong response in the near infrared. This response produces a signature that can, in fact, be photographically separated from the rest of the scene. Thus we get a binary product which can, in turn, be handled with far greater ease than a continuous-tone print. More important, with repetitive coverage, we could produce the scene sequentially and show the changes that occur during critical time periods.

Figure 12 shows surface water extracted by density slicing--a most difficult theme to isolate. Water, being a reflective surface, has a widely varying spectral response, and thus its signature varies tremendously. However we do believe surface water can, within certain limits, be isolated, as indicated.

ENHANCED IMAGES

For a scene which has been specially processed but not fully isolated, we use the term enhanced image.

Figures 13 and 14 show a natural flood in the Mississippi VAlley as seen from Apollo 9. This image has been photographically enhanced to show the original channel as well as the extent of the flood. Hydrologists state this treatment is very important for flood monitoring and water routing.

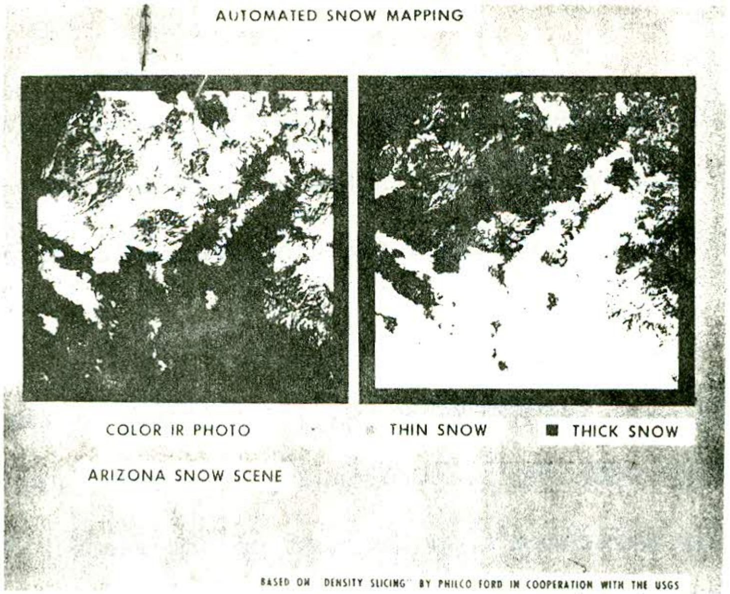


Figure 10.--An example of thematic mapping of snow cover. NASA space photograph.

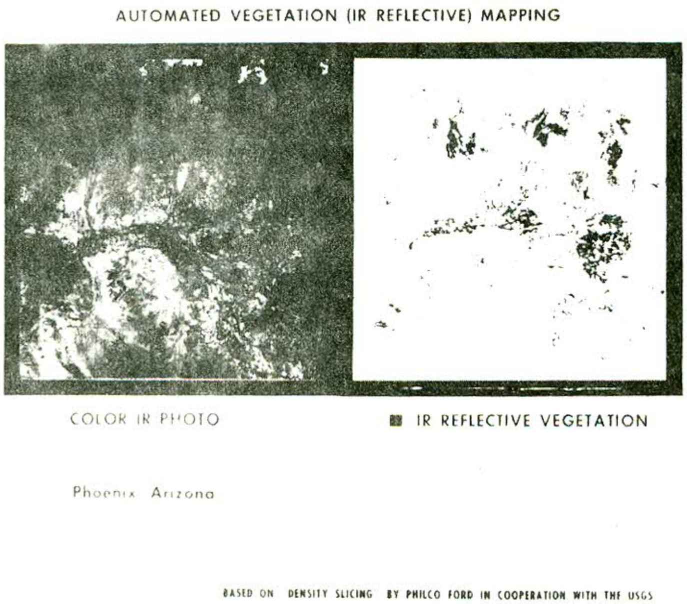


Figure 11.--An example of thematic mapping of IR reflective vegetation. NASA space photograph.

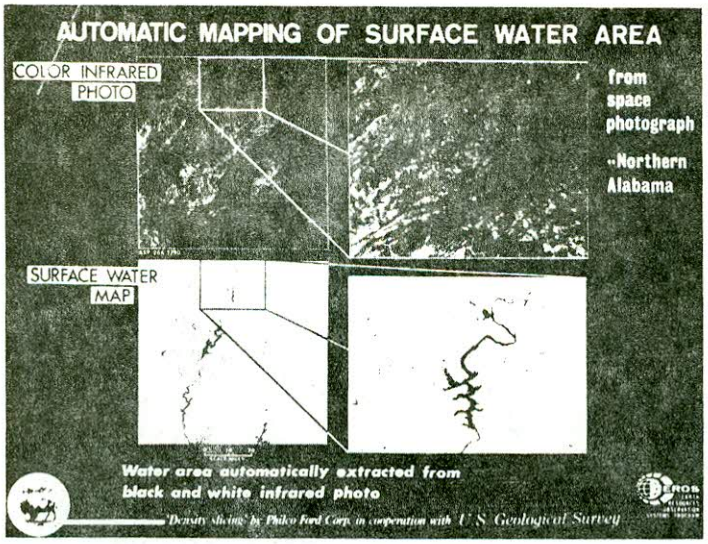


Figure 12.--An example of thematic mapping of water. NASA space photograph.

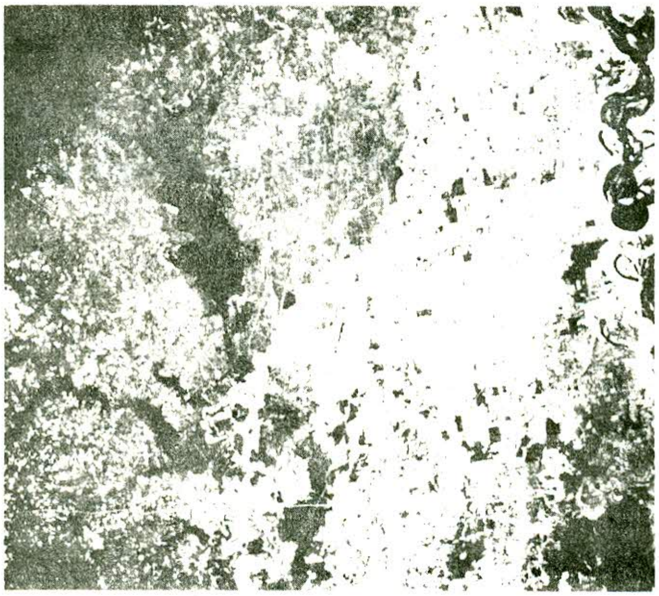


Figure 13.--A natural flood (large dark area) as seen from Apollo 9.

Figure 14.--An enhanced image of a portion of the natural flood shown on figure 13. The near IR band has been enhanced to show the channel as well as the flood plain.

Figure 15 depicts water tones of a river mouth, again from Apollo 9. Fisheries studies indicate correlation of such tones with the presence of shrimp. Water depth and sediments also are known to affect the tones.

Figure 16 is an unenhanced space photograph of the Dallas-Ft. Worth area in Texas. This scene has been studied for many purposes. We could make a "density slice" of the lighter tones, which would indicate areas of man's activities. Figure 17 shows areas that need revision on the standard 1:250,000-scale map, as determined from this photograph.

SUMMARY

The last two figures demonstrate the broad capabilities for remote sensing of the earth. Figure 18 was made from a color IR aerial photograph of part of Los Angeles taken with a mapping camera from about 9-km altitude. This scene shows the important synoptic aspect that cannot be attained at lower altitudes. Figure 19 shows the earth as seen from 170,000 km with a small camera. By comparing these two images and considering that several kinds of sensors can be carried between the altitudes at which they were exposed, we realize that the variations for remote sensing of the earth are almost unlimited. All such systems cost money, time, and effort, but man now does have the capability to survey the earth and its resources and the changes taking place. Intelligent application of remote sensing can help improve the environment of the earth. The cartographic engineer and the science of cartography are absolutely essential if this application is to be really effective.

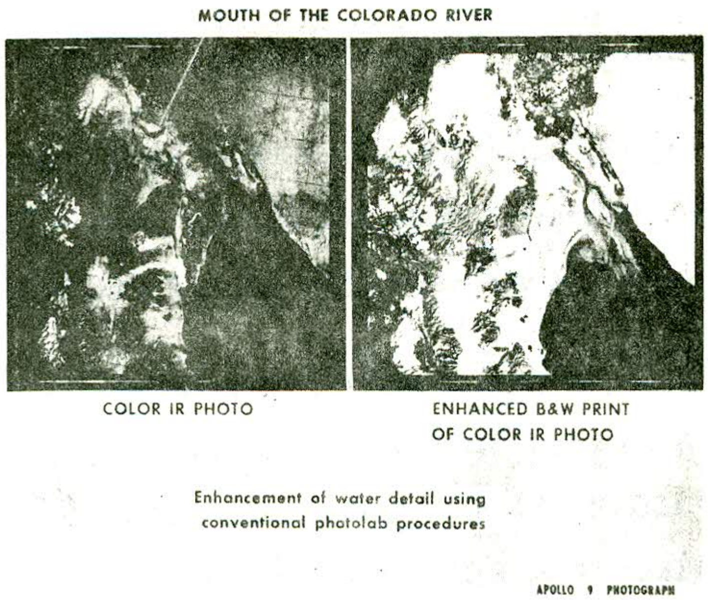


Figure 15.--Water tones enhanced by conventional photolab procedures. NASA space photograph.

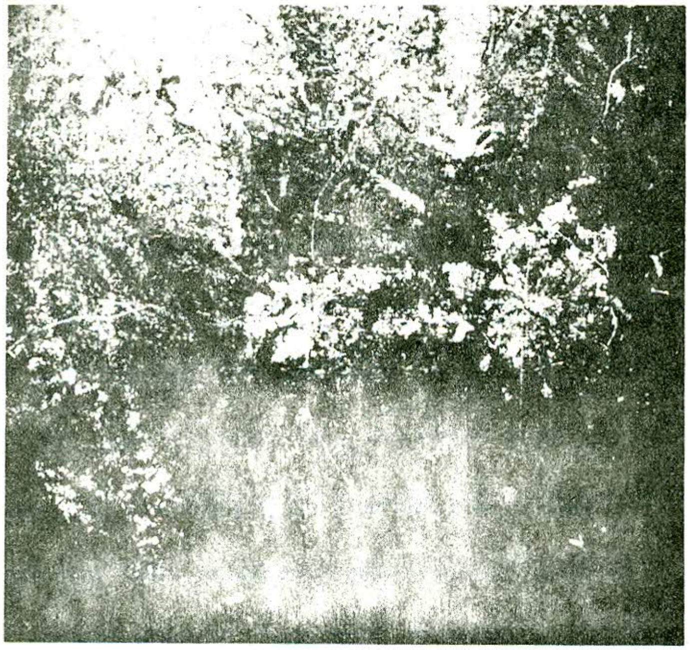


Figure 16.--An Apollo photo of the Dallas-Ft. Worth area. The extent of urbanization creates a unique signature (lighter tone).

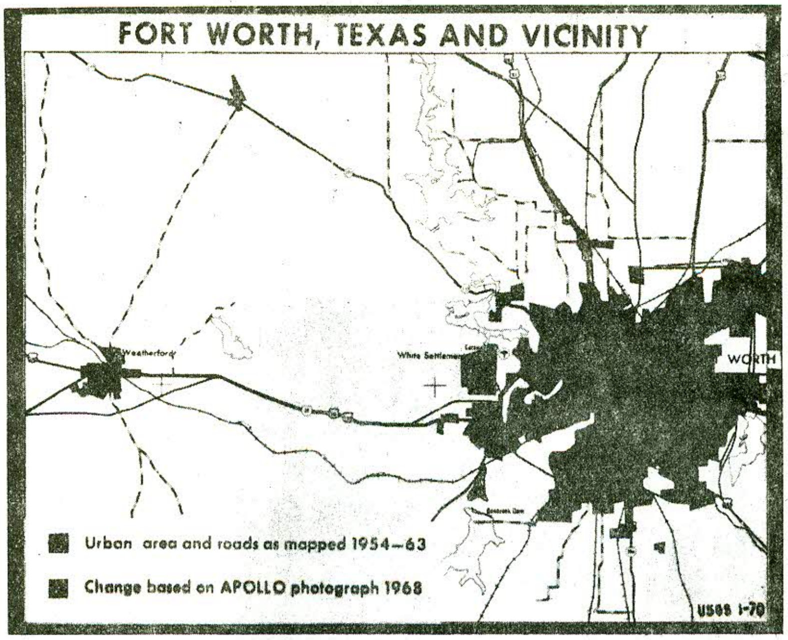


Figure 17.--Diagram of areas needing revision on a 1:250,000-scale map, as determined from Apollo photograph.

Figure 18.--Aerial photograph taken with a mapping camera at a flight height of 9 km.

Figure 19.--The earth as seen from 170,000 km with a hand held Hasselblad camera (240 mm f.l.).