

OVERALL EVALUATION OF ERTS-1 IMAGERY FOR CARTOGRAPHIC APPLICATION  
(SR 233)

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15. Supplementary Notes		14. Sponsoring Agency Code	
16. Abstract This experiment evaluated ERTS-1 with respect to: <ul style="list-style-type: none"> <li>● Image mapping</li> <li>● Map revision</li> <li>● Thematic mapping</li> <li>● Polar region mapping</li> <li>● Mapping by orbital data</li> <li>● Nautical and aeronautical charting.</li> </ul> <p style="text-align: right;"><b>PRICES SUBJECT TO CHANGE</b></p> <p>The conclusion reached is that an ERTS-type satellite has widespread cartographic application for scales of 1:250,000 and smaller. ERTS imagery also indicates those areas requiring revision at larger scales. For optimum cartographic application ERTS must be flown continuously as temporal change (seasonal and long term) detection requires comparative coverage. ERTS is the first imagery system that lends itself to automated mapping wherein cartographic products may be produced in a matter of days rather than in months or years. <u>Color of illustrations EDC-010027 to EDC-010035 are available for purchase from the EROS Data Center.</u></p>			
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Figure 2A. Technical Report Standard Title Page. This page provides the data elements required by DoD Form DD-1473, HEW Form OE-6000 (ERIC), and similar forms.

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## Illustrations

Note: Illustrations originally in color are identified in their caption by an EDC-0100\_ number. Copies of the original color are available for purchase from the EROS Data Center, Sioux Falls, South Dakota 57198, using the EDC number. Prices are available on request.

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# OVERALL EVALUATION OF ERTS-1 IMAGERY FOR CARTOGRAPHIC APPLICATION

## Summary

The object of this experiment was to determine the overall cartographic potential of ERTS. In order to achieve this objective the results of several specific cartographic experiments conducted by the USGS were analyzed as follows:

- Photomapping of the United States (SR 211)
- Map Revision (SR 237)
- Thematic Mapping (SR 116)
- Mapping of Polar Regions (SR 149)
- Mapping by Orbital Data (SR 150).

In addition the results of other related experiments, foreign as well as domestic, were analyzed. A listing of pertinent foreign documentation is carried in the appendix. Certain cartographic applications such as aeronautical and nautical charting, although not defined experiments, were also investigated in conjunction with concerned agencies as a part of the overall application.

The conclusions reached indicate that an ERTS-type satellite has widespread application to a variety of cartographic tasks--particularly those related to 1:250,000 and smaller-scale mapping. However, ERTS imagery also indicates areas of change which justify large-scale map revision, and this may be as important a cartographic application as the direct use of the imagery. By comparing ERTS images of the same area taken one or more years apart or in different seasons, far more cartographic information can be obtained than from the analysis of any single image. This application calls for the continuous operation of an ERTS-type satellite. ERTS is the first imaging system that lends itself to automated mapping, and this is probably the single most important cartographic characteristic of ERTS. As a result of these investigations it is recommended that ERTS-type satellites be flown continuously for at least a decade. The value of such a program to mankind as a whole in the form of cartographic and related products is believed to far outweigh the cost involved.

## CARTOGRAPHIC CHARACTERISTICS

When ERTS was first defined, mapping was not one of the primary applications anticipated. Cartographers as a group were highly skeptical of the Multispectral Scanner (MSS) as an imager and therefore looked to the Return Beam Vidicons (RBV's), which include 81 reseau marks per camera, as their only hope for suitable map source data. Since the RBV's were turned off shortly after launch because of a switching malfunction, cartographers had to make a choice--either use MSS imagery in their experiments or give up.\* They chose the first alternative and soon found that ERTS scanner imagery, when properly processed, has significant cartographic characteristics which warrant the following specific comments.

1. Coverage and long life. About a full year was needed to complete practically cloud-free coverage of the United States even though the MSS was turned on for nearly every pass. ERTS-1 has provided repetitive as well as complete coverage of the United States and thus far has doubled its life expectancy.

ERTS has been used only selectively in foreign areas because of the necessity to tape-record the data and play it back when in range of a ground station. With an adequate number of ground stations installed or more tape-recording capability, the system would cover virtually all the land and shallow-sea areas of the Earth as it has so far covered the United States.

Repetitive coverage provides some unexpected bonuses for the mapmaker. Seasonal mapping becomes a distinct possibility, and the differences in informational content as a function of season are significant. For example, winter snow-covered scenes (fig. 1) often define topography and cultural features such as roads and urban areas with a clarity well beyond that of summer imagery. Floods recorded by ERTS (fig. 2) are seasonal phenomena of importance to the cartographer since he should portray areas subject to inundation on general-purpose maps.

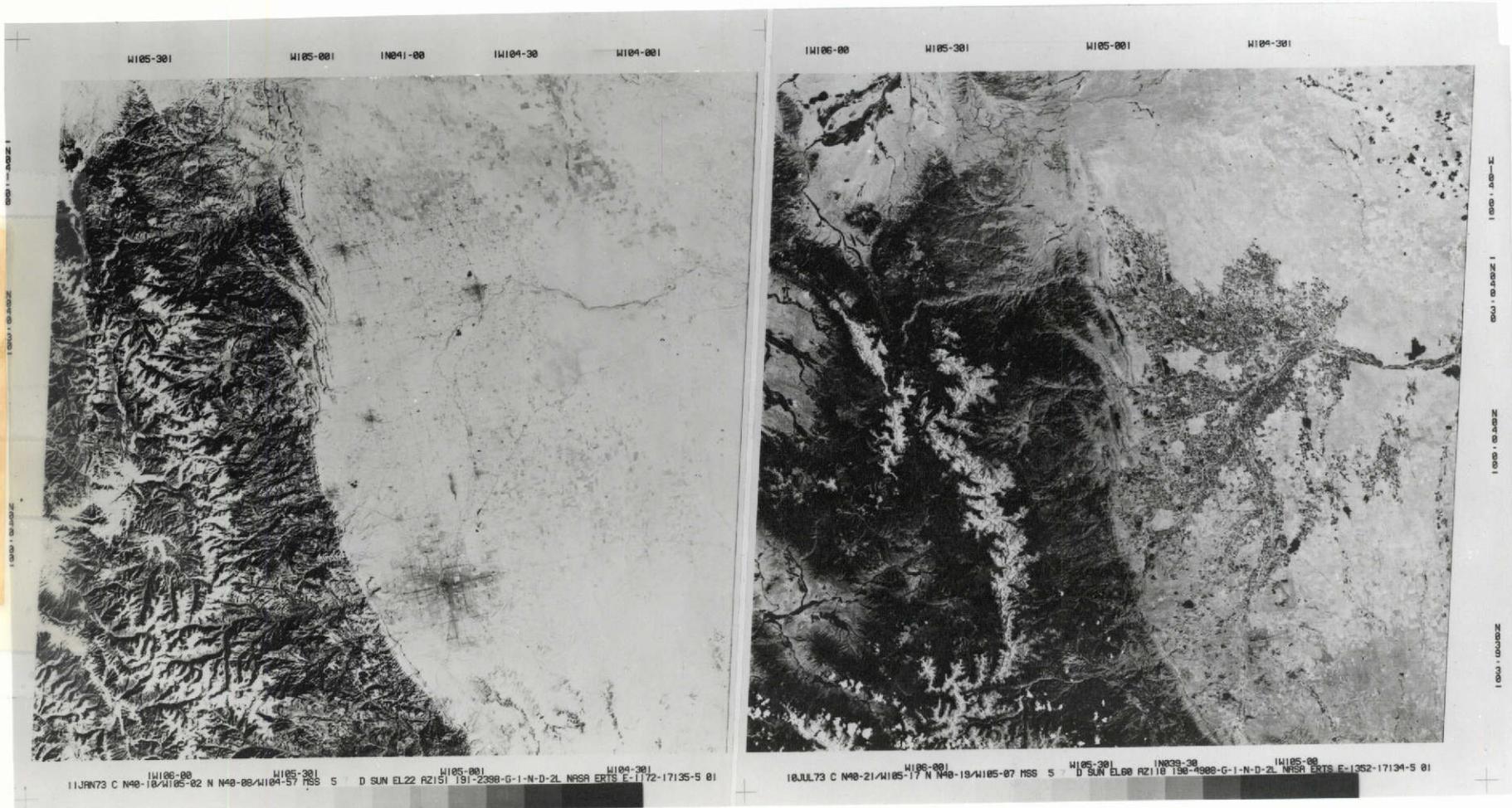
Figure 3 indicates how the 1974 flood in east-central Australia was recorded by ERTS. As a result the existing maps of the area will undoubtedly be revised and possibly recompiled to include the valuable cartographic information recorded by ERTS.

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\*Limited evaluation of RBV imagery indicates that it has geometric fidelity and spatial frequency (resolution) equivalent to MSS imagery. Radiometric response of the RBV is relatively poor but, as illustrated by figure 17, can be improved materially by appropriate processing.

# SEASONAL MAPPING WITH ERTS

## DENVER AREA



Jan. 73

- Road net
- Urbanization
- Enhanced topography

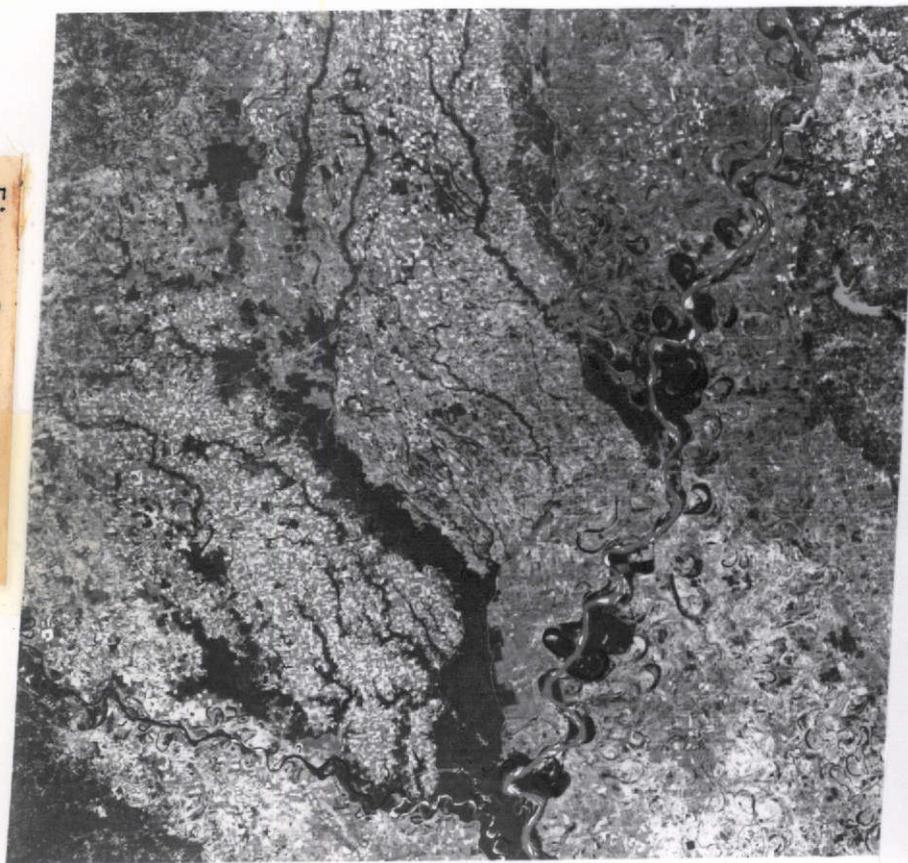
July 73

- Surface water
- Vegetation
- Land use

PHOTOGRAPH NOT REPRODUCIBLE



# MISSISSIPPI RIVER BELOW MEMPHIS AS IMAGED BY ERTS-1



2200172 C N34-42/489 00 N N34-48/489 57 MSS D SUN EL44 RZ 43 190 2989-N 111-N-D 11 NAPER ERTS EL 25 116 128 1 21

3 HARTO C N34-48/489 22 N N34-39/489 14 MSS D SUN EL44 RZ 131 190 3489-N 111-N-D 11 NAPER ERTS EL 25 116 128 1 21

**NORMAL LEVEL**  
Oct. 2, 1972

**DURING FLOOD**  
March 31, 1973

**PHOTOGRAPH NOT REPRODUCIBLE**



Figure 2. (EDC-010028)

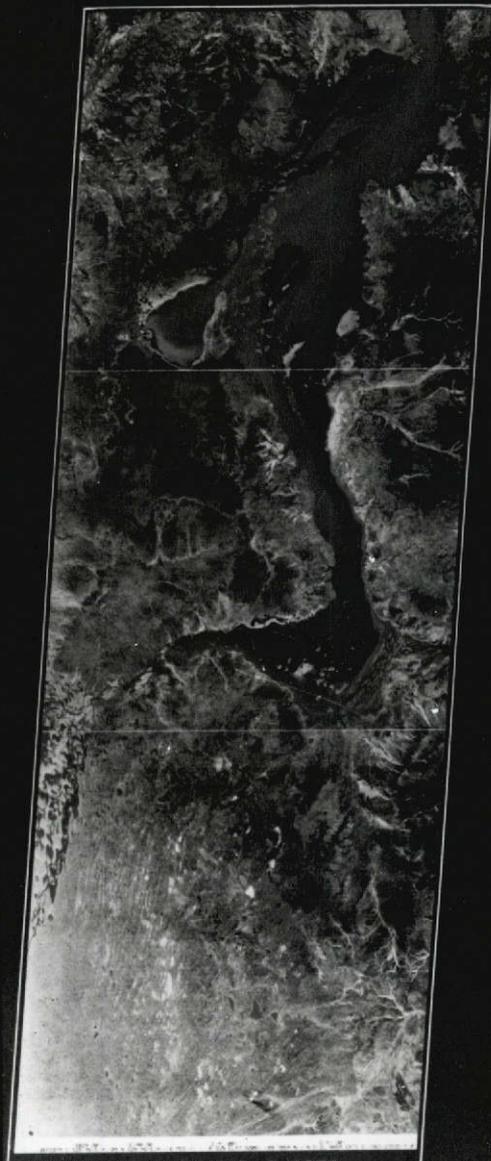
4

# ERTS MAPPING OF AUSTRALIAN FLOOD COOPER CREEK

0 10 20 30 40 50 MILES  
0 10 20 30 40 50 60 70 80 KILOMETRES



1:1,000,000 SCALE MAP



ERTS IMAGERY OF FEB. 6, 1974

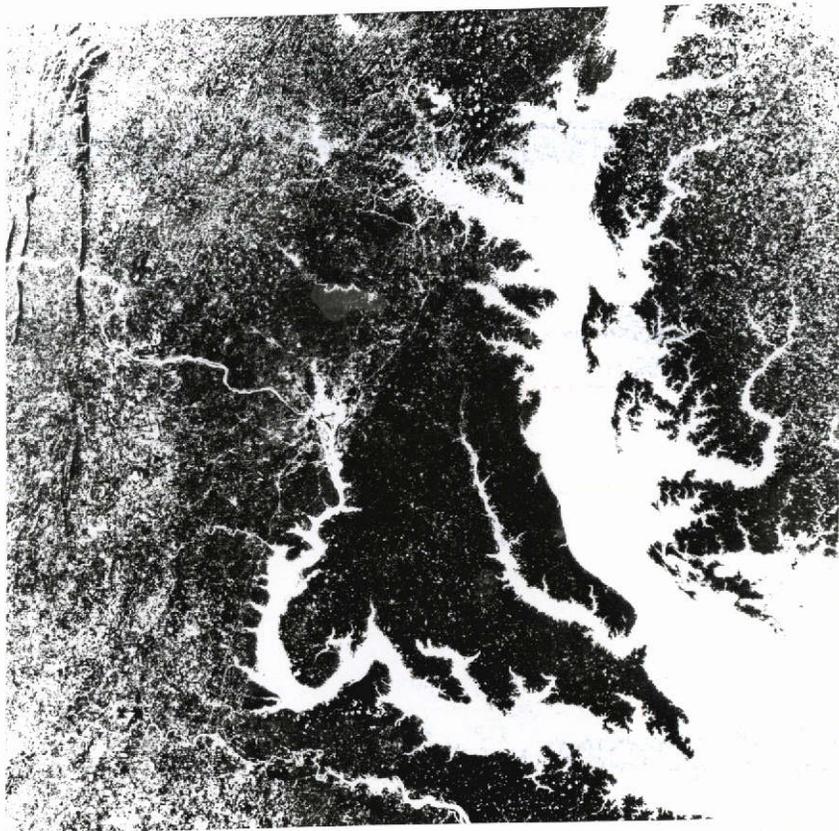
PHOTOGRAPH NOT REPRODUCIBLE

The areal extent of leafy (IR-reflective) vegetation is another feature that can be mapped seasonally with ERTS imagery. This information is important because it indicates droughts and other conditions associated with general plant-life vigor as well as the extent of agricultural crops. Figure 4 is a thematic extraction of the IR-reflective vegetation in the Upper Chesapeake Bay area as recorded by ERTS on Oct. 11, 1972.

2. Near real time. The advantage of electronic transmission in near real time is obvious even though the capability for realizing the advantage has not been fully developed. For example, a cartographic product was produced within 2 weeks after image acquisition by ERTS (fig. 5), and there is no reason why the production time cannot be reduced to a few days once the automated processing aspects of ERTS are developed.

3. Orthogonality. The field of view of the ERTS MSS extends only  $5.78^\circ$  from the nominal vertical. This near orthogonality of the imagery precludes compilation of topographic (contour) maps but simplifies small-scale planimetric mapping and revision. Since topography changes little, maintaining up-to-date planimetry is the major mapping problem once an area has been topographically mapped. A map consisting of little more than a multispectral image precisely referenced to the figure of the Earth is probably the most economical method of portraying the face of the land. ERTS imagery is ideal for small-scale image mapping for two reasons. First, external anomalies such as relief displacement are so small that the image can be used directly (except in isolated areas of extreme relief) without undergoing the complex transformation provided by an analytical plotter or an orthophotoprinter. Second, the narrow field of view means that the entire scene is being imaged from a nearly constant vertical aspect and thus provides uniform spectral response from similar objects throughout the scene.

4. Geometric fidelity. It is hard for a photogrammetrist to accept the proposition that an optical-mechanical scanner can generate imagery that has the geometric fidelity of a frame camera. However the MSS is indeed generating data that, as corrected by NASA, are printed out in a form containing relative spatial errors on the order of 50 to 100 m (rms). This indicates a system of high internal geometric fidelity since the scanner spot size (instantaneous field of view) is 79 m. The 50-m (rms) error equals about  $15 \mu\text{m}$  at the original MSS imagery scale of 1:3,369,000, which approaches the expected accuracy of a calibrated mapping camera. Although the internal geometric accuracy of the MSS may not be quite up to that of a good mapping camera, the



PHOTOGRAPH NOT REPRODUCIBLE

Figure 4.--IR-reflective vegetation theme (Upper Chesapeake Bay).

Figure 5. --Lake Tahoe area orthophoto image (EDC-010030).

accuracy it does have, coupled with the external advantage of the near-orthographic continuous view, results in two-dimensional (planimetric) mapping of geometric precision which may well exceed that obtainable from comparable camera systems and conditions. Table 1 summarizes the positional accuracy of ERTS image products based on various modes and forms.

5. Multispectral radiometric fidelity. The ERTS MSS signals are in effect those of a focusing radiometer recording radiated energy with a range and precision well beyond the capability of any current film system. Since ERTS records four wavebands, the images can be combined to provide a response optimized for particular scenes or sizable objects. Film cameras can record up to three bands on one film (color or color IR), but altering the combination for a particular scene or object is complex and imprecise. The separate-band characteristic of ERTS is particularly important for mapping objects or areas that have unique spectral responses or that are imaged under unusual conditions of illumination. The charting of underwater features, delineation of floods, and depiction of polar conditions are examples that require this high degree of radiometric fidelity and multispectral versatility.

Although the wavebands selected for ERTS-1 have proved to be very effective, there is no reason to believe that they are necessarily optimum for general purposes. There is evidence that minor changes in the bands which would add both shorter and longer wavelengths would improve the general utility of ERTS.

6. Extension into the near-IR wavelengths. Available aerial films can record up to a wavelength between 0.8 and 0.9  $\mu\text{m}$ , which is about the same limit for band 6 of the MSS. MSS band 7, at 0.8 to 1.1  $\mu\text{m}$ , has opened a window for remote sensing that operational film systems do not yet have. The near-IR band is enormously powerful and has demonstrated the following unique capabilities:

- a. Effective penetration of thin clouds and contrails under certain conditions (fig. 6).
- b. Definition of the land/water interface with high precision, enabling detection and identification of circular water bodies as small as 200 m in diameter and linear water bodies of only 20- to 50-m width. Under suitable conditions, where gently sloping areas of known elevation exist, water level can be determined to a small fraction of a metre. This capability is particularly remarkable when one remembers that the instantaneous field of view of the MSS is 79 m.

PHOTOGRAPH NOT REPRODUCIBLE

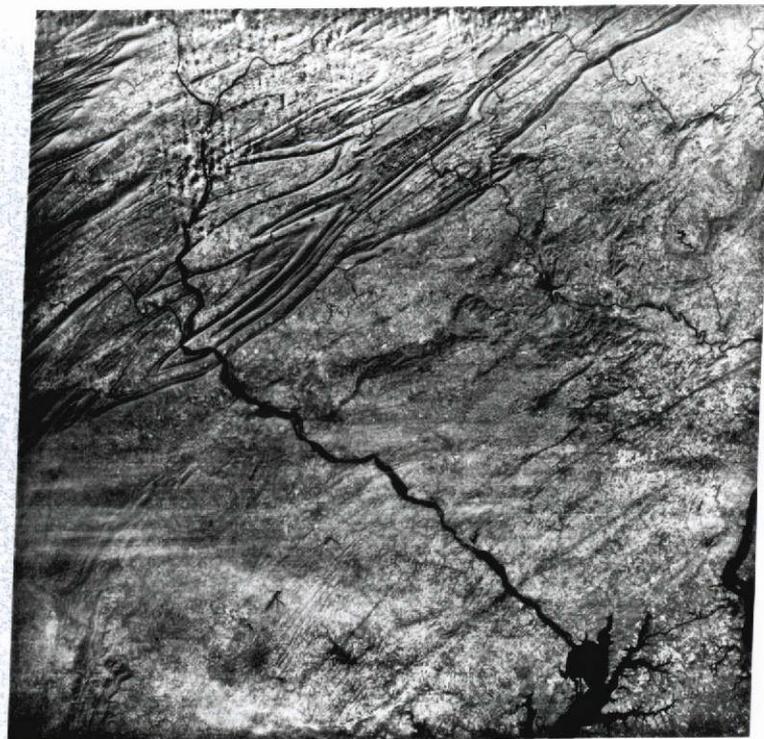
Figure 6.

### THIN CLOUD PENETRATION CAPABILITY OF ERTS IR SENSOR



14877-38 14877-221 14875-381 14875-001  
 16NOV72 C N48-15-4876-26 N N48-14-4876-21 MSS 5 D SUN EL27 RZ155 1B1 1E16-N-1-N-D-2L N48-15-15192-E 2

Visible spectrum  
 MSS Band 5 (0.6 - 0.7  $\mu\text{m}$ )



14877-38 14877-221 14875-381 14875-001  
 16NOV72 C N48-15-4876-26 N N48-14-4876-21 MSS 7 D SUN EL27 RZ155 1B1 1E16-N-1-N-D-2L N48-15-15192-E 2

14877-38 14877-221 14875-381 14875-001  
 16NOV72 C N48-15-4876-26 N N48-14-4876-21 MSS 7 D SUN EL27 RZ155 1B1 1E16-N-1-N-D-2L N48-15-15192-E 2

Near Infrared  
 MSS Band 7 (0.8 - 1.1  $\mu\text{m}$ )

SE Pennsylvania November 16, 1972.



Table 1.--Summary of ERTS MSS positional accuracy.

<u>Mode and Form</u>	<u>Error Range (rms)</u>
Raw--referenced to lat/long indicators	1 - 8 km
Bulk--referenced to ground control	
• Best fit to UTM projection	150 - 350 m
• UTM grid fitted to single-band image	50 - 100 m
• UTM grid fitted to single-band mosaic of 2 to 4 images	100 - 150 m
• UTM grid fitted to multiband (colored) single image (lithographed)	150 m*
• UTM grid fitted to multiband (colored) mosaic of 2 to 4 images (lithographed)	240 m*
Precision processed to UTM projection	125 - 150 m

\*based on the few products  
so far produced

- c. Superior definition of vegetation patterns, largely due to the differential sensitivity of band 7 to vegetation types.
- d. Superior definition of natural features. Many geologists (and others) are selecting MSS band 7 as the best single band for depicting the Earth's physiography.
- e. In some cases cultural features are best defined in band 7--for example, major road patterns in western U.S. cities so far recorded by ERTS. As previously indicated under item 5, the capabilities of MSS band 7 may be improved by extending this band further into the infrared wavelengths.

7. Suitability for automation. Frame cameras and vidicon imagers record discrete scenes on a plane. Each photograph or image plane (projection) has its own geometric characteristics, and unless extensive analytical adjustments are made, consecutive photographs will not form a continuous map. A scanner such as the MSS can produce a basically continuous image on a mathematically definable map projection of negligible distortion. Thus a means is established for relating image positions to the figure of the Earth continuously subject only to the limitations of the corrections. This characteristic provides the potential for developing an automated image-mapping system by either analog or digital techniques with only minimal requirements for ground control and processing. Table 2 indicates the steps required to automate ERTS mapping and the current status of each step.

The automation prospect is further enhanced by the fact that ERTS repeats its coverage with considerable precision. The same nominal Earth scene is covered every 18 days (subject to visibility) as long as ERTS is operating properly. Thus the basis for a worldwide "map series" defined by the nominal ERTS scene is established. The age-old mapping problem of fitting together source materials of different forms and epochs is eliminated as far as the individual scene map is concerned. Figure 7 illustrates the ERTS nominal scene mapping system as applied to Florida.

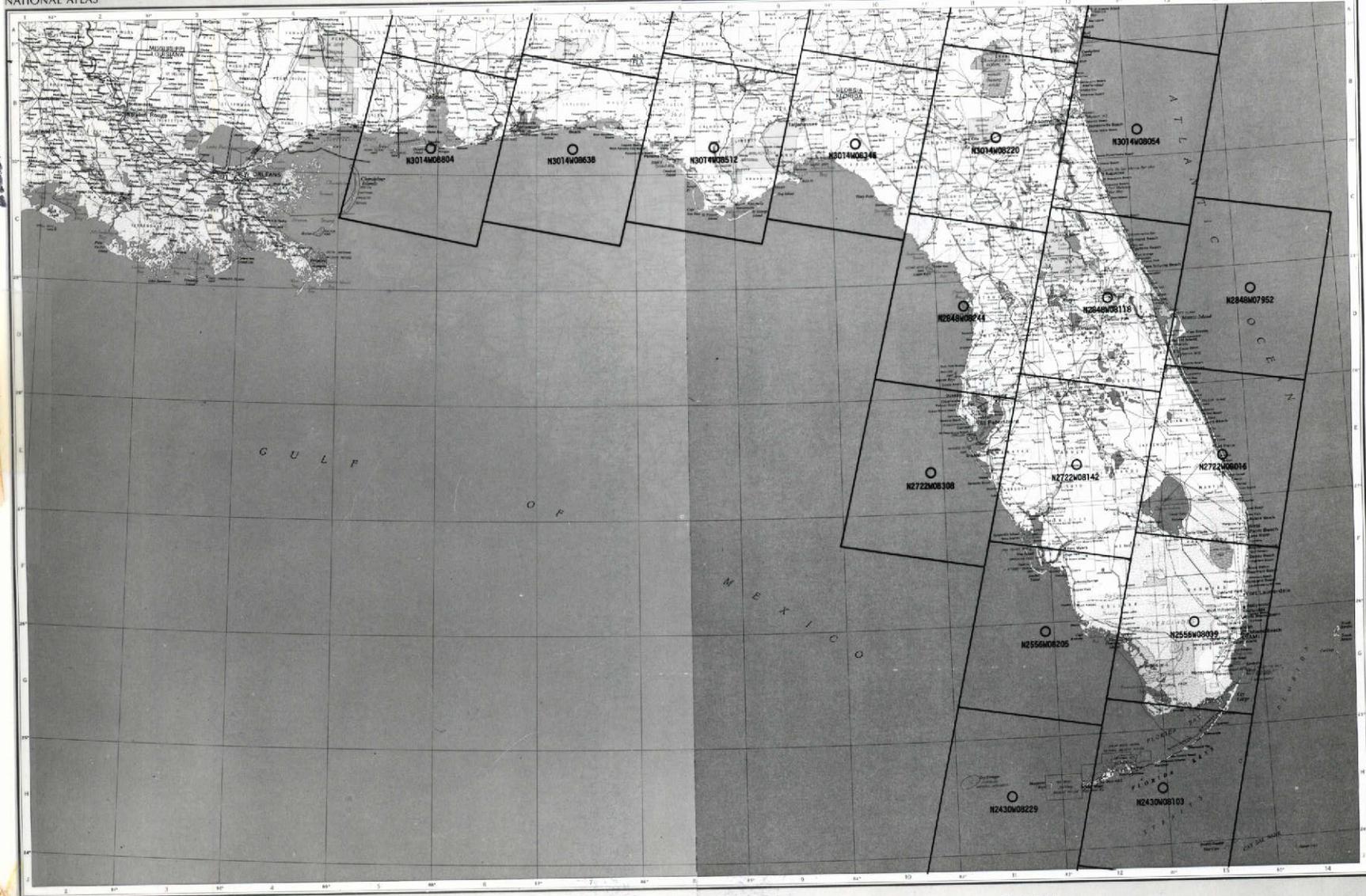
## RESULTS

Investigators in the United States and abroad have conducted a variety of cartographic experiments. These fall into the general categories of photomapping, map revision, and basic thematic mapping. Results from these experiments are only now being realized; the most significant are:

# NOMINAL ERTS SCENES — FLORIDA

NATIONAL ATLAS

FLORIDA



PHOTOGRAPH NOT REPRODUCIBLE

Figure 7.

Miller Equal Area Projection  
SCALE 1:2,000,000

Table 2.--Steps required to automate ERTS mapping.

<u>Step</u>	<u>Status</u>
• Continuous scanner coverage from orbit	Now provided on command
• Near real-time reception of digital data	Now provided within range of reception station
• System corrections to SOM* projection	Defined--to be implemented for ERTS-B
• Automated correlation of image to control	Under contract--within the state of the art
• Generation and printing of imagery and tapes referenced to Earth figure	Defined and within the state of the art--responsibility not determined
• Distribution in cartographic form	Capabilities developed within USGS--can be accomplished in a matter of days following image acquisition

\*Space Oblique Mercator

1. Prototype image maps of North and South America have been produced at scales ranging from 1:250,000 to 1:1,000,000 and in a wide variety of formats and modes. Within the United States these include quadrangles at 1:250,000, 1:500,000, and 1:1,000,000 scales and State image maps at 1:500,000 and 1:1,000,000 scales, all monochromatic. These image maps all bear the Universal Transverse Mercator (UTM) grid for geodetic reference purposes. Figure 8 compares ERTS imagery to aircraft imagery and a line map at 1:250,000 scale. Canada, South Africa, Brazil, and Bolivia have already produced ERTS image maps in color, and several other countries are working on similar products.

Selected image-format and State base maps in color at 1:500,000 scale have been duplicated and placed on public sale. The first 1:500,000-scale image-format map, Upper Chesapeake Bay (fig. 9), meets U.S. National Map Accuracy Standards (NMAS) as determined from the UTM grid and is printed in false (infrared) colors. The State base map of New Jersey (fig. 10) is significant in that it is the first colored mosaic in map form that maintains uniformly high image quality. The mosaic was laid in film rather than paper-print form, which is a departure from conventional practice made possible by the high geometric fidelity of ERTS. The scale, format, and mode of the Upper Chesapeake Bay image map are considered optimum as the prototype for a potential national or worldwide series of maps based on the ERTS image format.

Prototype image maps of Antarctica have also been produced. ERTS is in many ways ideally suited for mapping the polar regions with the exception of the 8.2°-radius circle surrounding each pole. A description of the mapping accomplished and planned for the polar regions is covered in a separate report by William R. MacDonald (SR 149). Figure 11 illustrates the utility of ERTS for Antarctic mapping.

2. Selective experimental revision of smaller scale line maps and the delineation of areas that will require revision from other source material are being accomplished with ERTS imagery. For the conterminous United States, source material suitable for map revision is generally available and thus ERTS imagery is of limited value in this use. However, ERTS imagery was used as one source in the revision of the Virginia State base map and also indicated changes to be made to the Arizona State base map (both 1:500,000 scale). For Alaska the imagery is considered suitable for revising part of the 1:250,000-scale map series, but this application has not been effected to date. Another

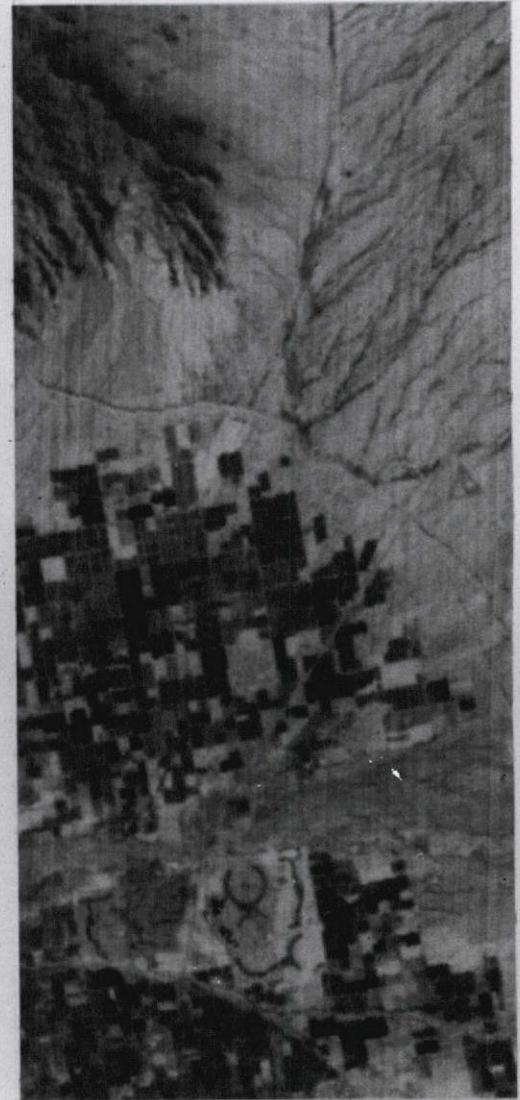
# 1:250,000 SCALE MAPPING



**Aircraft (U-2)  
Photomap 1970**



**Standard  
Line Map 1969**



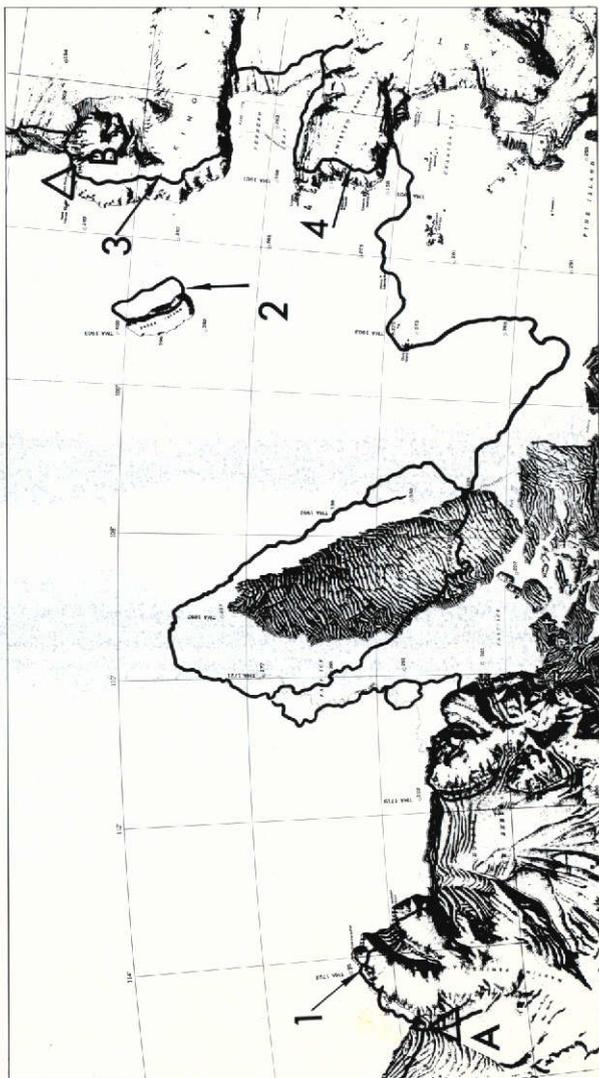
**Space (ERTS)  
Image Map 1972**

PHOTOGRAPH NOT REPRODUCIBLE



Figure 9. --Upper Chesapeake Bay image map (EDC-010031).

Figure 10.--New Jersey image mosaic (EDC-010032).



PHOTOGRAPH NOT REPRODUCIBLE

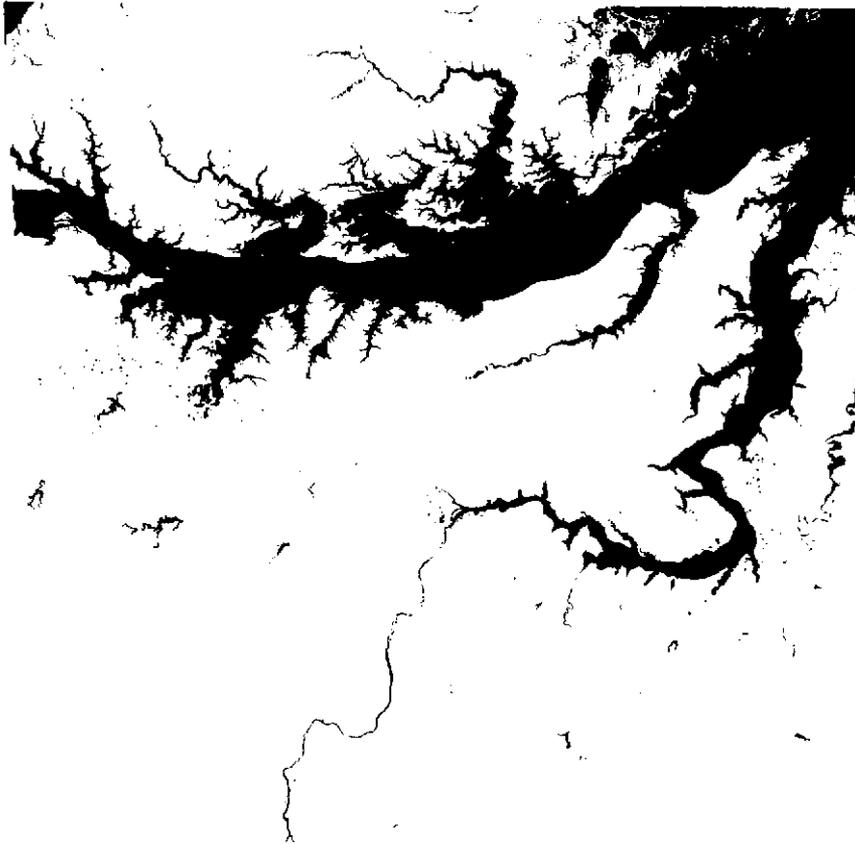
Figure 11.--Thwaites Iceberg Tongue (Antarctica).

promising application of ERTS relative to map revision within the United States is to indicate those areas where map revision is needed--large-scale as well as small-scale maps--even though other source material would be required for the actual revision. This application requires successive ERTS images acquired a year or more apart. On successive images, change in land cover extending over 4 or more hectares (10 or more acres) can generally be delineated, showing a change in land use that in most cases warrants some form of map revision. In Canada, ERTS is being applied to the revision of the 1:250,000-scale series and is also being used to indicate those areas where large-scale maps need revision. Brazil, Bolivia, Venezuela, and other countries in South America are revising small- and intermediate-scale maps using ERTS imagery. Figure 12 illustrates the potential of ERTS for map revision at 1:1,000,000 scale.

3. Basic thematic mapping was demonstrated with ERTS imagery. The multispectral aspects make ERTS ideally suited for thematic extraction. Infrared-reflective vegetation and open water are two examples of themes which can be readily isolated by either photographic or digital processing. Figures 4 and 13 illustrate such theme isolation. Although the technology to produce such graphics by automated methods exists, it has not yet been applied as a standard procedure.

4. The aeronautical and nautical charting potential of ERTS has been investigated. Both Apollo and ERTS have been used to demonstrate the advantages of small-scale imagery used as a base for aeronautical charts. Pilots who have evaluated the experimental space image bases indicate that they offer some advantage over existing line-map bases. Figure 14 illustrates an application of Apollo imagery to aeronautical charting, which applies similarly to ERTS imagery. The potential of ERTS imagery for nautical charting has not yet been determined. MSS band 4 indicates underwater features as deep as 10 m. By using both bands 4 and 5, actual depths down to about 5 m can be determined with reasonable accuracy under suitable conditions. ERTS also has the potential for positioning isolated reefs and islets within a kilometre of true position, but this is only now being fully investigated. Considering the inadequacy of nautical charts in many areas of the world and the fact that coastal areas are constantly changing, there is evidence that ERTS has practical application to nautical charting (fig. 15). Foreign as well as domestic charting agencies are currently exploring this use.

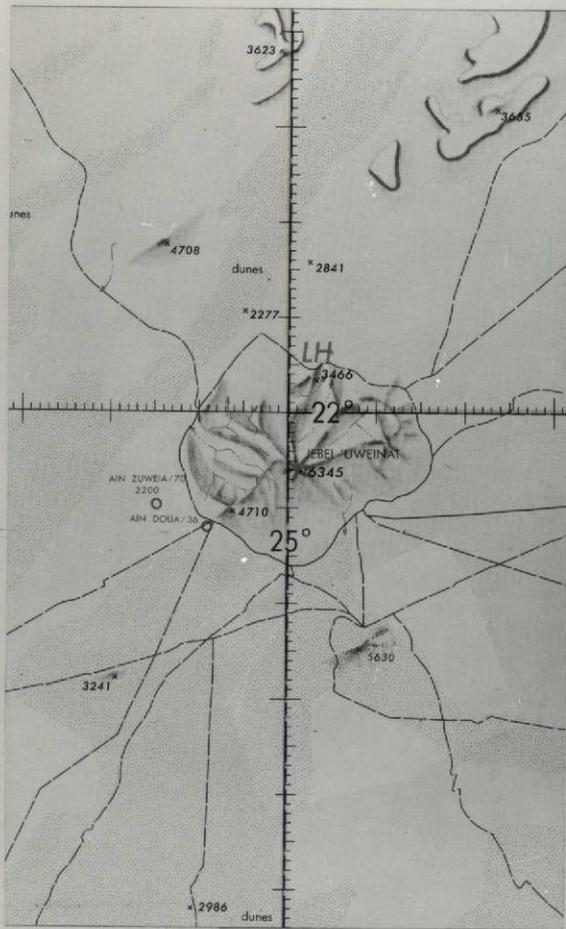




PHOTOGRAPH NOT REPRODUCIBLE

Figure 13.--Open-water theme (Upper Chesapeake Bay).

# Space Imagery Applied to Aeronautical Charting



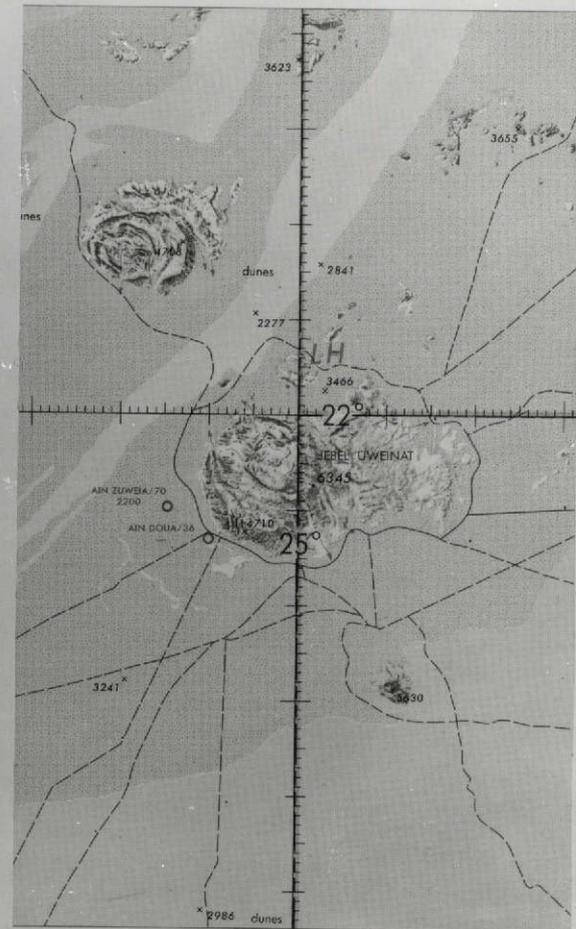
ONC J-5

(Standard Publication)

Edition 2



(NASA Photograph)



ONC J-5

(Using NASA photography)

Taken from paper by Gordon Stine of DEFENSE AEROSPACE CENTER



PHOTOGRAPH NOT REPRODUCIBLE

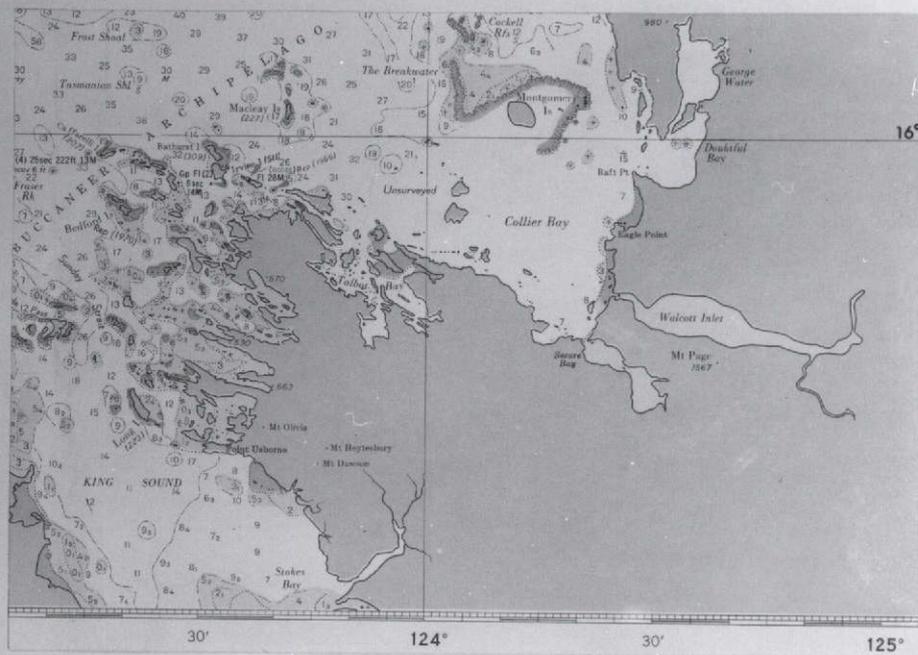
Figure 14. (EDC-010034)

# COMPARISON OF NAUTICAL CHART AND ERTS IMAGE

## COLLIER BAY, AUSTRALIA



ERTS IMAGE



NAUTICAL CHART  
(MERCATOR PROJECTION)



Figure 15. (EDC-010035)

5. Geometric analyses of RBV and MSS imagery have been performed. A sizable number of MSS and RBV images and image-derived products have been precisely analyzed through the measurement of photo-identified control points or the reseaus on the RBV's. The results of this work are summarized in table 1. Methodology for measurement and analysis of ERTS image products has been developed and is in various stages of documentation.

6. Modifications to MSS image processing have been made which improve the cartographic aspects of ERTS imagery. Based on both geometric and photometric analyses of ERTS imagery, several changes have been implemented by either NASA or USGS, and some of the more important are:

a. Removal by NASA of the MSS line scan anomaly which resulted from insufficient sampling and changes in the Earth-rotation effect.

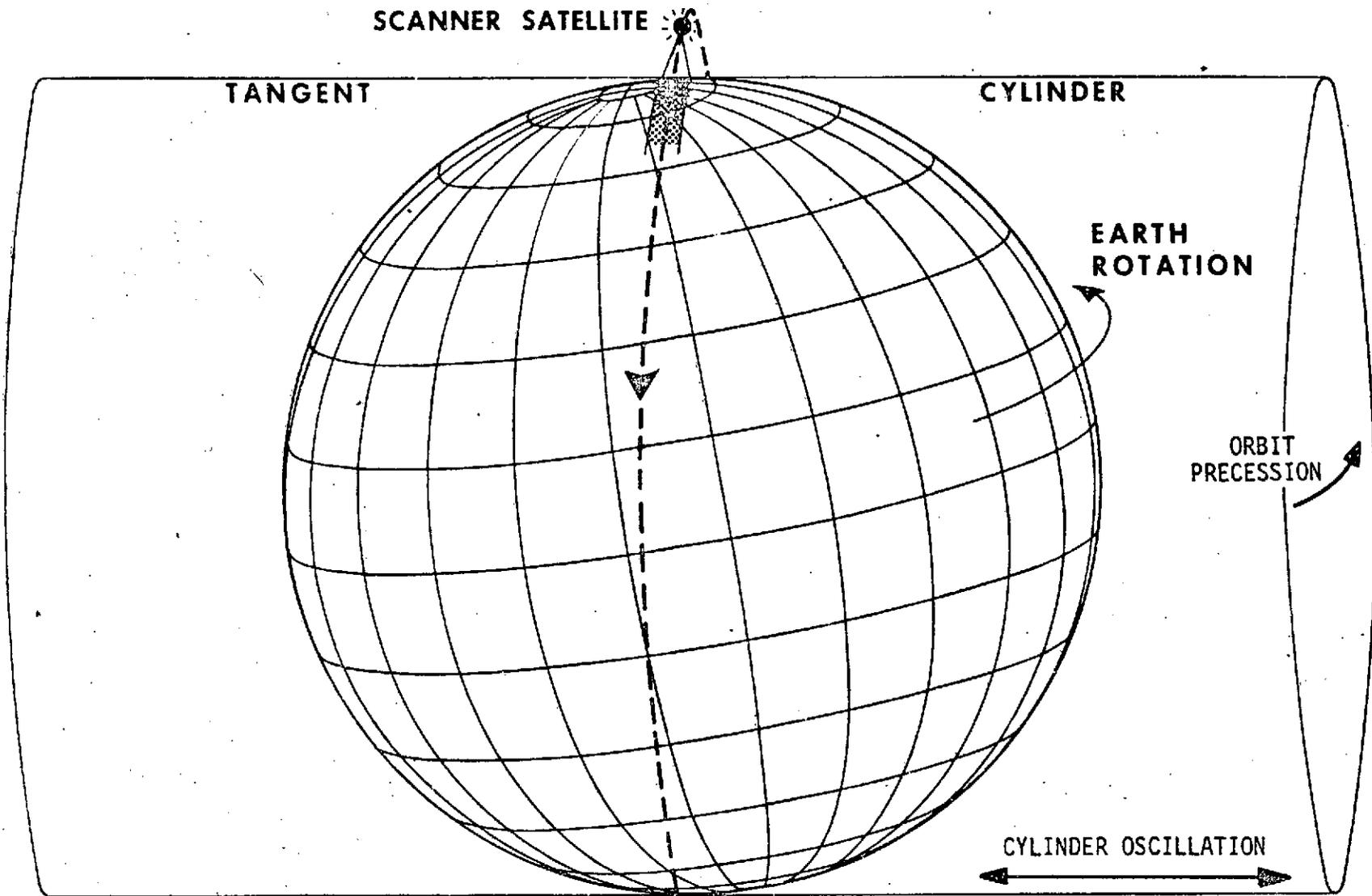
b. Removal of the along-track scale variation which alters the uniformity of MSS imagery. (To be implemented for ERTS-B).

c. Changes in image processing relative to density range and contrast. Although recommended changes have not been implemented by NASA, they have been applied by the USGS in the preparation of cartographic products.

d. Changes in color composite preparation. Tests indicate that, based on current NASA processing, color composites using bands 5 and 7 are superior for general purposes to those using bands 4, 5, and 7. The two-band approach simplifies cartographic processing and has been implemented by the USGS. However any change in basic processing of the bands may call for further change in the preparation of color composites.

A comprehensive set of specifications including recommended changes has been prepared for an operational ERTS satellite, based on cartographic requirements. It is intended that many of these changes will be implemented for ERTS-B and/or ERTS-C.

7. A map projection and precision processing have been defined which will permit the cartographic processing of ERTS imagery to be automated. The investigation of MSS imagery indicates that it can be recorded in system-corrected (bulk) form on a defined, cylindrical map projection (fig. 16). Several variations of cylindrical projections were considered and the conformal Space



### SPACE OBLIQUE MERCATOR PROJECTION

Images the Earth from N 82° to S 82° every 18 days

#### MOTIONS INVOLVED

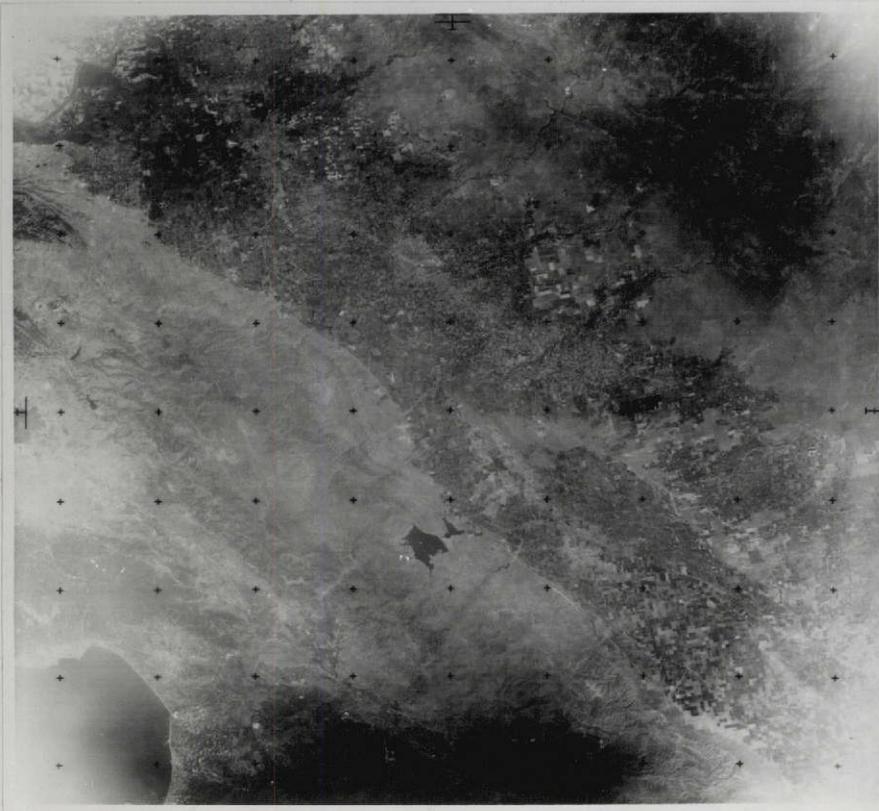
- Scanner sweep
- Earth rotation
- Satellite orbit
- Orbit precession

Figure 16.

Oblique Mercator (SOM) selected as the most suitable. The SOM projection is described fully in referenced reports; its most important characteristics are that it is uniform and continuous and that it develops only about 1:10,000-scale distortion. Defined processing procedures based on this projection provide for the automated production of cartographic products. These procedures could replace the scene-corrected (precision-processed) system of ERTS-1 and result in products available in a matter of days where justified.

In summary, from the mapping viewpoint, ERTS has exceeded expectations. It gives mapmakers a new source from which image maps of small scale can be produced efficiently and accurately. Moreover ERTS points the way towards a revolutionary concept--automated mapping of the Earth.

**ERTS RBV IMAGE (Band 2)**



as distributed by NASA



as radiometrically corrected (digitally) by IBM

MONTEREY BAY, CALIFORNIA



**PHOTOGRAPH NOT REPRODUCIBLE**

Figure 17.

## Appendix, including Bibliography

I. Papers derived from this and associated ERTS cartographic experiments conducted by USGS, not including periodic reports which have been submitted previously to NASA.

### A. EROS-Cartography (EC) in-house memos relative to ERTS

EC no.

1. RBV geometric distortion on ERTS-1
2. Preparation of a precision (map-corrected) ERTS image for comparison of U.S. and Canadian systems
3. Suggested realignment of ERTS imagery
4. Comments on NASA scene-corrected (precision-processed) products
5. Suggested RBV reseau pattern
6. Suggestion for ERTS-B
7. New standards for ERTS second-generation negatives
8. Return Beam Vidicon modulation transfer
9. RBV geometry
10. Parametric test of special-processed ERTS-1 70-mm negatives
11. MSS scan-line anomaly
12. Application of ERTS imagery to delineation of controlled water bodies
13. Potential capability of ERTS for delineating water boundaries at various stages in areas subject to inundation (analog approach)
14. Thin-cloud penetration capability of ERTS MSS band 7
15. Advantages of ERTS (TV) system over film return systems
16. Scene-corrected (precision-processed) ERTS images
17. Status of positional referencing of ERTS imagery
18. Map projection of the bulk (system-corrected) ERTS MSS image

19. Status of the ERTS image format as the basis for a map series
  20. Progress of ERTS-1 nominal scene
  21. Geometric accuracy of IBM precision image processing
  22. Stereo capability of a convergent RBV system on ERTS
- B. Documents presented, published, or in preparation as a result of this and associated experiments.
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