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The Cartographic Application of ERTS/RBV
Imagery in Polar Regions

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Type I Progress Report
ERTS-A

- a. Title: The Cartographic Application of ERTS/RBV Imagery in Polar Regions

ERTS-A Proposal No. 149

- b. GSFC ID No. of P.I.: IN 391

- c. Statement and explanation of any problems that are impeding the progress of investigation:

To date, only widely scattered cloud-free imagery over both polar regions has been obtained. This prevents the compilation of the majority of mosaics and cartographic products planned for each of the experiments.

- d. Discussion of the accomplishments during the reporting period and those planned for the next reporting period:

A polar stereographic projection at 1:10,000,000-scale (60° lat. to the Pole) was prepared for the polar regions for indexing the ERTS-1 imagery. Two composite indices were prepared depicting the total imagery obtained through 1 January 1973 for the Arctic region and through 19 January 1973 for the Antarctic region. The composite indices do not reflect the percentage of cloud cover; however, the Special Mapping Center, USGS, is preparing a separate index for each of the polar regions to reflect imagery that contains cloud cover percentage of: 0-10, 11-20, 21-30, 31-40 and 41-50.

The composite indices indicate about 90% of both polar regions (60° lat. to 82° lat.) is covered by ERTS-1, MSS imagery. However, only 5 to 10% of this imagery has been received from NASA. This perhaps can be attributed to the requirement for imagery containing no more than 10% cloud cover.

We plan to compare the imagery on hand against the cloud cover percentage indices to determine if supplemental orders can be submitted to NASA. Hopefully, this office research will provide needed coverage to compile several of the cartographic products outlined in the proposal. We also plan to start compilation on the 1:1,000,000-scale IMW map of Fairbanks, Alaska, as soon as the imagery on order at NASA is received. Research will continue to determine if other Alaska IMW 1:1,000,000-scale map areas are covered by cloud-free imagery.

- e. Discussion of significant scientific results and their relationship to practical applications or operational problems including estimates of the cost benefits of and significant results (To be prepared in scientific abstract form of 200 words or less):

Experiments under Proposal SR-149 have demonstrated the feasibility of revising coastlines on maps of Antarctica, detected gross changes in the northern limits of the three largest ice shelves in the world, and led to the discovery of uncharted mountain ranges.

A strip photomosaic, comprising portions of seven ERTS-1 images, was compiled at 1:1,000,000-scale along the Victoria Land Coast of Antarctica between Cape Adare and Harboard Glacier. Obvious changes in size, shape, and position of such features as glaciers, ice tongues, ice shelves, and fast ice are clearly identifiable when compared to the existing USGS 1:250,000-scale maps. Thus ERTS-1 imagery can greatly facilitate meaningful revision.

ERTS Scenes	1128-20293-7	1163-20230-7	1177-20001-7
	1128-20290-7	1163-20224-7	
	1128-20284-7		
	1128-20281-7		
	1128-20275-7		

Similar changes to features in the Thwaites Glacier Tongue area were also discovered. Two 1:500,000-scale USGS sketch maps in this area can be revised from ERTS-1 imagery.

ERTS Scenes	1137-14271-7	1157-14374-7	1160-14554
	1137-14265-7	1157-14380-7	1160-14551
		1157-14383-7	

Comparison of existing maps and photographs with ERTS-1 imagery over portions of the Ross and Filchner-Ronne Ice Shelves reveals that their northern limits have advanced about 6 and 15 km respectively in about 7 years.

ERTS Scenes	1212-11183-7	1151-19151-7	1165-18520-7
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ERTS imagery also revealed new and unmapped geographical features, of which some are mountains, in the area of the recently published Australian 1:1,000,000 IMW sheet SS 40-42 and USGS IMW sheet ST 57-60 which is presently in final stages of compilation. If sufficient cloud-free imagery becomes available over the Antarctic, 71 1:1,000,000-scale IMW sheets can be compiled at greatly reduced costs and man-year expenditure.

ERTS Scenes	McMurdo IMW		Australian IMW
	1128-20293-7	1194-19555-7	1196-02523
		1194-19383-7	1145-03101

Comparison of one ERTS scene with a recently published USGS 1:250,000-scale topographic map disclosed a unique change in the Erebus Glacier Tongue. Indications are that its present position is about the same as it was in 1910. In 1911 several miles of the leading end broke off. Comparisons with available source materials indicate advancement of about 9 km since 1947 and since 1962. A lateral shift or curving of the leading front toward the mainland seems to have occurred since 1970. If ground investigation proves it to be a surging glacier, it will be the first one found in Antarctica and therefore of keen interest to glaciologists.

ERTS Scene 1154-19322

Category 2D

- f. A listing of published articles, and/or papers, preprints, in-house reports, abstracts of talks, that were released during the reporting period:

Abstract and Paper "The Cartographic and Scientific Applications of ERTS-1 Imagery in Polar Regions," copy attached.
- g. Recommendation concerning practical changes in operations, additional investigative effort, correlation of effort and/or results as related to a maximum utilization of the ERTS system: N/A
- h. A listing by date of any changes in Standing Order Forms: N/A
- i. ERTS Image Descriptor forms: N/A
- j. Listing by date of any changed Data Request forms submitted to Goddard Space Flight Center/NDF during the reporting period: N/A
- k. Status of Data Collection Platforms (if Applicable): N/A

THE CARTOGRAPHIC AND SCIENTIFIC APPLICATION OF ERTS-1
IMAGERY IN POLAR REGIONS (A.6.4)

by

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Abstract

The first Earth Resources Technology Satellite (ERTS-1), launched by the National Aeronautics and Space Administration in July 1972, is providing valuable data for investigations of the most inaccessible and hostile regions of the earth--the Arctic and Antarctic. ERTS images and map products derived from them offer a whole new dimension in source material for multidiscipline investigations in the earth sciences. For the first time scientists can view synoptic, repetitive scenes of the polar regions in four spectral bands. Ongoing experiments funded by NASA and conducted in the U.S. Geological Survey have demonstrated the feasibility of revising coastlines on maps of Antarctica, detected gross changes in the northern limits of the three largest ice shelves in the world, and led to the discovery of uncharted mountain ranges.

Prepared for presentation at the Symposium on Approaches to Earth Survey Problems through the Use of Space Techniques, Konstanz, FRG, May 23-25, 1973.

1. Introduction

The launching of the first Earth Resources Technology Satellite (ERTS-1) and the successful operation of the onboard imaging systems introduced a whole new approach in monitoring and mapping the polar regions of the earth. Anticipating the potential usefulness of ERTS imagery as source material for cartographic products, the U.S. Geological Survey proposed a series of experiments, which were approved and funded by the National Aeronautics and Space Administration. The approved proposal, "The Cartographic Applications of ERTS/RBV Imagery in Polar Regions" (designated SR-194), set in motion a number of investigations to determine the feasibility of expediting the ongoing USGS mapping operations that support the immediate and long-range goals of the United States Arctic and Antarctic Research Programs, which are administered and funded by the National Science Foundation. Other experiments in the proposal were designed to implement recommendations of:

The Committee on Polar Research (CPR) of the
National Academy of Sciences--National Research
Council. [1]

The Working Group on Geodesy and Cartography,
Scientific Committee on Antarctic Research (SCAR). [2, 3]

The feasibility and economy of using ERTS imagery is being investigated for compiling maps of unmapped areas at scales of 1:250,000 to 1:1,000,000, for supplementing planimetric information such as crevasse fields and glacier flow lines, for preparing photomaps at various scales, and for map revision. Other experiments will include delineation and change detection of gross ice features, measuring seasonal variations of sea-ice boundaries, and mapping regional areas at 1:10,000,000 scale.

2. Status of ERTS-1

The Earth Resources Technology Satellite (ERTS-1), launched July 23, 1972, by the National Aeronautics and Space Administration (NASA), is in a circular, sun-synchronous, near-polar orbit at an altitude of 900 km. It circles the earth every 103 minutes (14 orbits a day) and repeats a given orbital track every 18 days. The science package includes three boresighted return-beam vidicon (RBV) cameras, each recording imagery in a discrete spectral band, and a multispectral scanner (MSS), which records in four spectral bands including near infrared. [4]

The U.S. Geological Survey planned to use imagery from the RBV cameras for cartographic experiments because of its favorable geometric characteristics. Shortly after the satellite achieved the desired orbit, however, the switches that activate the RBV cameras malfunctioned and one of the two onboard tape recorders became inoperable. It was therefore necessary to substitute

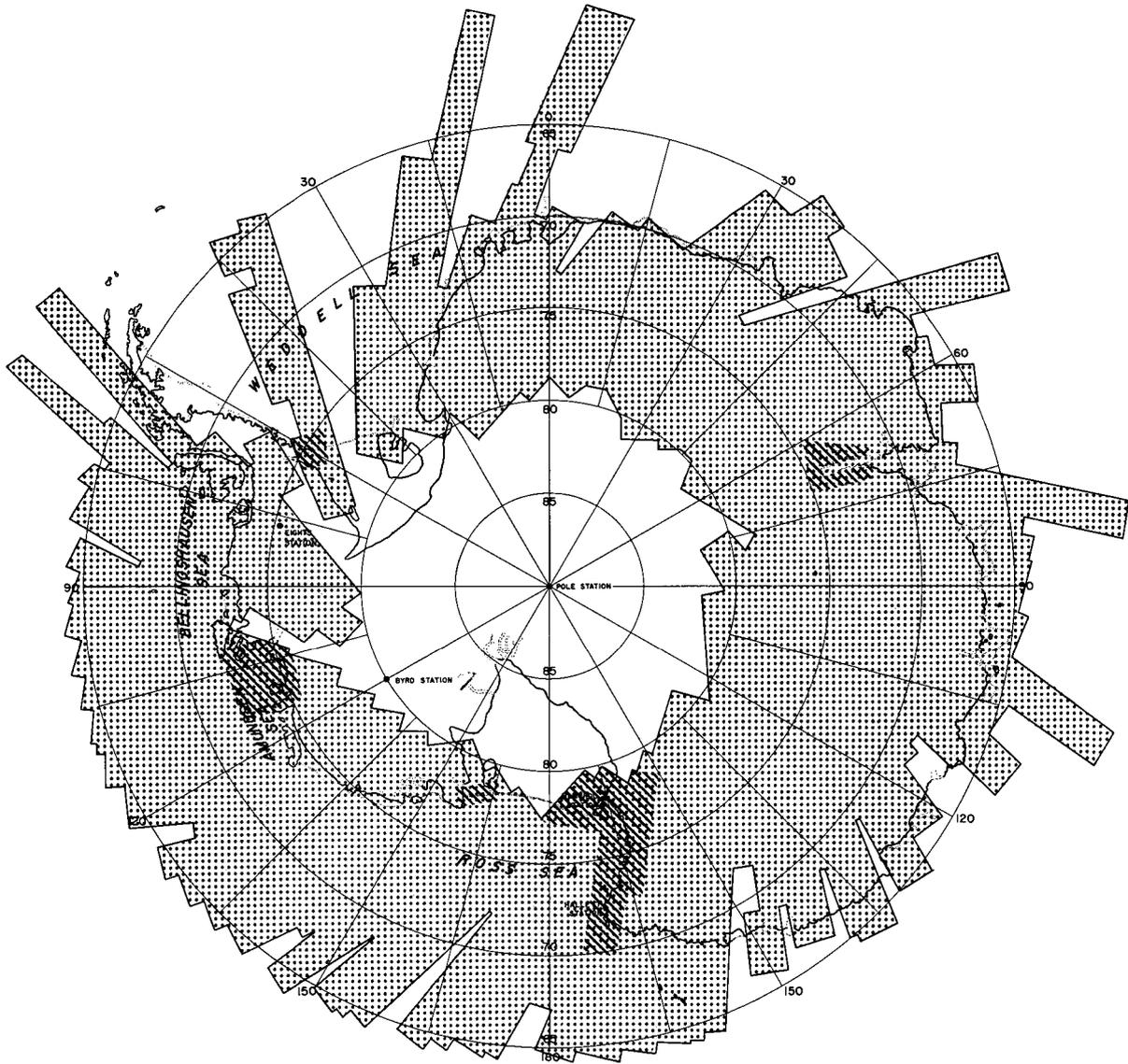
MSS imagery as source material for the experiments. Although the geometric characteristics of MSS are not as desirable as those of RBV, the distortions of MSS are systematic and the imagery has good spatial and spectral resolution. (Perceptual and geometric image qualities of MSS and RBV were described by Colvocoresses and McEwen [5].)

Widely scattered MSS imagery has been received over both polar regions (figs. 1 and 2). Imagery beyond the range of the receiving stations in the United States and Canada was stored on a tape recorder and later transmitted on command to the receiving stations. Unfortunately, in early April, sporadic noise was interjected into the second recorder, which degraded the images, and it was turned off by NASA in April 1973.

The tape recorder functioned well until this event and actually had exceeded its 500-hour designed lifetime by about 10 percent. Without the recorder, the ERTS-1 satellite has very limited capability of providing any further imagery of the polar regions. No further imagery can be obtained of areas beyond the range of the few existing ground stations.

3. Imagery Requirements

For the preparation of maps in support of the U.S. Antarctic Research Program, the United States has obtained aerial photography over an area of about 3,250,000 km². This effort has cost many



Imagery obtained — Jan. 19, 1973

Imagery used during investigations

Figure 1.--ERTS-1 space imagery (MSS), Antarctica index.

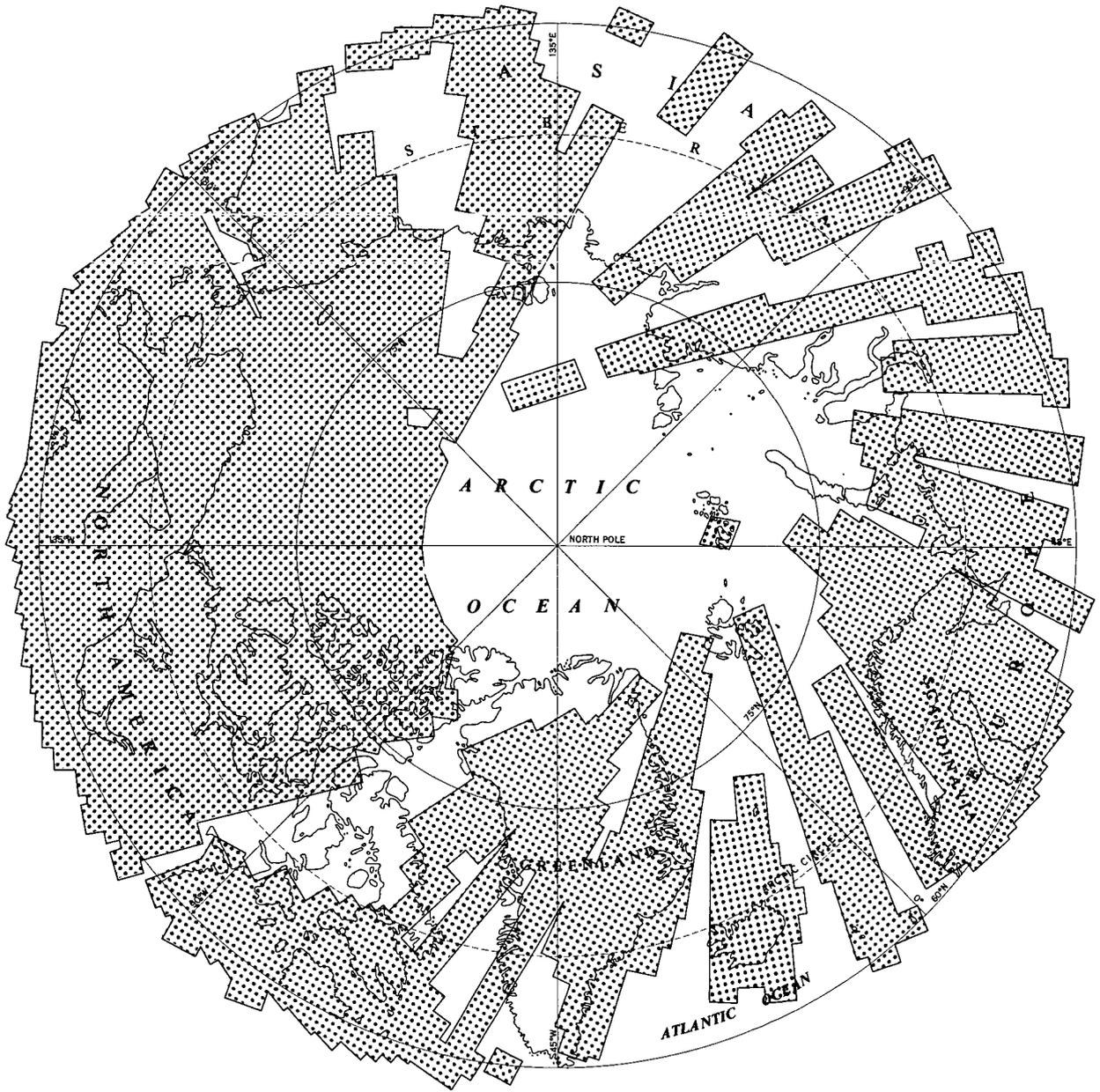


Figure 2.--ERTS-1 space imagery (MSS), Arctic index.

years and many millions of dollars. ERTS-1 now provides the capability of producing a single frame of imagery covering an area of about 34,000 km² (185 by 185 km). About 100 frames of ERTS imagery would cover the same area now covered by over 100,000 aerial photographs. Thus we have seen the development of a system that produces highly useful and readily available synoptic imagery for meeting many of the mapping requirements of scientific investigations of the polar regions.

For use in the ERTS experiments, imagery with no more than 10 percent cloud cover was specified. Only about 5 percent of the imagery received so far met this specification (fig. 1). All available coverage is now being examined to find additional usable MSS imagery (50% cloud cover or less) of the polar regions.

NASA delivered the first MSS scenes of the Arctic region in October 1972, and of the Antarctic in December 1972. Of the four spectral bands, the near infrared (band 7) appears to offer the best data for cartographic applications and image interpretation in the polar regions.

4. Investigations

4.1 Strip Mosaic and Change Detection

An important objective now is to compile 1:1,000,000-scale photoimage mosaics along the coastal areas of Western Antarctica and, eventually, along the coastal areas of all Antarctica. These imagery products will enable the U.S. Geological Survey to build a

historical record which, when compared against existing maps and sequential ERTS coverage, will show changes in size, shape, and position of features such as ice shelves, glaciers, and ice tongues (fig. 3).

A strip photomosaic, comprising portions of seven ERTS-1 images, was compiled at 1:1,000,000 scale along the Victoria Land Coast of Antarctica between Cape Adare and Harbord Glacier. This mosaic, covering an area of 185 km by 644 km, depicts 45 glaciers and ice tongues, numerous ice shelves, and the northern extent of the Transantarctic Mountains. This experiment is a pilot effort, and other 1:1,000,000-scale photoimage mosaics along the coastal areas of West Antarctica between the Ross Ice Shelf north and westward to 180° east longitude will be compiled under this proposal.

Glaciers, ice tongues, and ice shelves were clearly identifiable on the 1:1,000,000-scale ERTS imagery. This pilot project indicated that the imagery was of sufficient resolution to be used as a source for photoimage revision and for glaciological change detection.

Further investigations proved that ERTS imagery can be used effectively for planimetric revision of small-scale maps, and this technique is being applied to the six 1:250,000-scale topographic maps that fall in the area of the Victoria Land strip mosaic.

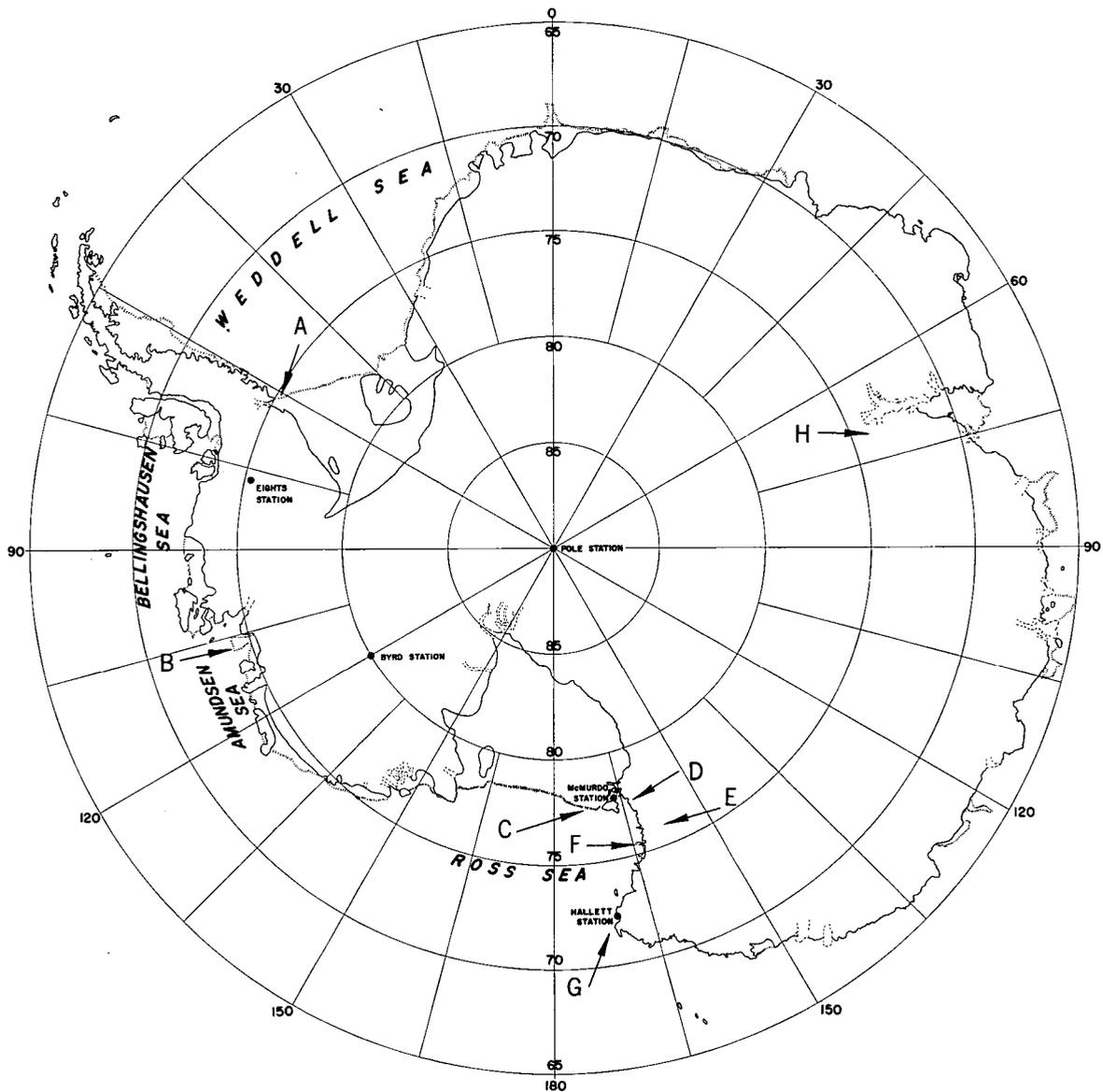


Figure 3.--Locations of significant changes evident from ERTS imagery (Dec. 1972 - Feb. 1973):

- | | |
|------------------------|--------------------------------------|
| A. Ronne Ice Front | E. New features on IMW |
| B. Thwaites Ice Tongue | F. Drygalski Ice Tongue |
| C. Rose Ice Shelf | G. Hallett (fast ice) |
| D. McMurdo | H. Lambert Glacier
(new features) |

A detailed cartographic analysis has not been completed over the entire area of the mosaic, but the coastline was carefully compared with existing maps, and several major changes in coastal features were found. The comparison showed that the new satellite imagery can greatly facilitate meaningful revision of the existing maps (figs. 4 and 5).

Because the 1:250,000-scale source maps were compiled from multiyear aerial photography, it would be erroneous to use the map publication date as a benchmark for determining ice movement. Accordingly, in our analysis, it was necessary to determine the date of aerial photography used as source for each feature on the existing map. In the future, scientists need only refer to the taking date of the ERTS imagery.

4.2 Map Revision

Figure 6 illustrates the application of ERTS imagery for evaluating and revising published maps. The graphic on the bottom is a composite of two 1:500,000-scale sketch maps compiled from conventional photographs taken during the austral summer of 1965-66. The graphic on the top is a mosaic of parts of 7 scenes of MSS bulk imagery. Area coverage is about 117,000 km². The two triangles represent geodetic positions used to fit the imagery mosaic to the map base. The ERTS imagery greatly improves the absolute and relative positioning of shoreline configurations,

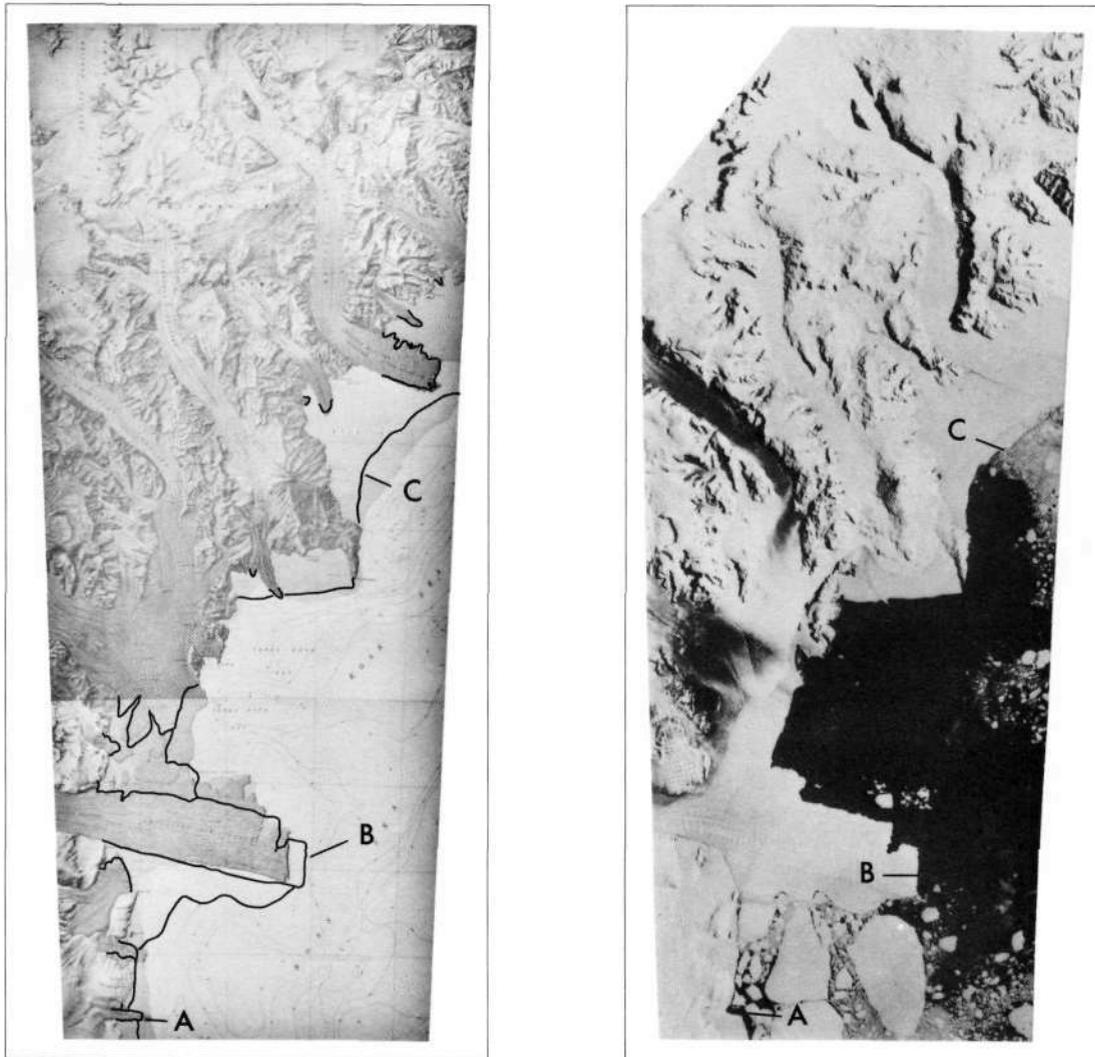


Figure 4.--Drygalski Ice Tongue, Victoria Land Coast Area. Left, three 1:250,000-scale U.S. Geological Survey topographic maps compiled from source data, 1955-64. Annotated revisions based on ERTS-1 imagery. Right, ERTS photoimagery mosaic showing significant changes:

- A. Harbord Glacier
- B. Drygalski Ice Tongue
- C. fast ice

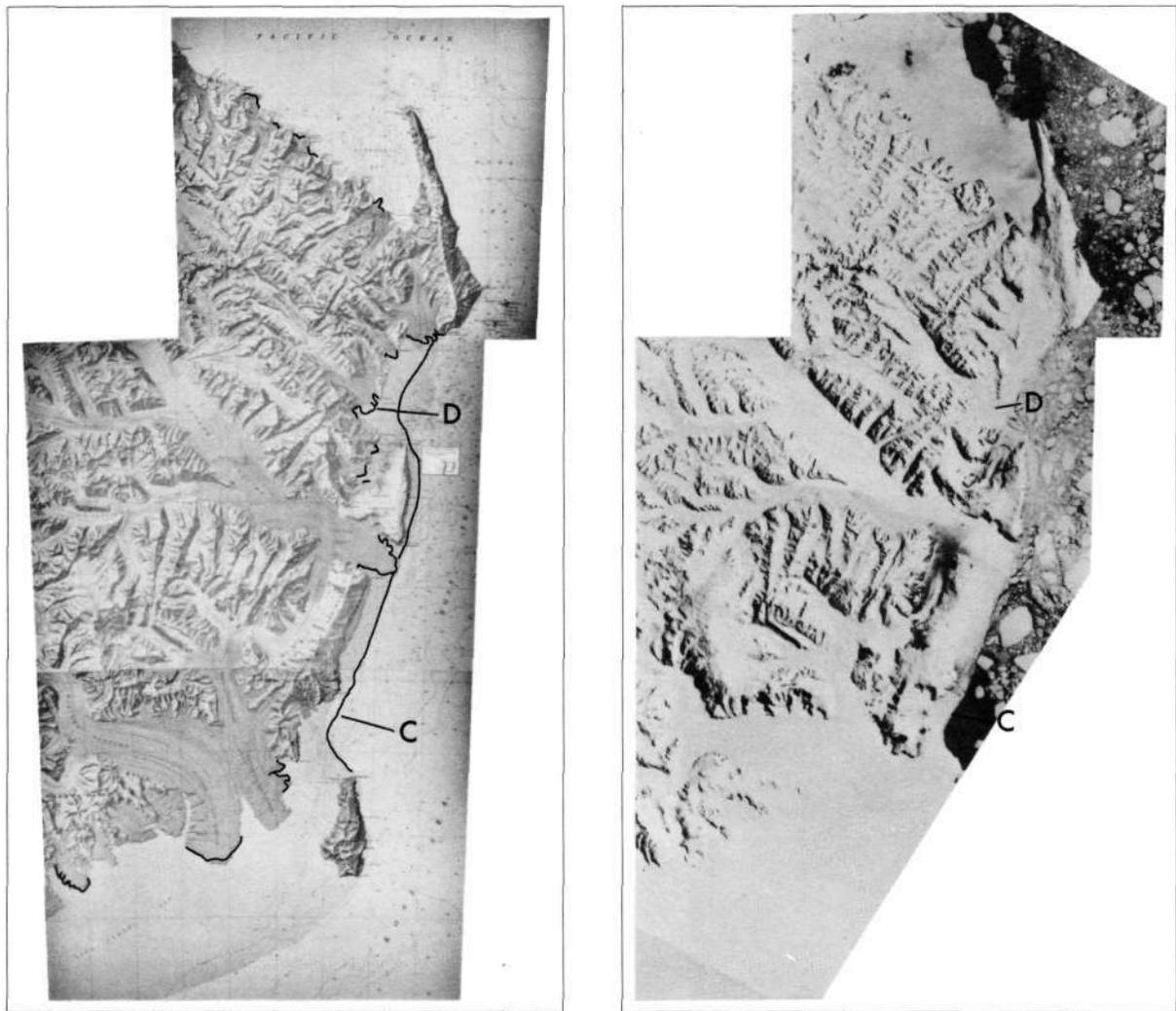


Figure 5.--Cape Adare, Victoria Land Coast Area. Left, three 1:250,000-scale U.S. Geological Survey topographic maps compiled from source data, 1961-64. Annotated revisions based on ERTS-1 imagery. Right, ERTS photoimagery mosaic showing significant changes: C--Boundary of fast ice and bay ice has changed; D--The shape of Honeycomb and Ironside Glaciers has changed and their tongues have advanced about 3.2 km.

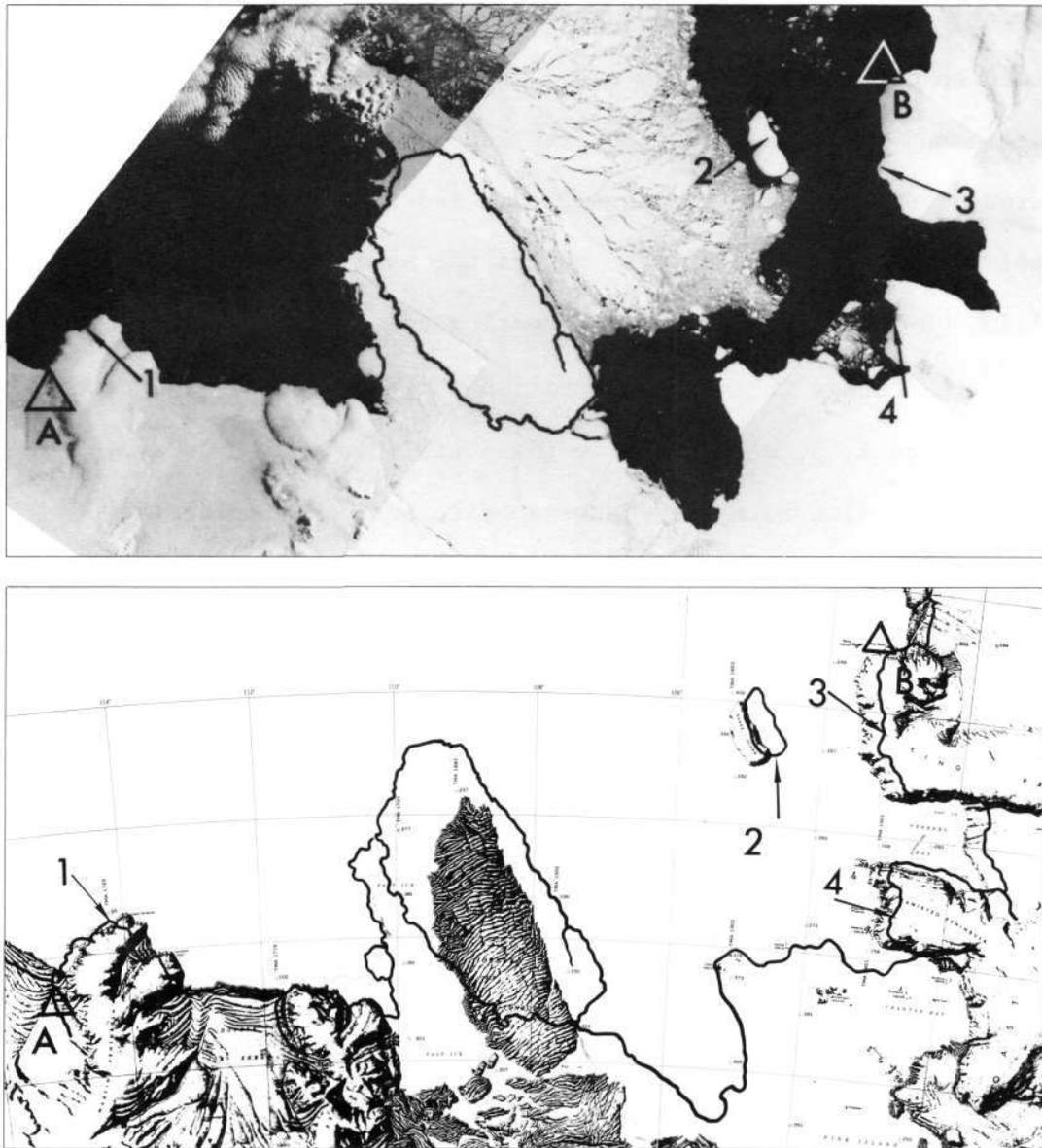


Figure 6.--Thwaites Iceberg Tongue. Annotated mosaic of ERTS-1 imagery (top) and corresponding sketch map (bottom). Annotations on the map show significant changes to be the coastline and position changes to map features that can be made with ERTS-1 imagery. Geodetic control points are shown at A and B.

ice tongues, and other map features. Because of the limited amount of control and the large number of conventional photographs used to compile the sketch maps, it was not possible to maintain scale and position throughout the map compilation, especially in areas devoid of readily identifiable features that make good pass points. A single ERTS scene covers the same area as 1,320 1:40,000-scale photographs. Comparing the two parts of figure 6, note the change in the configuration of the coast, as indicated by numbers 1, 3, and 4, and in the position of Burke Island, number 2. Also note the change in size and position of the Thwaites Iceberg Tongue, number 5. Area has increased from 44,200 km² (map) to 71,500 km² (image), and the position has shifted about 8 km.

4.3. Small-Scale Mapping

The main immediate application of ERTS-1 imagery in the polar regions, particularly in Antarctica, is for compiling 1:1,000,000-scale maps and photoimage mosaics. The need for million-scale coverage of Antarctica has been recognized by several organizations, including SCAR [1, 2, 3].

Because of the virtual impossibility of taking photographs with normal aircraft at altitudes high enough for efficient million-scale mapping, efforts before the launching of ERTS-1 were directed primarily toward mapping the coastal and mountain areas at 1:250,000 scale. ERTS imagery, however, meets the needs for million-scale photomapping, which is expected to prove most

beneficial to the international scientific community. To cover an IMW map area, cartographers will only have to assemble 15 to 20 ERTS scenes rather than 12,000 conventional photographs. Production cost will decrease as production rate increases. The user will have at his disposal a visual representation of vast areas that have never been mapped. Moreover, he will not have to wait years before the image maps are available.

Comparisons carried out on the USGS-compiled McMurdo Sound Region, IMW Sheet ST 57-60 (fig. 7), and on the Australian-compiled IMW Sheet SS 40-42 (fig. 8) clearly demonstrate the application. Revisions and additions to the two sheets are readily apparent. The most obvious changes are the large block of new and unmapped geographical features revealed by the ERTS imagery. Noteworthy revisions include the repositioning of the Ross Ice Shelf Front (about 6.4 km north) and Franklin Island (7.2 km south). The position of Franklin Island has been in contention for many years and has been continually reported in error by U.S. ships.

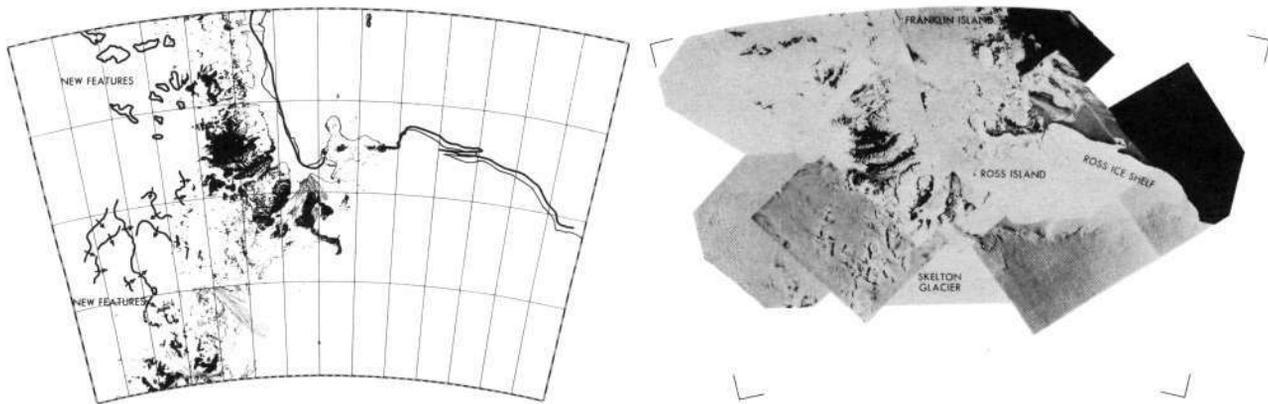


Figure 7.--McMurdo 1:1,000,000-scale map (IMW series)/ERTS imagery. With the aid of the ERTS imagery mosaic, newly discovered mountains, land features, and coastal changes will be depicted on the USGS 1:1,000,000-scale manuscript prior to publication.

AUSTRALIAN 1:1,000,000 SS 40-42

ERTS-1 IMAGERY LAMBERT GLACIER

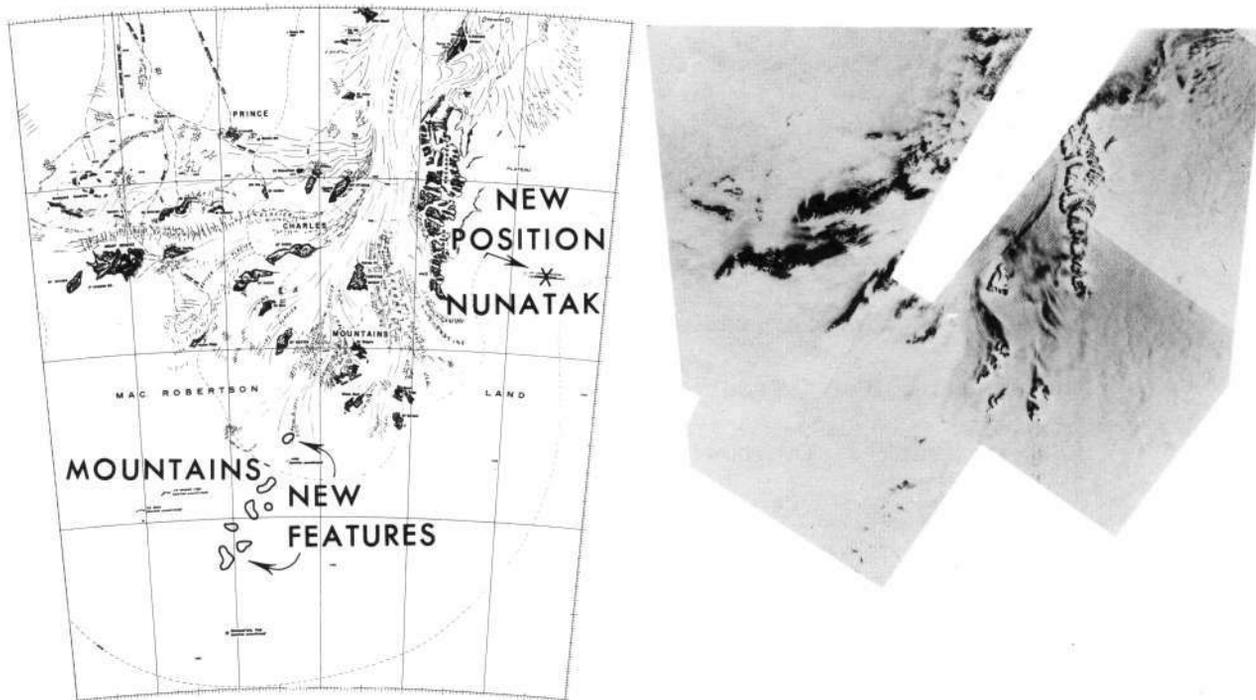
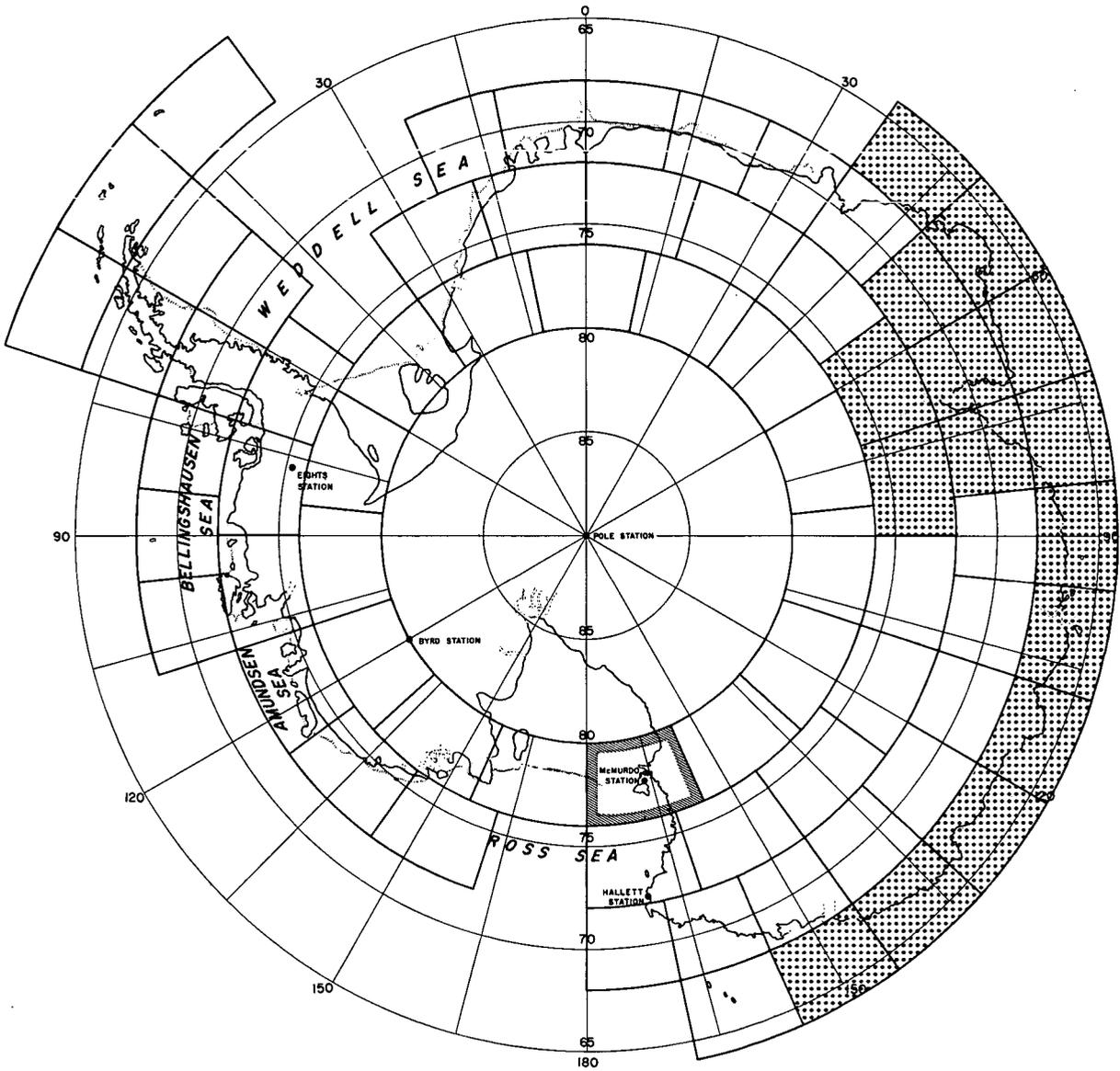


Figure 8.--Australian 1:1,000,000-scale map (IMW series)/ERTS imagery. With the aid of ERTS imagery, it is possible to analyze and evaluate existing source maps. The imagery reveals new mountains and other significant features which can be added to the Australian 1:1,000,000-scale map.

Reference to the IMW 1:1,000,000-scale index of Antarctica (fig. 9) and the space-imagery index (fig. 1) indicates the value of ERTS-1 imagery to the IMW mapping program. Because of the 99° orbital inclination (ascending node) of the satellite, imagery cannot be obtained between 82°S latitude and the pole. Accordingly, if all the available imagery is of satisfactory quality, which has yet to be determined, 71 maps can be compiled.

5. Scientific Application

Comparison of ERTS scene 1154-19322, dated December 24, 1972, with the published Ross Island 1:250,000-scale map disclosed a unique change in the Erebus Glacier Tongue (fig. 10). Further examination of photographs and historical maps indicated that the present position of the tongue is about the same as it was in 1910 [6] and that the tongue has advanced about 9.6 km since 1947 and 4.8 km since 1962. A lateral shift or curving of the leading front toward the mainland seems to have occurred since 1970. Sources are not adequate to determine whether the movement occurred gradually or over a very short period. Some evidence does seem to indicate that the tongue may have gone through a surging period. Perhaps it has completed a growth cycle and will again break off as it did in 1911. If ground investigation proves it to be a surging glacier, it will be the first one found in Antarctica and therefore of keen interest to glaciologists.



- U.S. Geological Survey IMW in-work
- Non U.S. published IMW's

Figure 9.--Antarctica IMW 1:1,000,000-scale index.

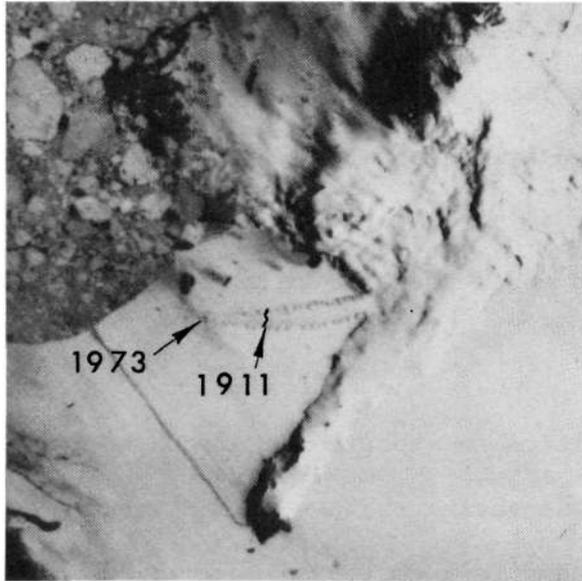
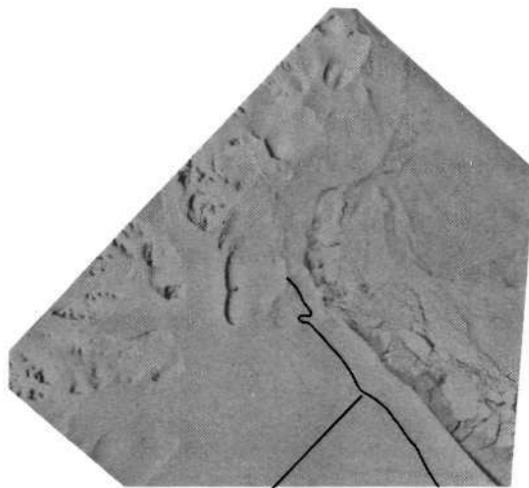


Figure 10.--ERTS imagery of Erebus Ice Tongue. Analysis of ERTS images and library sources determined that the Erebus Glacier Tongue has advanced 9.6 km since 1947. Place where the tongue broke off in 1911 is annotated.



MAP POSITION
BASED ON 1966 SOURCES

Figure 11.--ERTS imagery of Ronne Ice Shelf. The edge of the shelf has advanced about 16 km since 1966.

Further indication that ERTS imagery is useful for detecting glaciological changes is given in figure 11. ERTS scene 1212-11183, dated Feb. 20, 1973, was compared with the published 1:500,000-scale sketch map of Ellsworth Land and Palmer Land and with aerial photographs to determine that the Ronne Ice Shelf has advanced about 16 km since January 1966.

6. Future Plans

In addition to experiments discussed in this paper, plans include investigating the use of MSS imagery

- to compile a small-scale (1:10,000,000) photomap of the entire continent of Antarctica
- to compile thematic maps of sea-ice conditions
- to begin an analysis of the variations of the sea-ice boundary and rate of deformation of pack ice
- to compile physical maps of the Arctic region
- to compile 1:1,000,000-scale photoimage mosaics of Alaska as a reference for evaluating ecological effects of North Slope and pipeline development and for revision of published maps.

With the ERTS imagery as a current guide, Doppler satellite-tracking equipment will be used to establish geodetic control for Antarctic mapping. Survey teams will be sent to the field

during the Antarctic austral season to establish geodetic positions (x, y, and z) on preselected points identifiable on ERTS scenes.

7. Conclusion

Though we have had only a few months of experience in using ERTS imagery for investigations of the polar regions, we are sure that it can form the basis of a quality map product that will meet most users' needs. We are also sure that ERTS imagery can be used as source for revision of published small-scale and medium-scale maps of coastal areas in the polar regions.

The U.S. Geological Survey is responsible for maintaining the United States SCAR Library, distributing copies of all U.S.-completed cartographic products of Antarctica to the 11 other Antarctic Treaty nations. We therefore already have an established system which can be expanded to distribute ERTS imagery on request to member nations of SCAR.

References

- [1] Polar Research--A Study published by the National Academy of Sciences (NAS), Mar. 1970, ch. 5.
- [2] SCAR Bulletin No. 3, Sept. 1959, p. 591-593.
- [3] SCAR Bulletin No. 26, May 1967, International Activities, p. 579-583.
- [4] Data Users Handbook, National Aeronautics and Space Administration, Goddard Space Flight Center, Document No. 71SD4249, Appendix A.
- [5] A. P. Colvocoresses and R. B. McEwen, Progress in Cartography EROS Program, U.S. Geological Survey, Washington, D.C. 20244, paper presented to XII Pan American Consultation on Cartography, Pan American Institute of Geography and History, Panama, April 22-May 9, 1973.
- [6] Map of Ross Island - West Coast, scale 1:100,000, Dec. 1912.

