

Mapping activities in antarctica

R.B. SOUTHARD

*National Mapping Division
U.S. Geological Survey
Reston, Virginia 22092*

Aerial photography dominated the 1984 – 1985 field season effort for mapping Antarctica. The LC-130 aircraft outfitted for aerial photography flew approximately 77 hours dedicated to the acquisition of photographs in support of various scientific projects.

Over 17,000 square kilometers of color vertical photography was obtained of exposed rock areas around the Beardmore Glacier within reach of the Beardmore field camp. Much of this has been supplied to scientists who will be based at that camp during the 1985 – 1986 summer field season. These aerial photographs were taken at 4,600 meters above mean terrain and are of mapping quality.

Black-and-white vertical photographs were taken over the Siple Coast and Crary Ice Rise. These missions were flown in support of glaciologists doing a multiyear ice dynamics study by photogrammetric means. Over 22,000 square kilometers of mapping quality aerial photographs were acquired in support of these projects.

Reconnaissance aerial photography was obtained over Terra Nova Bay and Cape Washington. These will be used to evaluate

the feasibility of studying polynya photographically and to determine safe surface routes for expeditions studying penguins in that area.

In addition, aerial photographs were obtained to get better coverage over areas that were photographed previously through thin cloud cover. Black-and-white infrared photographs were obtained of the Mount Erebus crater at a time when there was minimum plume, resulting in higher resolution photographs for more detailed analysis.

For the 13th consecutive year, two U.S. Geological Survey cartographers were on duty at Amundsen-Scott South Pole Station. During the 1984 – 1985 winter, H. Scott Lawson and Buel Way Grout, Jr. continued to conduct seismic studies as part of the Worldwide Seismic Network and to use satellite Doppler tracking to support ice-motion studies. They also provided surveying support for the operation of the station and operated the South Pole Satellite Data Link for the transmission of scientific data from South Pole Station to McMurdo Station.

Three large-scale photo images were published in map form of Hut Point Peninsula, McMurdo Station, and Amundsen-Scott South Pole Station. The resulting prints use single air-photo images and provide detailed visual bases for station planning and scientific analysis.

A Memorandum of Understanding between the U.S. Geological Survey and the National Science Foundation was signed covering Scientific Committee on Antarctic Research (SCAR) library for Cartography and Geodesy operation and maintenance and for aerial photography, field positioning, geodetic operations, standard mapping, and special mapping. All of these efforts are part of joint planning between the U.S. Geological Survey and the National Science Foundation for mapping activities in the Antarctic.

Landsat multispectral images of Antarctica applied to mapping and glaciology

B.K. LUCCHITTA, K. EDWARDS, E.M. ELIASON, and J. BOWELL

*U.S. Geological Survey
Flagstaff, Arizona 86001*

The U.S. Geological Survey is conducting a program to provide digitally enhanced, multispectral (MSS) Landsat images of Antarctica. The goal is to furnish accurate planimetric, false-color composite-image maps in polar stereographic projection for these purposes: (1) to locate and delineate blue-ice areas for the collection of meteorites; (2) to produce special-purpose maps showing selected features only; (3) to provide synoptic views that aid in the detection and interpretation of glaciological features associated with ice sheets, outlet glaciers, ice streams, and ice shelves; (4) to monitor changes in coastlines and glacial features; (5) to enable the superposition and correlation of different types of digital cartographic data; and (6) to furnish

spectral and/or structural information in areas of limited bedrock outcrop to aid in regional geologic interpretation. The last two objectives are not addressed in this report.

About 170 computer-compatible tapes (CCT's) covering Victoria Land, the coastline of West Antarctica, the Antarctic Peninsula, and other selected areas (Lucchitta, Eliason, and Southworth 1985) are now available as false-color, multispectral, digital composites of band 4 (0.5 to 0.6 micrometer, green), band 5 (0.6 to 0.7 micrometer, red) and band 7 (0.8 to 1.1 micrometers, infrared). The tapes were subjected to routine image-processing procedures such as noise removal and radiometric and geometric corrections. Further processing included haze removal and enhancement by linear stretching of individual MSS bands based on inspection of gray-value (digital-number) histograms. Saturation of snow-covered scenes in bands 4 and 5 is a severe problem in Landsat MSS images of Antarctica and makes many images unsuitable for multispectral work. We developed special techniques to restore the saturated snow and ice information in bands 4 and 5 (figure 1) (Lucchitta et al. 1985).

We have prepared two image-mosaic products: (1) a map of the Ellsworth Mountains, which is preliminary because it is based on poor ground control; and (2) a map of the McMurdo Sound region, which is based on excellent ground control and is processed at full resolution. The latter comprises five complete

and three partial 1:250,000-scale topographic quadrangles. These multicolor mosaic maps are superior to previously published monochromatic mosaic maps because they clearly separate snow from ice. Ice shows as light blue; its recognition will

help in the search for meteorites, which occur in blue-ice areas (Whillans and Cassidy 1983).

Special-purpose maps. In Antarctica, where vast regions are difficult to reach on the ground, the location of features by

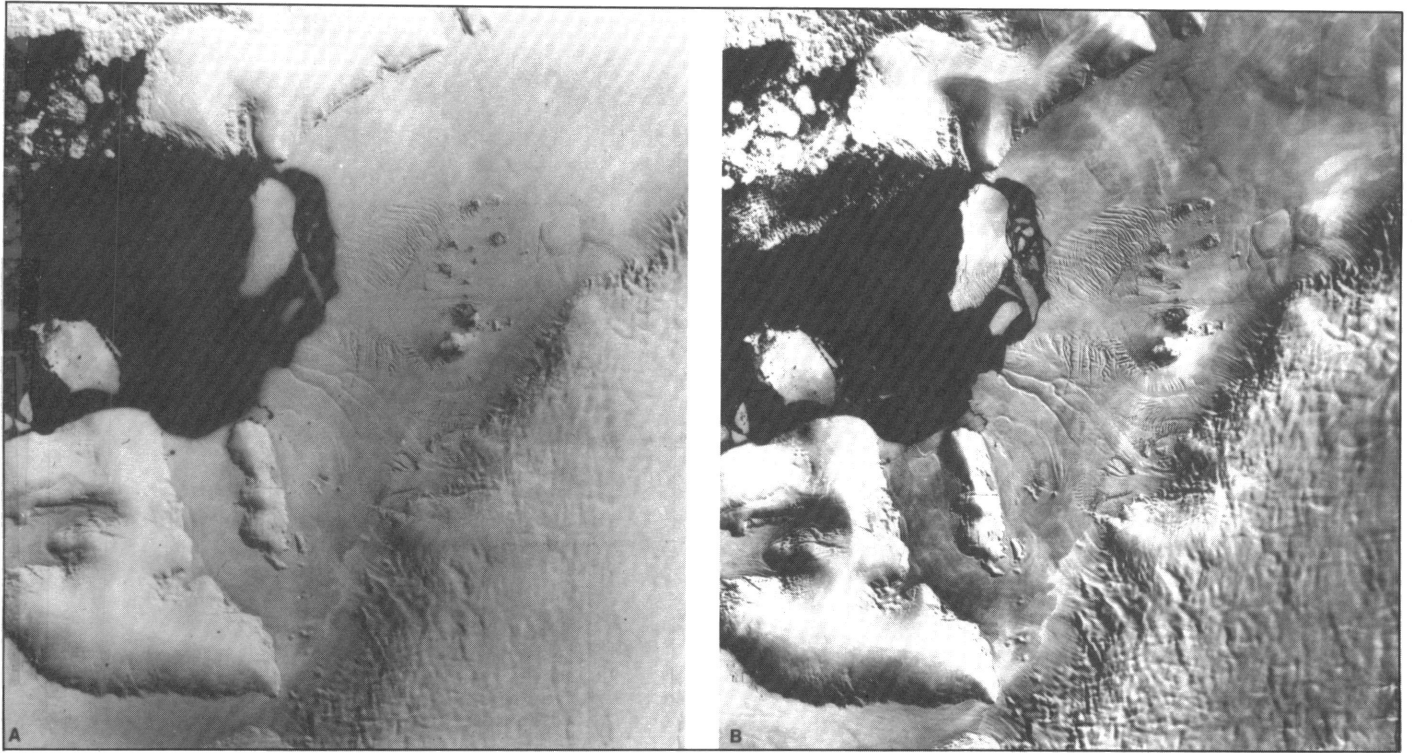


Figure 1. Landsat-1 mss image 1170-12260, 9 January 1973, path 231, row 112. Spaatz Island is in lower left. Image is 180 kilometers wide; north is toward the upper left. A. Black-and-white rendition of multispectral composite of bands 4, 5, and 7. The image is badly saturated in bands 4 and 5. B. Same image after saturation correction and application of a filter that enhanced fine detail.

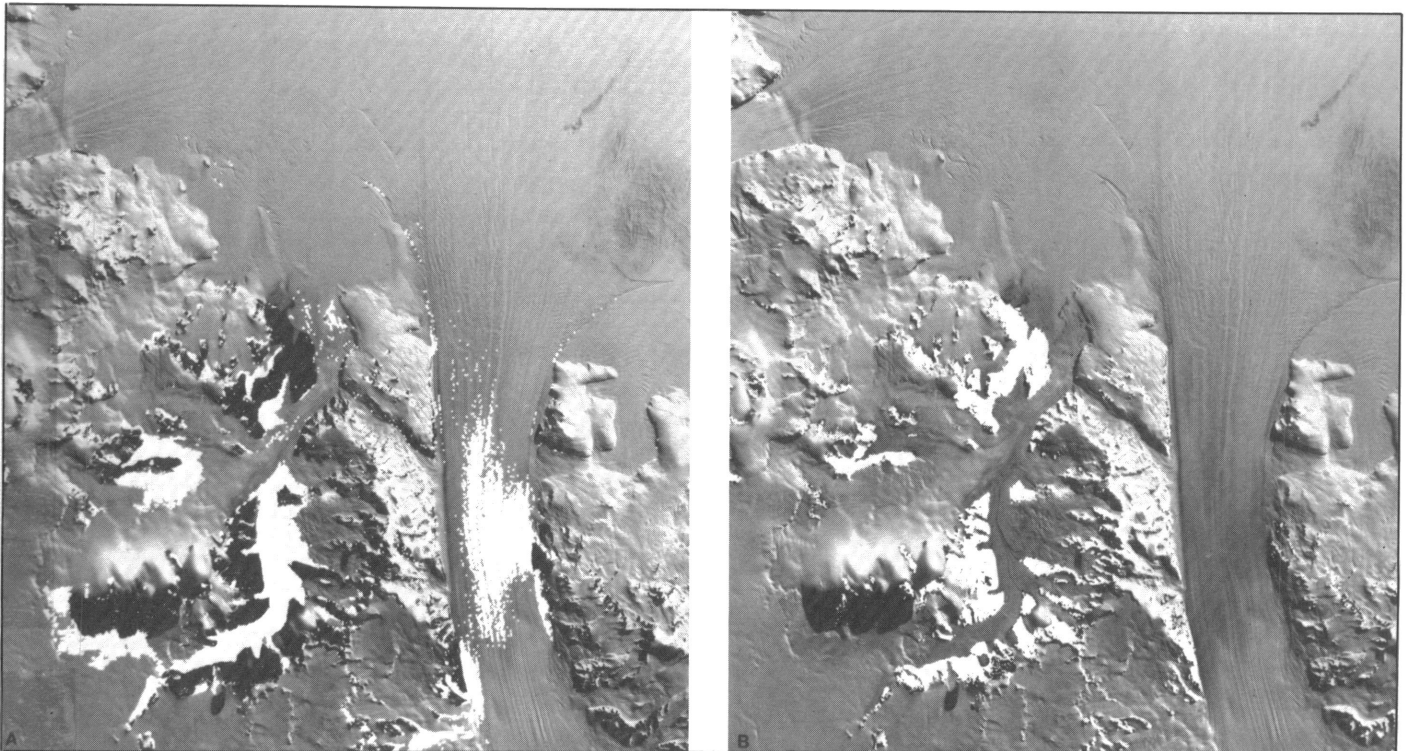


Figure 2. Landsat-1 mss image 1542-18435, 16 January 1974, path 46, row 119, band 7. Byrd Glacier is in center right. Image is 180 kilometers wide; north is toward the upper left. Selected features (white) designated by unsupervised classification program of band ratios 4/5, 5/6, and 6/7. A. White areas are ice on glaciers and near nunataks. B. White areas are rock or soil; black areas are mostly shadows from mountains and clouds.

remote-sensing techniques is extremely useful. To this end, multispectral digital-image maps can be converted into special-purpose maps that delineate features of interest. Figure 2a is an image of the Byrd Glacier and environs, in which ice is highlighted; figure 2b is an image in which rock or soil outcrops are shown. The images were prepared by first producing versions showing the ratios of MSS bands 4/5, 5/6, and 6/7 for each pixel in the image. An unsupervised classification program on the ratioed images then separated snow from ice and rock. Each pixel showing ice or rock was enlarged five times for easier recognition.

Glaciological features. The synoptic view afforded by Landsat images is especially useful for the recognition and identification of glaciological features. Landsat images show that many ice rises have distinct ridges along their crestlines (figure 3) (Martin 1976), but flow laws predict slopes close to zero in the vicinity of the crest, which would give rise to flattened domes (Nye 1959). Our digitally enhanced Landsat images clearly show that the ridges are actually doubled on several ice rises. The ridges follow sweeping, broadly sinuous curves along the ice-rise crest. They are superposed on topographic irregularities, suggesting that they are relatively young, perhaps even ephemeral features. Their apparent youth and their sinuous shapes suggest that they may be caused by wind action, perhaps by a combination of wind sculpture and deposition of drifts.

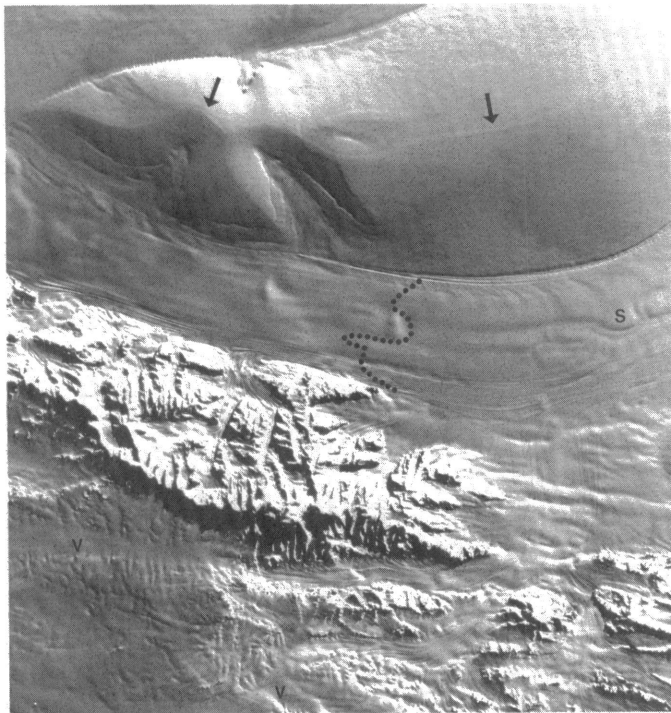


Figure 3. Landsat-1 mss image 1560-11492, 3 February 1974, path 225, row 117. Rutford Ice Stream in center, flowing to right. Image is 180 kilometers wide; north is toward the upper left. Black-and-white rendition of multispectral composite of bands 4,5, and 7, especially enhanced to bring out detail in snow and ice; however, detail of rock outcrops in Ellsworth Mountains (left center) is suppressed by this method. Grounding line of Rutford Ice Stream (dots) after Stephenson and Doake (1982). Note contrast between sliding part of ice stream (linear flow markings, left of grounding line) and floating part of ice stream (linear and transverse markings, right of grounding line); sinuous depressions where floating glacier slides over suspected shoals at (v); buried valleys at (v); double ridge along ice-rise crestline (arrows).

Digitally enhanced Landsat images are also superior to unenhanced images in that they clearly show flow lines in ice streams and on ice shelves, ice rumples, and crevasse fields. An analysis of an image of the Rutford Ice Stream region and the Ronne Ice Shelf by Swithinbank and Lucchitta (in press) revealed contrasts between surface features on an ice stream segment that is sliding (figure 3, left) and features on one that is floating (figure 3, right). The sinuous depressions on the right of the image suggest that here the ice is sliding over shoals and being partly deflected by them. Subtle relief variations on the ice surface delineate the extent of buried topography. The image in figure 3 clearly shows buried valleys upstream of the two glaciers (bottom left of picture) and the edge of the Ellsworth Mountains where these glaciers drop over a series of escarpments and join the Rutford Ice Stream (right center). Further, images of the Ronne Ice Shelf (not shown) show the principal flow lines, their origin from individual ice streams, and the persistence of flow lines across hundreds of kilometers of ice shelf.

Monitoring of changes in coastline and glaciers. The synoptic view of Landsat images is well suited to the monitoring of changing antarctic features, such as shorelines, grounding lines, ice-shelf margins, positions of glacier tongues in ice streams, and sea-ice distribution. For example, Ferrigno et al. (1983) determined the velocity of the Pine Island Glacier, a tidal-outlet glacier on the coast of West Antarctica. During the 750-day interval covered by repetitive Landsat images, the terminus moved about 4.5 kilometers (at an average velocity of 6 meters per day). Landsat images of the Byrd Glacier of southern Victoria Land, taken in January 1974 and November 1983, show that the glacier, beyond the grounding line, moved about 7.5 kilometers in a 10-year interval, or about 750 meters per year. The documentation of such changes detected on Landsat images may help in the interpretation of the dynamics and mass balance of ice sheets and ice shelves and in the prediction of future changes. Monitoring of changes is especially important for the west antarctic ice sheet, which is thought to be inherently unstable and in danger of disintegration (Hughes 1973; Weertman 1974). Because most Landsat images of Antarctica were acquired in the early to mid-1970's, a 10-year time lapse is already available for comparative analysis.

Digitally enhanced false-color Landsat MSS images composed of multiple bands are a significant improvement over the commonly used unenhanced black-and-white images of MSS band 7. They show considerably more detail in surficial morphology and can be used for the preparation of thematic maps of rock outcrops or blue-ice areas. The synoptic view of the images and mosaics provides information on the trends of flow lines in ice streams and ice shelves, the location of ice rises, ice rumples, or other possible grounded areas, and the extent and structure of some buried mountain ranges. Monitoring of the dynamics of coastline changes with time may indicate waxing or waning of the ice sheets that presage variations in world climate.

References

- Ferrigno, J.G., R.S. Williams Jr., C.S. Southworth, and T.K. Meunier. 1983. Glaciological and geological studies of Antarctica with satellite remote sensing technology (abs.). *U.S. Geological Survey Polar Research Symposium - Abstracts with Program* (12-14 October 1983, Washington, D.C.), U.S. Geological Survey Circular 911, 20-21.
- Hughes, T.J. 1973. Is the West Antarctic ice sheet disintegrating? *Journal of Geophysical Research*, 78, 7884-7910.

- Lucchitta, B.K., E.M. Eliason, and C.S. Southworth, 1985. Multi-spectral digital mapping of Antarctica and Landsat images. *Antarctic Journal of the U.S.*, 19(5), 249 – 250.
- Martin, P.J. 1976. Ridges on Antarctic ice rises. *Journal of Glaciology*, 17, 141 – 144.
- Nye, J.F. 1959. The motion of ice sheets and glaciers. *Journal of Glaciology*, 3, 493 – 507.

- Stephenson, S.N., and C.S.M. Doake. Dynamic behaviour of Rutford Ice Stream. *Annals of Glaciology*, 3, 295 – 299.
- Swithinbank, C. and B.K. Lucchitta. In press. Multispectral digital image mapping of Antarctic ice features. *Annals of Glaciology*.
- Weertman, J. 1974. Stability of the junction of an ice sheet and an ice shelf. *Journal of Glaciology*, 13, 3 – 11.
- Whillans, I.M., and W.A. Cassidy. 1983. Catch a falling star; meteorites and old ice. *Science*, 222, 55 – 57.

The use of Landsat data to map bedrock and surficial geology of the ice-free valleys of southern Victoria Land

C.S. SOUTHWORTH

*U.S. Geological Survey
Reston, Virginia 22092*

Landsat multispectral scanner (MSS) image data (20279 – 19361) and laboratory spectra of field samples were used to differentiate different lithologic units in bedrock and surficial deposits of part of the ice-free valleys of Antarctica. The absence of vegetation, the clean atmosphere, and the physically weathered bedrock provide a good area for using spectral discrimination of geologic materials to facilitate geologic mapping in an area where field work is difficult and costly. A previous study, which used Landsat MSS image data of the ice-free valleys, established that MSS band 7 images provide the best spectral contrast between rock units for photogeologic interpretation and are, therefore, best used for tracing lithologic contacts (Houston, Zochol, and Smithson 1974). Outcrops of igneous and metamorphic rocks, sandstone, and dolerite, ranging in age from Precambrian to Jurassic, were mapped with an accuracy of 60 to 70 percent. Houston et al. (1974) concluded that rocks of similar reflectance (such as granite, felsic igneous rock, and marble) could not be differentiated. In addition, they concluded that Quaternary surficial deposits, specifically glacial drift and alluvium, were difficult to differentiate from their parent bedrock because of similar spectral reflectance.

The theoretical basis for discrimination among rock types by using remotely sensed data is the known variation in spectral reflectance of different lithologic materials in the visible to near-infrared (NIR) region of the electromagnetic spectrum. The reflectance variations are due, in part, to absorption bands of ferric-iron-bearing minerals, commonly known as limonite. Absorption bands in the NIR region are associated with electronic vibration of the ferric-iron cation in the mineral lattice of oxides (Hunt and Salisbury 1971). Reflectance variations in the visible to NIR region, as well as variations due to ferric-iron absorption in the NIR, can be visually enhanced by band-ratio techniques (Rowan et al. 1974).

Landsat digital number (DN) values, correlation coefficient matrices (Chavez, Berlin, and Sowers 1982), and laboratory spectral-reflectance measurements of the Beacon sandstone, the Ferrar dolerite, and the Vida granite were obtained to determine the optimum band-ratio and contrast-enhancement parameters needed best to differentiate each rock type. Correlation coefficient matrices of MSS bands 4, 5, 6, and 7 (0.5 to 0.6 micrometer, 0.6 to 0.7 micrometer, 0.7 to 0.8 micrometer, and 0.8 to 1.1 micrometer, respectively) show a low correlation of MSS band 4 to band 7, which is caused by differences between reflectance spectra of geologic materials. The high values displayed by the MSS band 7/band 4 ratio for sandstone, granite, and felsic igneous rock make this a good ratio to discriminate these from other rocks. The MSS band 7/band 6 ratio proved optimum for distinguishing dolerite. Reflectance spectra were obtained of sandstone, granite, and dolerite samples provided by Gunter Faure, Ohio State University, by using a Beckman UV5240 spectrophotometer. Ratio values of reflectance spectra correlate with the DN band ratio selection.

A linear stretch of MSS band 7 was used to enhance the contrast in reflectance between mafic and felsic rocks at these NIR wavelengths (figure). A hybrid color composite was produced by using the MSS band 7/band 4 ratio (red), the MSS band 7/band 6 ratio (blue), and the stretched MSS band 7 (green). Outcrops of Beacon sandstone (A), Vida granite (B), Ferrar dolerite (C), Asgard metasediments (D), and felsic igneous rocks (E) could be distinguished (figure). Mafic to intermediate differentiated rock in a Ferrar dolerite sill (C), stratigraphic variations in the Beacon Sandstone Supergroup (A), and the contact of felsic igneous intrusives into gneiss basement (F) were visually delineated.

Nearly one-third of the study area is covered by Quaternary deposits, many of which are difficult to distinguish from bedrock because they are derived from the same parent material. Correct geologic interpretation also requires that both landforms and surface roughness be taken into account because of the effects of shadows on the apparent reflectance. Photogeologic interpretation of the computer-enhanced MSS image allows discrimination between postglacial alluvial/colluvial deposits and glacial drift on the basis of surface roughness and composition. Alluvial/colluvial deposits tend to be bright because of their relatively smooth surfaces, a result of the comparatively uniform grain sizes associated with wind sorting and water sorting. Quaternary glacial drift and till deposits, on the other hand, tend to be darker, both because of the rougher surface associated with diverse grain size and because of the presence of abundant mafic clasts. For example, deposits de-