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Coastal-Change and Glaciological Map of the Trinity Peninsula Area and South Shetland Islands, Antarctica: 1843–2001

By Jane G. Ferrigno, Alison J. Cook, Kevin M. Foley, Richard S. Williams, Jr.,
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Conversion Factors

Multiply	By	To obtain
	Length	
meter (m)	3.281	foot (ft)
kilometer (km)	0.6214	mile (mi)
	Area	
square kilometer (km^2)	0.3861	square mile (mi^2)

Coastal-Change and Glaciological Map of the Trinity Peninsula Area and South Shetland Islands, Antarctica: 1843–2001

By Jane G. Ferrigno,[1] Alison J. Cook,[2] Kevin M. Foley,[1] Richard S. Williams, Jr.,[3] Charles Swithinbank,[4] Adrian J. Fox,[2] Janet W. Thomson,[2] and Jörn Sievers[5]

Introduction

Background

Changes in the area and volume of polar ice sheets are intricately linked to changes in global climate, and the resulting changes in sea level could severely impact the densely populated coastal regions on Earth. Melting of the West Antarctic part alone of the Antarctic ice sheet would cause a sea-level rise of approximately 6 meters (m). The potential sea-level rise after melting of the entire Antarctic ice sheet is estimated to be 65 m (Lythe and others, 2001) to 73 m (Williams and Hall, 1993). In addition to its importance, the mass balance (the net volumetric gain or loss) of the Antarctic ice sheet is highly complex, responding differently to different conditions in each region (Vaughan, 2005). In a review paper, Rignot and Thomas (2002) concluded that the West Antarctic ice sheet is probably becoming thinner overall; although it is thickening in the west, it is thinning in the north. Thomas and others (2004), on the basis of aircraft and satellite laser altimetry surveys, believe the thinning may be accelerating. Joughin and Tulaczyk (2002), on the basis of analysis of ice-flow velocities derived from synthetic aperture radar, concluded that most of the Ross ice streams (ice streams on the east side of the Ross Ice Shelf) have a positive mass balance, whereas Rignot and others (2004) infer even larger negative mass balance for glaciers flowing northward into the Amundsen Sea, a trend suggested by Swithinbank and others (2003a,b, 2004). The mass balance of the East Antarctic ice sheet is thought by Davis and others (2005) to be strongly positive on the basis of the change in satellite altimetry measurements made between 1992 and 2003.

Measurement of changes in area and mass balance of the Antarctic ice sheet was given a very high priority in recommendations by the Polar Research Board of the National Research Council (1986), in subsequent recommendations by the Scientific Committee on Antarctic Research (SCAR) (1989, 1993), and by the National Science Foundation's (1990) Division of Polar Programs. On the basis of these recommendations, the U.S. Geological Survey (USGS) decided that the archive of early 1970s Landsat 1, 2, and 3 Multispectral Scanner (MSS) images of Antarctica and the subsequent repeat coverage made possible with Landsat and other satellite images provided an excellent means of documenting changes in the coastline of Antarctica (Ferrigno and Gould, 1987). The availability of this information provided the impetus for carrying out a comprehensive analysis of the glaciological features of the coastal regions and changes in ice fronts of Antarctica (Swithinbank, 1988; Williams and Ferrigno, 1988). The project was later modified to include Landsat 4 and 5 MSS and Thematic Mapper (TM) [and in some areas Landsat 7 Enhanced Thematic Mapper Plus (ETM+)], RADARSAT images, and other data where available, to compare changes that occurred during a 20- to 25- or 30-year time interval (or longer where data were available, as in the Antarctic Peninsula). The results of the analysis are being used to produce a digital database and a series of USGS Geologic Investigations Series Maps (I–2600) consisting of 23 maps at 1:1,000,000 scale and 1 map at 1:5,000,000 scale, in both paper and digital format (Williams and others, 1995; Williams and Ferrigno, 1998; Ferrigno and others, 2002) (available online at http://www.glaciers.er.usgs.gov).

Objectives

The coastal-change and glaciological mapping project has five primary objectives, listed as follows:

1. to determine coastline changes that have occurred during the past three decades, or longer where additional information exists;

2. to establish an accurate baseline series of 1:1,000,000-scale maps (fig. 1) that defines, from the analysis of Landsat and other satellite images, the glaciological characteristics (for example, floating ice, grounded ice, and so forth) of the coastline of Antarctica during three main time intervals: (1) early 1970s (Landsat 1, 2, or 3), (2)

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middle 1980s to early 1990s (Landsat 4 or 5), and (3) late 1990s to early 2000s (RADARSAT or Landsat 7 ETM+);

3. to determine velocities of outlet glaciers, ice streams, and ice shelves, and the position of the grounding line from analysis of Landsat images and other sources;

4. to compile a comprehensive inventory of named (from published maps) and unnamed (from analysis of Landsat images) outlet glaciers and ice streams in Antarctica that are mappable from Landsat and other satellite images or from ancillary sources (for example, maps, gazetteers, digital databases, and so forth) (Swithinbank, 1980, 1985; Alberts, 1981, 1995; National Science Foundation, 1989; British Antarctic Survey and others, 1993);

5. to compile a 1:5,000,000-scale map of Antarctica derived from the 23 1:1,000,000-scale maps. Each 1:1,000,000-scale map extends to the southernmost nunatak within each map area or to the southernmost extent of Landsat images (about lat 81.5° S.). The coverage area of some maps (for example, those covering the Ronne and Filchner Ice Shelves) was extended farther south to encompass the entire ice shelf.

Sources

Most of the earlier maps in the Coastal-Change and Glaciological Maps of Antarctica series relied almost exclusively on Landsat and other satellite data as the source of information.

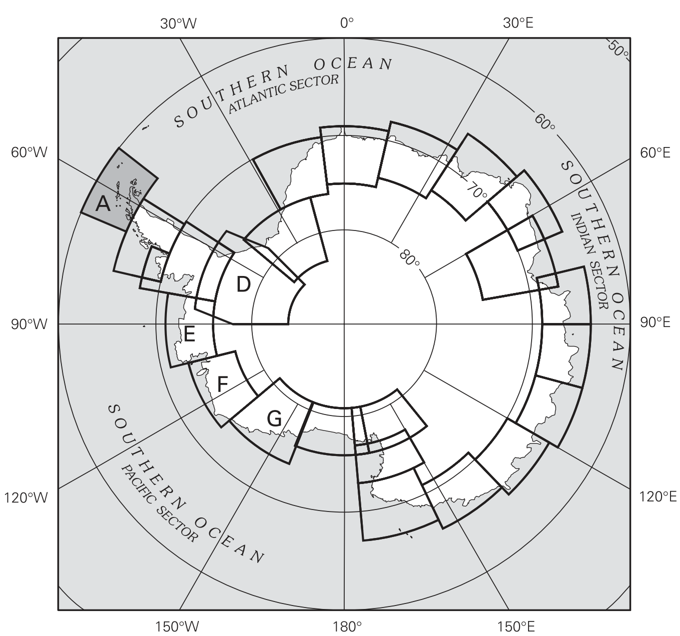

Figure 1. Index map of the planned 23 coastal-change and glaciological maps of Antarctica at 1:1,000,000 scale. Trinity Peninsula area and South Shetland Islands map is shaded. Maps published to date are indicated by letter and are described in table 9 (follows the References Cited; see p. 32).

In addition to Landsat and other satellite imagery, this map, as well as the other two Antarctic Peninsula maps [Larsen Ice Shelf area (map I–2600–B) and Palmer Land area (map I–2600–C)], was able to utilize the abundance of current and historical source material archived by the British Antarctic Survey (BAS). This source material included aerial photographs from 1956 to 2001 (table 1*A*), maps from 1946 to 1985 (table 2), and manuscripts and publications from 1847 (of observations made in 1843) to 1997 (table 3 and References Cited). (Tables 1*A*, 2, and 3 follow the References Cited; see p. 22, 23–26, and 27, respectively.)

The Landsat 4 and 5 TM image base used for the Trinity Peninsula area map is derived from images of the Antarctic Peninsula that were digitally mosaicked and georeferenced by the former Institut für Angewandte Geodäsie (IfAG), now known as the Bundesamt für Kartographie und Geodäsie (BKG), and made available by Jörn Sievers. The resulting image mosaic was augmented by the addition of two Landsat 4 TM scenes and one Landsat 7 ETM+ scene to provide coverage of islands in the northern part of the map area that were not included in the original image mosaic. Landsat images used for the IfAG mosaic or for analysis are listed in table 1*B* (p. 22). The coverage areas of the Landsat 1, 2, and 3 MSS images, Landsat 4 and 5 MSS and TM images, and Landsat 7 ETM+ images used in the compilation of the printed map are shown in the index maps on the accompanying map.

Other Landsat images in photographic or digital format were used for the analysis of geographic and glaciological features. Photographic prints at 1:500,000 scale were used in the early analytical phase of the project by Charles Swithinbank.

The early Landsat scenes cover the years 1973 to 1979. The Landsat 4 and 5 MSS and TM images date from 1986 to 1990. The Landsat 7 ETM+ images used in the completion of the mosaic and the analysis of coastline change were digital and dated from 2000 and 2001. Other satellite images and photographs used for analysis of coastal change were a Corona photograph (1963) from the United States KH-4 satellite (McDonald, 1997); Kosmos Programme KATE-200 photographs (1975) from the former Soviet Union Resurs-F1 satellite; European Remote Sensing (ERS) satellite Synthetic Aperture Radar (SAR) images (1992, 1993); and RADARSAT images (1997) from the Canadian Space Agency radar satellite.

Analytical and Other Methodologies Used for Each Data Source

The large number of data sources, each having different characteristics, spatial resolutions, and geodetic accuracies, necessitated the application of different methodologies to each source; these methodologies are discussed in the following section. Relative accuracy assigned to each data source is shown in the following table and is described more fully in the Coastline Accuracies section below. The large amount of information produced as a result of the abundance of data sources and the extensive analysis is generally too complex to properly portray on the printed map at 1:1,000,000 scale. As a result, much of the data used and analysis employed is found on the SCAR ADD (Antarctic Digital Database) Web site hosted by BAS at http://www.add.scar.org.

Relative accuracy assigned to each data source

Source material	Relative accuracy compared to IfAG mosaic (1, most accurate)
IfAG mosaic	1
Landsat 1–5 images	1 or 2
Landsat 7 ETM+ images	1 or 2
Vertical aerial photographs	1, 2, or 3
Oblique aerial photographs	2 or 3
Maps, manuscripts, and publications	3, 4, or 5
Corona satellite photograph	1
European Remote Sensing (ERS)-SAR Images	2
Kosmos KATE-200 photographic mosaic	2
RADARSAT images	2 or 3

IfAG Mosaic

The IfAG Landsat TM image mosaic was used as the image base onto which the coastlines were mapped for each of the three maps of the Antarctic Peninsula (I–2600–A, –B, and –C). This mosaic was determined to be the most geodetically accurate image base available of the peninsula. It was created using 62 control points from the BAS geodetic-control network of the area adjusted in 1985. Conventional block-adjustment techniques were used (Sievers and others, 1989). The accuracy was calculated by A.P.R. Cooper, BAS, to be ± 150 m (Cooper, oral commun., 2001).

The coastline on the image mosaic was digitized and assigned a reliability of 1. Because the IfAG mosaic was used as the map base, the accuracy of all other data sources was assigned relative to the accuracy of the IfAG mosaic. For those parts of the rock coastline that were hidden in shadow, or in areas obscured by cloud, the IfAG mosaic was used in conjunction with Falkland Islands and Dependencies Aerial Survey Expedition (FIDASE) photographs (table 1*A*; p. 22) and the Antarctic Digital Database (ADD) coastline (British Antarctic Survey and others, 1993).

The IfAG mosaic did not extend northward to Elephant Island and Clarence Island, and new satellite images were added to the mosaic for these islands. The image of Elephant Island was registered using existing ground-control points. The Clarence Island image underwent similar processing, but because geodetic control is poor in that area, the image was georegistered using the corner coordinate positions given on the header file.

Landsat Images and Overlays

The initial analysis of glaciological features and coastal change began with annotation of glaciological features by Charles Swithinbank using the SCAR Code (Scientific Committee on Antarctic Research, 1980) for symbols on maps or the SCAR ADD geocode (British Antarctic Survey and others, 1993) on transparent overlays of the enlarged Landsat images. The resulting images and overlays were later transferred to BAS to be combined digitally with the other sources of information.

In the BAS Mapping and Geographic Information Centre (MAGIC), each satellite image was incorporated into the digital database using a series of nine artificial control points that could be identified on the IfAG image mosaic. The arcs (line segments) were digitized following, for the most part, the glaciological annotations made by Charles Swithinbank. Because they were digitized at scale 1:500,000, they were given a reliability of 1 or 2.

Landsat 7 ETM+ Images

The Landsat 7 ETM+ images were imported digitally and reprojected. Where necessary, an image was registered and rectified. Once correctly positioned, the ice-coast areas (floating or grounded) were digitized and assigned a reliability of 1 or 2.

Vertical Aerial Photographs

Vertical aerial photographs were by far the most common data source used, and the reliability was generally high. When it was possible to digitize the ice front or ice wall accurately from the photographs, the ice front or ice wall was assigned a reliability of 1. In other cases, for example where features were obscured to a greater or lesser degree by clouds, the information was given a reliability rating of 2. Frequently, there were no permanent features visible or present on the background image or the photograph, so that positioning of the ice front or ice wall was difficult or impossible. In such cases, the ice front or ice wall either was not drawn at all, or was assigned a reliability of 3 if it could be placed with reasonable confidence. In cases of reliability 2 or 3, the reliability rating chosen is explained in the comment field of the Excel file on the SCAR ADD Web site.

Oblique Aerial Photographs

Oblique aerial photographs were always given a reliability of 2 or 3. Although it was difficult to accurately define scale or distance from oblique aerial photographs, it was still possible to position the coastline relative to other features. If the ice front or ice wall could be clearly seen, was in the foreground, and could be positioned relative to fixed features, it was drawn with a reliability of 2. If it was obscured by cloud, or if the photograph was grainy, or if the coast was in the background of the photograph, it was assigned a reliability of 3. Often a coastline was positioned by using a combination of oblique aerial photographs from different directions or in conjunction with vertical aerial photographs; in these cases it was possible to give a reliability of 1 or 2.

Maps, Manuscripts, and Publications

Many paper maps and written documents, dating back to 1843 [Ross, 1847; tables 2 and 3 (p. 23–26 and 27); other publications in the References Cited], show the ice-bound coast before the acquisition of aerial photographs. Although such sources of data are usually too inaccurate to meet the scientific objectives of this project, the coastlines revealed on these historical maps and charts give a qualitative idea of the approximate position of the ice front. Some maps were able to provide a position of the ice front when used in conjunction with aerial photographs. Other maps were published at a large enough scale (for example, 1:100,000) to make them useable, and they were assigned a reliability of 3.

Corona Satellite Photograph

One Corona photograph was used to locate the position of the Larsen Ice Shelf in 1963. This photograph was scanned and georegistered so that the ice front could be drawn with high accuracy.

European Remote-Sensing (ERS) SAR Images

Two low-resolution ERS-1 SAR images were used to monitor the ice front of the Prince Gustav Ice Shelf. They were assigned an accuracy of 2.

Kosmos KATE-200 Photographic Mosaic

A photographic mosaic of satellite images by Skvarca (1994), showing the coastline of the northern Larsen Ice Shelf in 1975, was used directly from his article. It was possible to place the ice front with reasonable accuracy (reliability of 2) because of the fixed features visible on the image mosaic.

RADARSAT Images

Individual RADARSAT images having a pixel resolution of 25 m were used for the project. Because of geodetic position errors and layover problems associated with the high-relief terrain of the Antarctic Peninsula, the coastline digitized from these images had an offset of features ranging from 500 m to 3 kilometers (km) when compared to the IfAG mosaic. Where possible, the RADARSAT coastline was corrected using the more reliable areas of rock coastline, allowing some areas of ice shelf and outlet-glacier fronts to be included in the dataset with a reliability of 2 or 3.

Coastline Accuracies

Reliability 1 (within 60 m)
Accurately digitized from:

- Vertical aerial photographs which have adequate rock-outcrop features for positioning.
- Landsat TM and Landsat 7 ETM+ digital satellite images (good, georeferenced imagery).

Reliability 2 (within 150 m)
Interpreted from:

- Vertical aerial photographs in which the image is grainy or the coastline is slightly obscured by cloud.
- Near-oblique aerial photographs in which the ice coastline is clearly visible and is in the foreground, and adequate fixed features are visible.
- Photographs (enlarged to 1:500,000 scale) of Landsat MSS and TM images interpreted on a digitizing table.
- Digital RADARSAT images registered to the IfAG mosaic.

Reliability 3 (within 300 m)
Interpreted from:

- Vertical or oblique aerial photographs in which few or no reference features are visible.
- Oblique aerial photographs in which the coastline is in the distance or is poorly visible.
- Satellite images in which some features are poorly georeferenced but still show useful coastline data.
- Non-georeferenced large-scale maps, and sketch maps.

Reliability 4 (within 600 m)
Interpreted from:

- Non-georeferenced large-scale (1:200,000 or larger) historical maps, in which the inaccuracy is probably greater than the coastal change.
- Non-georeferenced small-scale (1:500,000) historical maps.
- Very generalized maps of areas for which no other information is available.

Reliability 5 (within 1 km)

- Coastline based on interpretation from written descriptions. Such descriptions can give a good indication of the location of an ice front or ice wall (in general terms), but not the shape. They are useful because they show where the ice front or ice wall may have been, before the introduction of primary cartographic data.

Glaciological Features

The Trinity Peninsula area and South Shetland Islands map covers the northernmost part of the Antarctic Peninsula and adjacent islands, and extends from lat 60° to 65° S., and from long 52° to 67° W. The map shows the northern part of

Graham Land, including the Danco, Davis, and Nordenskjöld Coasts. Except for a few small areas of exposed rock, the entire region is covered by glacier ice and permanent snow. The most significant glaciological features on the eastern side of the Trinity Peninsula in the early 1970s were the Prince Gustav Ice Shelf, between the Trinity Peninsula and James Ross Island, and the northernmost part of the Larsen Ice Shelf, extending southward from Cape Longing. However, during the 1980s and 1990s major retreat occurred, culminating in the disintegration in 1995 of the Prince Gustav Ice Shelf and most of the northern Larsen Ice Shelf (which became known as Larsen A) (Vaughan and Lachlan-Cope, 1995). Prince Gustav Channel thus became accessible to navigation for the first time historically, allowing a ship to transit the channel from north to south and continue onward for a circumnavigation of James Ross Island in February 1997 (Crosbie and Splettstoesser, 1997). These ice shelves had been present since the early visits to the Antarctic Peninsula in the middle 1800s (Ross, 1847). In fact, oceanographic research has indicated that the northern Larsen Ice Shelf probably had been in place since the late Holocene Epoch, or during the last 2,500 years (Domack and others, 2001). The remainder of the eastern coastline in the map area is characterized by ice walls, a few small ice shelves, and numerous outlet glaciers.

The coastline of the western side of the Antarctic Peninsula and adjacent islands appears to be composed mainly of grounded ice walls interspersed with the floating ice fronts of a few, very small ice shelves and numerous small (by Antarctic standards) named and unnamed glaciers. On the map are 161 named glaciers and related glacier-ice features, as defined in various scientific glossaries (Armstrong and others, 1973, 1977; Jackson, 1997), whose names are recognized by the United States, including 73 on the mainland, 4 on Anvers Island, 9 on Brabant Island, 1 on Clarence Island, 4 on Elephant Island, 5 on Greenwich Island, 8 on James Ross Island, 29 on King George Island, 25 on Livingston Island, and 3 on Wiencke Island (table 4*A*, p. 27–29). Other glaciological features have been identified and are listed on the SCAR Composite Gazetteer of Antarctica Web site, but are not discussed here as they are not recognized by the U.S. Government.

Glacier Inventory

Producing a sophisticated glacier inventory of the entire continent of Antarctica according to the requirements of the World Glacier Monitoring Service (WGMS), as part of its ongoing "World Glacier Inventory" program, has been impossible with the present state of glaciological knowledge about Antarctica (Swithinbank, 1980). However, as more remotely sensed data become available, and as more scientific interest is focused on Antarctica, more glacier inventories continue to be developed, especially for localized areas. The first glacier inventory carried out in Antarctica using the methodology of the World Glacier Inventory was done on James Ross Island by Rabassa and others (1982) and identified 138 glaciers. Simöes and others (1999) combined field work and remotely sensed data to define 70 glacier drainage basins on King George Island. Braun and others (2001) did further work on King George Island and proposed a Geographic Information System (GIS)-based glacier inventory for the Antarctic Peninsula as part of the Global Land Ice Measurements from Space (GLIMS) Project (Kieffer and others, 2000). Continuing this work, Rau and others (2004) monitored frontal positions of glaciers and compiled a glacier inventory of more than 900 individual glaciers and glacial features in the northern Antarctic Peninsula. The data are currently available at http://www.geographie.uni-freiburg.de/ipg/forschung/ap3/antarctica.

Because of the glaciological complexity and the large number of unnamed and unidentified glaciers on the islands and mainland of the Antarctic Peninsula, we have not attempted to compile a comprehensive glacier inventory. Instead, we have used satellite images, aerial photographs, available maps, and historical records to focus on and document coastal change. From gazetteers and published maps, we compiled a list of 161 named glaciers and related glaciological features within the Trinity Peninsula area and South Shetland Islands map. We also documented 126 unnamed glaciers and ice fronts where substantial coastal change has occurred; these unnamed glaciers and ice fronts were given a latitude/longitude identifier and related to adjacent geographic features (table 4*B*, p. 30–32), and are located on the map as numbered dots.

Analysis

Overview

As would be expected, ice fronts, iceberg tongues, and glacier tongues (all floating ice) are the most dynamic and changeable features in the coastal regions of Antarctica. In this map area, the positions of the dynamic ice fronts as observed on the three sets of Landsat imagery, the aerial photographs, other satellite imagery, and historical data sources have been mapped and annotated with the date for each position. This makes it possible to accurately date and analyze changes that have occurred. The drawback of this methodology, regardless of the amount of data sources used, is that the observations are "snapshots" in time, providing variable time-lapse intervals to document change. We are able to determine trends of coastal change, but we have not necessarily seen the maximum advance or retreat, and changes that occurred between observations would have been missed entirely.

After the coastal changes were digitally mapped, we determined that the magnitude of the change on an annual to decadal basis is generally not discernible at 1:1,000,000 scale (the scale of the printed map) except in areas of substantial change. Therefore, we decided to limit the coastal-change data on the printed map to the information that is visible at the map scale. However, three enlargements of areas of special interest are included as maps in this publication. An enlargement of James Ross Island is inset on the map, and enlargements of the northern Admiralty Bay area (King George Island) and the Duse Bay and Eyrie Bay area (Trinity Peninsula) are in this pamphlet. The entire dataset of mapped changes is, of course, included in the digital dataset available on the SCAR ADD Web site (http://www.add.scar.org).

Methodologies Used in Coastal-Change Analysis

A rigorous procedure was used to analyze coastline changes. More than 7,500 individual measurements were made on 211 named and unnamed glaciers, ice shelves, and other fluctuating ice-front areas along the glacier-ice coast. Sample lines—lines extending from the ice front to an established baseline—were drawn on each of the 211 glaciers to measure ice-front advance and retreat. The number of sample lines drawn through each glacier varied according to the nature of the glacier. For wide areas of glacier-ice coast or for large ice shelves, the sample lines were typically spaced at 1-km intervals, whereas for small, narrow glaciers the sample-line spacing was much closer. The lines were drawn to reflect a true sample of the way in which the terminus of each glacier changed between observations (fig. 2).

The sample-line coverage was intersected with the coastline coverage, and the nodes created at these intersections were converted to points in ArcInfo. The attributes of the coastline on which each point was situated were transferred to the points.

Simultaneously, the sample-line coverage was buffered in ArcInfo to create narrow polygons around each sample line. The items 'location', 'glacier', and 'sample' were added to this polygon coverage. All the sample lines were then named in terms of their location and glacier names. Within each glacier, the sample lines were numbered in order.

The point coverage was then intersected with the polygon coverage, and the new attributes that had been added to the polygons were transferred to the points. Only the points along each sample line were retained. X and Y coordinates were also added. This point coverage was unloaded to Excel, and the values were sorted by glacier, sample, and year.

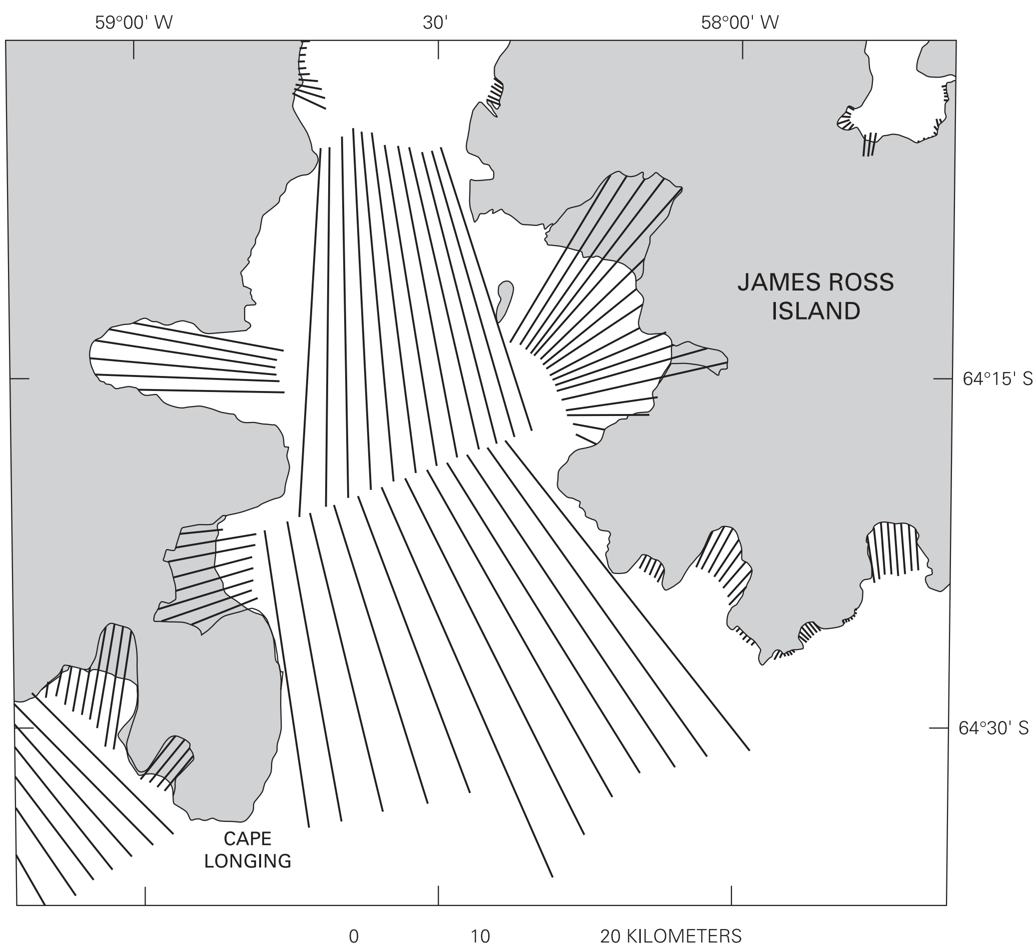

Figure 2. Sample lines drawn for analysis of ice-front change in the Prince Gustav Channel region of the Trinity Peninsula.

It was necessary to determine not only the distance that the glacier had advanced or retreated between the dates of observation, but also the direction of this change (for example, toward or away from land). The positions of the endpoints of the sample lines therefore had to be determined. The sample-line coverage was converted to points, and they were intersected with the polygon coverage, which produced the endpoints with attributes attached; X and Y coordinates were added to these endpoints. The odd values of the endpoint coordinates were utilized because the odd number was always the one on the land side of the glacier. These endpoint locations were also unloaded to Excel.

The final results in Excel show all of the attributes of the coastlines for each sample line within each glacier. The distance from each glacier-ice coastline to land was calculated (using the endpoint values); also calculated was the advance or retreat between each observation. The number of months for each time period could be determined, and the change per year in meters could also be calculated. The Pivot Table in the Excel file on the SCAR ADD Web site displays a summary of these results, showing the maximum, minimum, and average changes in meters observed across each time interval for each glacier, comparing the change values of all of the sample lines for that particular glacier.

Coastal Change

The procedure described above for documenting and analyzing coastal change in the Trinity Peninsula area and South Shetland Islands has generated a large GIS dataset. Because the volume of data is far too large to discuss comprehensively, the following sections describe only the most dramatic changes and overall trends, and then focus on three separate areas of noticeable change (James Ross Island, the northern Admiralty Bay area of King George Island, and the Duse Bay and Eyrie Bay area of the Trinity Peninsula) that are illustrated in enlarged maps (see inset on the map and figures 3 and 4 in this pamphlet). The complete dataset can be found on the SCAR ADD Web site (http://www.add.scar.org).

The most dramatic changes that have occurred in the Trinity Peninsula area are sustained retreat of ice fronts during several years, followed by the rapid and complete disintegration of the Prince Gustav Ice Shelf and much of the northern Larsen Ice Shelf during a short period in 1995. The first observations of the continuous Prince Gustav-Larsen ice front were made by James Clark Ross in 1843 (Ross, 1847). Recession of the Prince Gustav Ice Shelf was well documented by Cooper (1997). Our mapping of its retreat is based on the above references and on ice-front locations taken from the following sources: 1957 FIDASE aerial photographs, a 1961 unpublished map, a 1969 published map and aerial photographs, a 1977 Landsat 2 MSS image, 1979 BAS aerial photographs, Landsat 4 and 5 TM images from 1986, 1988, and 1989, and European Remote Sensing (ERS-1) satellite Synthetic Aperture Radar (SAR) images from 1992 and 1993. The observations showed almost continual recession of both ice shelves, with the greatest retreat occurring from 1957 to 1959, from 1986 to 1988, and from 1992 to 1993. The maximum single retreat of 16.5 km was measured on the northern ice shelf front between 1992 and 1993. Measurements were made at 12 locations for both the northern and southern ice fronts.

The Larsen Ice Shelf front had separated from the Prince Gustav Ice Shelf by 1961. Measurements were made at 15 locations in the northern (Larsen Inlet) part of the Larsen Ice Shelf and at 18 locations in its southern part (south of Sobral Peninsula to the edge of the map). The ice front retreated an average of 13.6 km in the north and 6.2 km in the south between 1961 and 1968. Between 1968 and 1977, however, the ice front advanced an average of 10 km in the north and 7.8 km in the south. After 1977 there was continuous retreat. By 1989, most of the ice shelf in Larsen Inlet had disappeared, with an average retreat of the ice front of almost 26 km during this 12-year period. The southern area, which became known as Larsen A, retreated an average of 14.2 km between 1977 and 1989. From 1989 to 1995, when the remaining ice shelf catastrophically disintegrated, the average ice-front retreat was 48 km.

Since that time, the fringing remnants of the ice shelves have continued to retreat, and the fronts of outlet glaciers that had previously flowed into the ice shelves are also retreating. The source material for the measurements of the front of the Larsen Ice Shelf included a 1:200,000-scale published map from 1961, a Corona photograph from 1963, USA Trimetrogon Antarctica (TMA) photography from 1968 and 1969, Landsat 2 and 3 MSS images from 1977 and 1979, Landsat 4 and 5 TM images from 1986, 1988, and 1989, BAS aerial photography from 1995, RADARSAT images from 1997, and Landsat 7 ETM+ images from 2000.

Many scientists have monitored the retreat of the glaciers and ice shelves of the area, described the dramatic breakup, and examined the climatological warming and other factors that have precipitated the major ice-front changes. These workers include Koerner (1961), Skvarca (1993, 1994), Bindschadler and others (1994), Skvarca and others (1995, 1998, 1999), Rott and others (1996, 1998, 2002), Vaughan and Doake (1996), Cooper (1997), Doake and others (1998), Rack and others (1999, 2000), Scambos and others (2000), and Domack and others (2001). Their body of work and this map and pamphlet provide a comprehensive discussion and additional references concerning the breakup of the Prince Gustav Ice Shelf and northern Larsen Ice Shelf.

In addition to the most obvious changes discussed above, other noteworthy changes have occurred. Of the 211 ice fronts measured in the map area, 44 locations have had an average change of >75 m a^{-1} during at least one time period. These locations are shown on the map by colored dots and indicated in tables 4*A* and 4*B* (p. 27–29 and 30–32, respectively). Of the 44 locations, 34 retreated, 6 advanced, and 4 both retreated and advanced. Considering all the ice fronts measured, it is obvious that the overwhelming trend of ice-front movement within the map area is retreat. Of the 211 ice-front locations that were monitored, 195 showed a net retreat. There were, however, 16 locations that showed slight to moderate advance, with a slight net advance. Fifteen of these latter ice fronts are on the western side of the Antarctic Peninsula or on islands to the west of the peninsula. The ice fronts include seven unnamed locations and Grubb, Krebs, Rozier, Sultan, Usher, Wheatstone, Whitecloud, and Woodbury Glaciers. Only one location, on the northern side of James Ross Island, is on the eastern side of the Antarctic Peninsula. Although glaciers in similar locations are known to respond differently to similar climatological conditions, it would be worth investigating those locations that are responding so differently to the regional trend.

We have selected three areas of the 44 locations having an average change of >75m a^{-1} to discuss more fully—the South Shetland Islands (represented by King George Island), James Ross Island, and the Duse Bay and Eyrie Bay area at the northeastern tip of the Trinity Peninsula.

James Ross Island

James Ross Island (lat 64° S., long 58° W.) was selected for discussion because it is an area where substantial, measurable ice-front change is occurring and for which there are numerous source materials for making coastal-change measurements. The island is located east of the Trinity Peninsula; it measures 77 km north to south and 67 km east to west and has an area of 2,478 km^2 (Skvarca and others, 1995).

Earlier workers have investigated the glaciers of James Ross Island and their fluctuations. Rabassa and others (1982) made a glacier inventory of James Ross and Vega Islands on the basis of 1:250,000-scale maps, Landsat MSS images, and 1979 to 1980 aerial photography. Their effort was the first glacier inventory of the area using the methodology proposed by the Temporary Technical Secretariat of the World Glacier Inventory (Müller and others, 1977, 1978). The inventory identified 138 glaciers on James Ross Island having a total area of 1,989 km^2, or about 80 percent of the island area. The glaciers comprised many types, including a large ice field with numerous outlet glaciers, small ice caps, and mountain and valley glaciers.

Skvarca and others (1995) studied the fluctuation of 39 outlet glaciers from 1975 to 1993 using Kosmos KATE-200, Landsat MSS and TM, and ERS-1 SAR images. They documented a general retreat of 33 of the glaciers, with 15 tidewater glaciers showing significant retreat. They reported a total ice loss of 22.8 km^2 between 1975 and 1988, an average retreat of 1.84 km^2 a^{-1}. Rau and others (2004) studied the glacier frontal variation on James Ross Island. They measured the retreat from 1988 to 2001, and found average retreat of 3.79 km^2 a^{-1}, more than double the previous measurements during a similar time period. They also reported that although the highest retreat rates were found in tidewater glaciers, nevertheless 81 percent of the glaciers terminating on land were retreating in 2002 compared to only 20 percent earlier.

Our measurements of ice-front change were made at 26 locations around the island, of which 12 experienced rapid change of more than 75 m a^{-1}. Of the 26 locations, 8 glaciers have names recognized by the U.S. Advisory Committee on Antarctic Names (ACAN)—Ball, Coley, Gourdon, Hobbs, Howarth, Ineson, Swift, and Tait Glaciers; the other 18 are described by nearby geographic features. All of the measured locations correspond with glaciers measured by Skvarca and others (1995).

The source materials for our coastal-change measurements of James Ross Island date from 1945, 1952, 1956, 1957, 1964, 1968, 1974, 1977, 1979, 1980, 1986, 1988, 1989, 1995, 1997, and 2000 (see table 5). Not every source covers the entire island. The greatest number of source materials covering any one location is 10 and the fewest is 4. Refer to the inset map of James Ross Island, to tables 5 and 6 in this pamphlet, and to the Excel table on the SCAR ADD Web site (http://www.add.scar.org) for more detailed information.

The average coastal change per year for James Ross Island, as for most other areas on this map, is overwhelmingly negative, with the most dramatic evidence for retreat occurring since the middle 1980s, and with recession continuing to increase in most areas through the most recent measurements in 2000. All the earlier measurements show that recession occurred between 1945 and the middle 1950s. From the middle 1950s to about 1980 there were instances of both retreat and advance before the trend became strikingly negative.

Some glacier and ice-front locations have been especially active. Coley, Gourdon, Swift, and Tait Glaciers, and the unnamed ice fronts south of Sungold Hill (b), in Holluschickie Bay, east of Nygren Point, and in Whisky Bay are the most active. Coley, Swift, and Tait Glaciers advanced a maximum of 1.3 km, 0.9 km, and 1.2 km, respectively, between 1952 and 1964. Coley, Gourdon, Swift, and Tait Glaciers, and the unnamed ice front east of Nygren Point, had maximum retreats ranging from 0.8 to 1.6 km during various time periods between 1964 and 2000. (For more detail see the Excel file on the SCAR ADD Web site.) Of these, Tait and Swift Glaciers and the ice front east of Nygren Point are most noteworthy in the more recent years. Tait Glacier and the ice front east of Nygren Point may be responding to both the changing climate conditions and the disappearance of the Prince Gustav Ice Shelf, which had constrained and protected their termini prior to the late 1950s. Swift Glacier was recognized and named for its activity as early as the Falkland Islands Dependencies Survey (FIDS) fieldwork of 1958–61.

Of all of the locations measured, Howarth Glacier and the unnamed ice fronts in Holluschickie Bay, north of Coley Glacier, north of Stark Point, south of Blyth Spur, near Sungold Hill (b), east and west of Cape Foster, and west of Ula Point showed average annual change that was consistently negative (table 6). Considering the wealth of source material and the previous scientific work done on James Ross Island, the island offers superb opportunities for further studies of glacier fluctuation.

King George Island

King George Island was selected as one of the map areas for more discussion because its location may represent the climatological conditions of the South Shetland Islands and the western

Table 5. Source materials for coastal-change measurements of James Ross Island.

[Reliability ranking is explained in the Coastline Accuracies section of this pamphlet, p. 4. Abbreviations used: BAS, British Antarctic Survey; ETM+, Enhanced Thematic Mapper Plus; FID, Great Britain Colonial Office, Falkland Islands (and) Dependencies; MSS, Multispectral Scanner; TM, Thematic Mapper; USA TMA, United States of America, Trimetrogon Antarctica]

Date	Type	Reliability	Identification
1945	Published map	4	FID, 1:500,000 scale, South Shetlands and Graham Land, Sheet B (1948).
1945	Published map	2	FID, 1:100,000 scale, South Shetlands and Graham Land, Sheets 63.56 SE and SW (1948).
1945	Published map	3	FID, 1:100,000 scale, Sheets 64.58 NE and NW.
1952	Published map	3	FID, 1:200,000 scale, DOS610, Sheet 64.56 (1961).
1952	Unpublished map	3	FID, 1:100,000 scale, Sheets 63.56 NE, 63.58 SE, 64.56 NW, 64.58 NE.
27 Dec 1956	Aerial photography	2	FID.
2 Jan 1957	Aerial photography	1	FID.
26 Sep 1964	Aerial photography	2	USA TMA 1352, 1353.
30 Dec 1968	Aerial photography	2	USA TMA 2159.
1974	Published map	3	BAS 1:250,000 scale, Sheets SP 21–22/1, SP 21–22/13, and SQ 21–22/1.
31 Jan 1977	Satellite image	2	Landsat 2 MSS (2740–11454; Path 229, Row 105).
1 Dec 1979	Aerial photography	2	BAS.
1 Jan 1980	Aerial photography	1	BAS.
3 Jan 1986	Satellite image	2	Landsat 5 TM (50730–12295; Path 217, Row 105).
29 Feb 1988	Satellite image	1	Landsat 4 TM (42054–12162; Path 215, Row 105).
5 Nov 1989	Satellite image	2	Landsat 4 TM (42669–12303; Path 216, Row 105).
23 Feb 1995	Aerial photography	1	BAS.
10 Jan 1997	Satellite image	2	RADARSAT.
21 Feb 2000	Satellite image	1	Landsat 7 ETM+ LE7216105000005250.

Table 6. Average annual change of ice fronts on James Ross Island calculated for the time intervals between years when measurements were made.

[In meters per year, rounded to the nearest meter. Negative values are retreat; positive values are advance. #, time of first measurement at each location. In location column, numbers in parentheses represent unnamed features on inset map and correspond to numbers in table 4*B*, p. 30–32. For more detailed information, see complete digital file at http://www.add.scar.org]

Location	1945	1952	1956	1964	1968	1974	1977	1979	1980	1986	1988	1989	1995	1997	2000
Ball Glacier		#		+3			-8	+28	-67*		-3				-6
Coley Glacier	#	-12		+63		-73	+116	-142			-22			-44	-50
E. of Cape Foster (10)		#		-9				-3	-17*		-3		-12		-4
E. of Lomas Ridge (6)		#		+1			-1				-20				-8
E. of Nygren Point (12)		#			-13	+8	+80				-23	-146	+11	-184	-130
E. of Skep Point (2)	#	-6				+8					-28			-24	+14
E. of Tortoise Hill (5)		#		+5			-6	-23	-44*		-11				-17
Gourdon Glacier	#	-18		-25		+69	-279	+32			-36			-60	-65
Hobbs Glacier	#	-7		-23		+40	-102	-53			-12			-47	-24
Holluschickie Bay (13)	#	-56	-78					0	-116*	-73	-72	-75		-60	-2
Howarth Glacier		#		-14				-9			-20			-8	-82
Ineson Glacier	#	-20	-21 (1957)			+9		-19		-59	+142				-52
N. of Coley Glacier (4)	#	-6									-6				-10
N. of Flett Buttress (16)		#								+20	-20	+3		-64	-1
N. of Stark Point (18)	#	-18								-4	-27				-49
S. of Blyth Spur (15)	#										-4	-3			-52
S. of Stark Point (17)		#							+2		-23				-2

Table 6. Average annual change of ice fronts on James Ross Island calculated for the time intervals between years when measurements were made.—Continued

[In meters per year, rounded to the nearest meter. Negative values are retreat; positive values are advance. #, time of first measurement at each location. In location column, numbers in parentheses represent unnamed features on inset map and correspond to numbers in table 4*B*, p. 30–32. For more detailed information, see complete digital file at http://www.add.scar.org]

Location	1945	1952	1956	1964	1968	1974	1977	1979	1980	1986	1988	1989	1995	1997	2000
Sungold Hill a (8)		#		-7					+5		-8				-13
Sungold Hill b (9)		#		-30				-3	-39*		-5	-19	-5	-48	-112
Swift Glacier		#		+30		-74		-117	-110*		-73	-225		-142	-128
Tait Glacier		#		+76	-91			+8			-101	-95	-59	-519	-103
W. of Cape Foster (11)				#				-3			-10		-15		-29
W. of Lomas Ridge (7)		#		+22			+2	-6			-18	-35		+9	-77
W. of Skep Point (1)	#	-6				+1					-28				-13
W. of Ula Point (3)	#	-4									-5			-11	-29
Whisky Bay (14)	#	-9	-31			-10		-22		-42	-69	+39		-31	-70

*Average monthly measurements made from December 1, 1979, to January 1, 1980. The substantial retreat is noteworthy, but it is not possible to calculate an annual average from such a short time interval.

Table 7*A*. Average annual change of ice fronts on King George Island calculated for the time intervals between years when measurements were made.

[In meters per year, rounded to the nearest meter. Negative values are retreat; positive values are advance. #, time of first measurement at each location. In location column, names in parentheses are as described in the Excel table at the SCAR ADD Web site (http://www.add.scar.org) and do not necessarily agree with names shown in figure 3, p. 12. For more detailed information, see the complete digital file at http://www.add.scar.org]

Location	1947	1950	1956	1975	1979	1989	1999
Ajax Icefall	#	-27	-47	-1	-55	+20	
Baranowski Glacier	#				-6	+3	
Cardozo Cove	#	+22	-26	-3	-4	+4	
Collins Harbor (Harbour)		#	-49		-8	+11	
Dobrowolski Glacier (S. Precious Peaks)	#	+151	-138	-1	-21	-20	
Doctors Icefall (Goulden Cove)	#	-7	-69	-8	-8	-2	
Domeyko Glacier, east (W. Keller Peninsula)	#	+15	-69	-7	-3	-12	
Domeyko Glacier, west (MacKellar glacier)	#	+22	-42	-4	+40	-18	
Fourcade Glacier (Potter Cove)		#	-39		-2	-11	
Goetel Glacier (E. Ullmann Spur)	#	-21	-31	-1	-87	+31	
Hektor Icefall		#	-87		-6	-27	
Krak Glacier (Lussich Cove)	#	-4	-19	-7	-13	-6	
Lange Glacier	#	-8	-22	-8	-103	-1	
Moczyłowski Glacier (Marian Cove)		#	-43		+4	-14	
Polar Club Glacier (Telefon Point)		#	-38	-5	-70	-14	
Polonia Piedmont Glacier (King George Bay)		#	-59		-2	-8	-10
Stenhouse Glacier	#	-8	-47	-2	-38	+9	
Usher Glacier			#		+1	0	

Table 7*B*. Source materials for coastal-change measurements of King George Island.

[Reliability ranking is explained in the Coastline Accuracies section of this pamphlet, p. 4. Abbreviations used: BAS, British Antarctic Survey; FID, Great Britain Colonial Office, Falkland Islands (and) Dependencies; MSS, Multispectral Scanner; TM, Thematic Mapper]

Date	Type	Reliability	Identification
1947	Published map	3	Chilean Navy Hydrographic map, 1:100,000 scale, Admiralty Bay.
1950	Unpublished map	3	BAS archive, compiled by G. Jefford, 1:200,000 scale, King George Island.
12 Jan 1956	Aerial photography	1	FID.
26 Jan 1975	Aerial photography	1	British Royal Navy.
20 Feb 1979	Satellite image	2	Landsat 3 MSS (30352–12173; Path 232, Row 104).
28 Jan 1989	Satellite image	2	Landsat 4 TM (42388–12354; Path 217, Row 104).
21 Jan 1999	Aerial photography	1	British Royal Navy.

side of the Antarctic Peninsula. It is also the location of numerous research stations staffed by different nations; therefore, a variety of historical and current source material is readily available.

Coastal-change measurements were made at 18 locations on King George Island (table 7*A*). Sixteen of the locations have names recognized by ACAN (Ajax Icefall, Baranowski and Dobrowolski Glaciers, Doctors Icefall, the east and west parts of Domeyko Glacier, Fourcade and Goetel Glaciers, and Hektor Icefall; Krak, Lange, and Moczyłowski Glaciers; Polonia Piedmont Glacier; and Polar Club, Stenhouse, and Usher Glaciers); the other two locations are described by nearby geographic features. The coastal-change measurements at four ice-front locations (Dobrowolski, Goetel, and Lange Glaciers, and Hektor Icefall) show dramatic change in average advance or retreat of more than 75 m a^{-1} during one or more time periods.

The main source materials used for King George Island are from 1947, 1950, 1956, 1975, 1979, and 1989 (table 7*B*). The majority of ice-front locations measured for coastal change were covered either by all six of these data sources, or by five of the six. A few sites (Baranowski Glacier, Collins Harbor, Fourcade Glacier, Hektor Icefall, Moczyłowski Glacier, and Usher Glacier) were covered by only three or four sources. However, one location, Polonia Piedmont Glacier, had an additional source of information from 1999.

The measured coastal change of the glaciers on King George Island is not generally visible on the 1:1,000,000-scale printed map, but can be better seen on the enlargement of the northern Admiralty Bay area (fig. 3) and in the digital data on the SCAR ADD Web site. The average of the coastal-change measurements shows an overwhelmingly negative trend, with an increase in the amount of recession between 1950 and 1956 and between 1975 and 1979. Interestingly, the period from 1956 to 1975 showed much less recession and the period between 1979 and 1989 showed even less recession, and, in some cases, a slight advance (table 7*A*). The maximum advance in any time interval was 1,051 m at Dobrowolski Glacier between 1947 and 1950, and the maximum retreat was 1,244 m at the same location between 1950 and 1956. The seaward edge of Polonia Piedmont Glacier (King George Bay) retreated 938 m between 1950 and 1956. Baranowski Glacier in Admiralty Bay and Usher Glacier on the north coast of King George Island seem to show little change, although Usher Glacier has a small overall net advance. The lack of noticeable change in the position of the ice front of Usher Glacier may be a result of the scarcity of data, or may be due to the exposed location on the western coast of the island where wind and wave action may prevent ice-front advance. Because these measurements are averages over arbitrary time intervals when data sources were available, it is difficult to know what may have occurred during the intervening time, but the overall negative trend is very clear.

Other researchers who have worked on King George Island also reported recessionary trends. Park and others (1998) measured retreat in Moczyłowski Glacier (Marian Cove) and Fourcade Glacier (Potter Cove), and, although their measurements are made differently from ours, they show a similar trend. Their fieldwork also documents continued retreat in Marian Cove from 1989 to 1994. Braun and others (2001) documented retreat in Admiralty Bay and Potter Cove from 1979 to 1995 using aerial photographs, Landsat TM images, and Satellite Probatoire pour l'Observation de la Terre (SPOT) images. Braun and Gossman (2002) gave a comprehensive summary of glacial retreat on King George Island. Simöes and others (2003) noted the substantial reduction of sea ice in Admiralty Bay and stated that the King George Island icecap has lost 7 percent of its area in the last 25 years. Glaciological measurements have also been made on other islands in the South Shetlands. Calvet (1997), Calvet and others (1999), and Ximenis and others (1999) noted an approximate 4 percent reduction in area of the icecaps of Greenwich, Livingston, Robert, and Snow Islands from 1956 to the 1990s.

Duse Bay and Eyrie Bay

The Duse Bay and Eyrie Bay area was chosen for a more comprehensive discussion because (1) it is representative of the climatic conditions on the northeastern tip of the Trinity Peninsula, north of the areas of dramatic disintegration of the Larsen and Prince Gustav Ice Shelves, and (2) our coastal-change measurements show that this area has also been subject to substantial fluctuation, at times experiencing retreats of more than 75 m a^{-1} (fig. 4). Coastal-change measurements were made at 34 locations around Duse Bay and Eyrie Bay (table 8*A*).

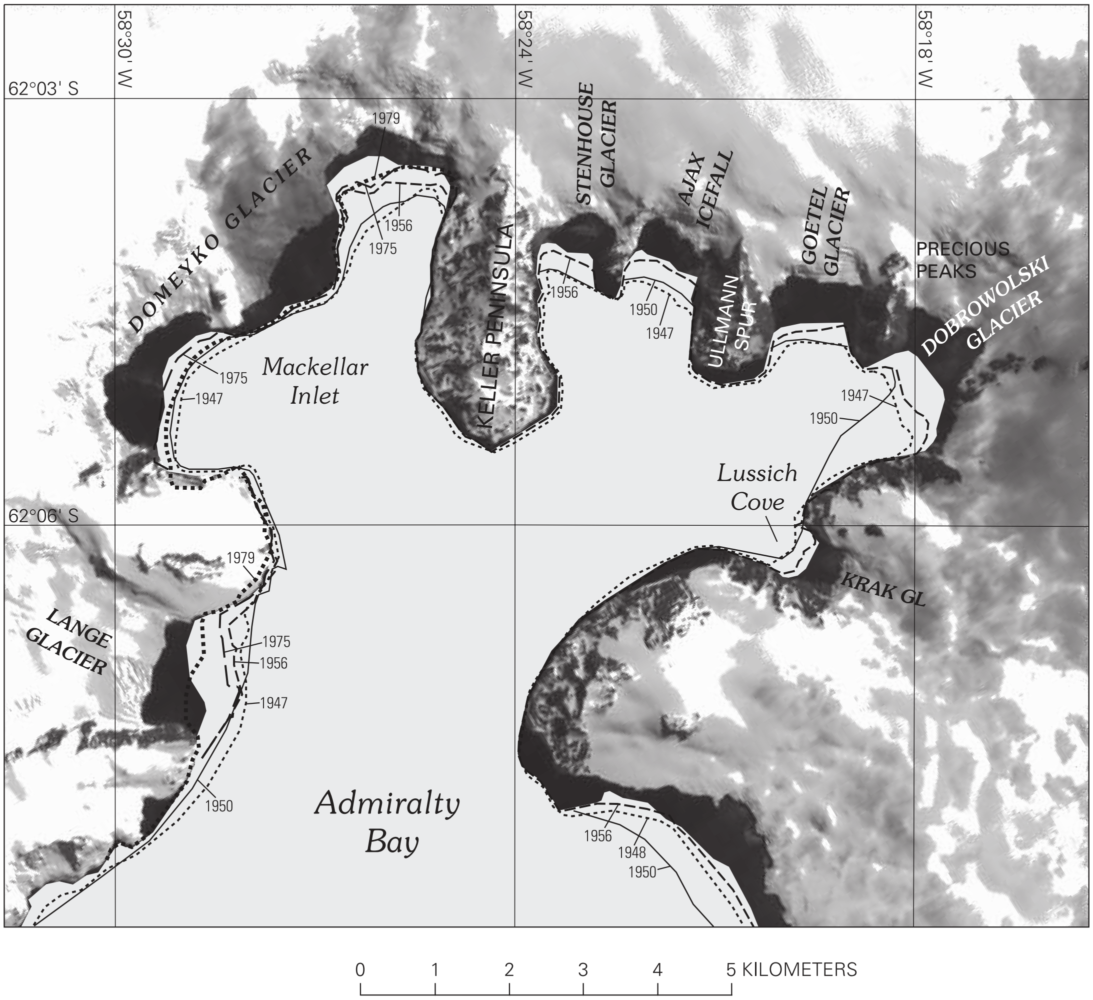

Figure 3. Enlargement of the northern Admiralty Bay area, King George Island, showing ice-front change. Image shows coastline position as of 1989.

Duse Bay (lat 63°30′ S., long 57°15′ W.) is surrounded on three sides by the Trinity Peninsula. The ice front is formed by ice flowing from the southern part of Mott Snowfield, the western part of Tabarin Peninsula, and the eastern part of Laclavère Plateau. Mondor Glacier is the only named glacier flowing into Duse Bay.

The source materials for ice-front-change measurements in Duse Bay were from 1947, 1956, 1977, 1988, 1997, and 2000 (table 8*B*). Ice-front measurements were made at 20 locations around the bay. All locations were covered by the 1947, 1956, and 1988 data; 11 locations were included in the 1977 data, 10 locations were included in the 1977 and 1997 data, and 9 locations had measurements from all six data sources. Of the 70 measurements of change, 3 showed minor advance averaging 1 to 5 m a^{-1}, and 1 showed major advance averaging 93 m a^{-1}. The remaining measurements showed continual retreat, with maximum retreat occurring as follows: 1.2 km between 1947 and 1956, 1.2 km between 1956 and 1977, 1.7 km from 1977 to 1988, and 1.3 km from 1988 to 1997. The average change per year indicated that the largest annual retreat (>100 m a^{-1}) generally occurred from 1977 to 1988 and from 1988 to 1997. Between 1997 and 2000, retreat continued, but at a slower rate.

Eyrie Bay (lat 63°35′ S., long 57°40′ W.) is just southwest of Duse Bay. The ice front is formed by ice flowing from the Cugnot Ice Piedmont on the west and from the Laclavère Plateau and Broad Valley. The source materials for ice-front-change measurements in this area were from 1946, 1956, 1977, 1988, 1997, and 2000 (table 8*B*).

Ice-front measurements were made at 14 locations in Eyrie Bay, and all locations except one were covered by all six data sources. The measurements of change showed both similarities and differences to changes in Duse Bay. In Eyrie Bay, the ice front retreated substantially between 1946 and 1956, with a maximum total change of 1 km and average annual change ranging from 5 to 108 m a^{-1}. Between 1956 and 1977, the ice front retreated in the northern part of the bay a maximum of more than 800 m, and advanced in the southern part a maximum of 1.5 km. From 1977 to 1988, substantial retreat occurred along the entire ice front, with a maximum total change of 2.6 km and average annual change as large as 234 m a^{-1}. Between 1988 and 1997, retreat continued in most areas but not as rapidly. Surprisingly,

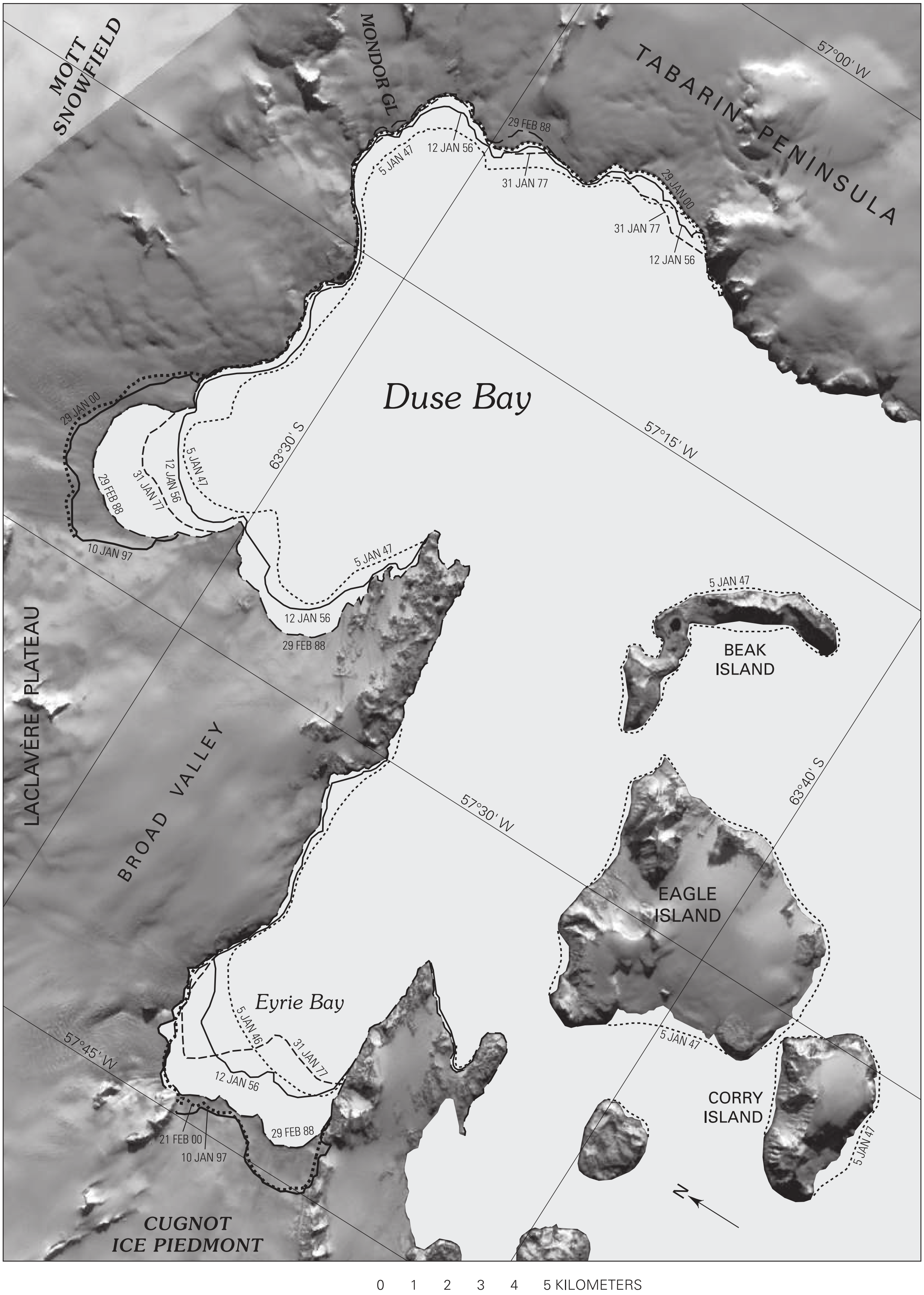

Figure 4. Enlargement of the Duse Bay and Eyrie Bay area, Trinity Peninsula, showing ice-front change.

between 1997 and 2000 the trend changed, and most areas of the ice front advanced somewhat, most noticeably in the northern section. The reason for this advance is unknown, because most other areas were receding; it would be worth further investigation.

Table 8*A*. Average annual change of ice fronts in the Duse Bay and Eyrie Bay area, Trinity Peninsula, calculated for the time intervals between years when measurements were made.

[In meters per year, rounded to the nearest meter. Negative values are retreat; positive values are advance. #, time of first measurement at each location. For more detailed information, see complete digital file at http://www.add.scar.org]

Location	1946	1947	1956	1977	1988	1997	2000
Duse Bay							
1.		#	+93	-11	+1	+5	-18
2.		#	-129	-7	+1	-94	-49
3.		#	-39	-15	-1	-145	-92
4.		#	-20	-32	-109	-46	-40
5.		#	-15	-50	-114	-91	-68
6.		#	-14	-55	-132	-95	-33
7.		#	-26	-49	-149	-56	-91
8.		#	-36	-34	-158	-116	-48
9.		#	-42	-32	-146	-147	-27
10.		#	-55	-29	-110	-68	
11.		#	-68	-19	-25		
12.		#	-41		-9		
13.		#	-22		-6		
14.		#	-124		-18		
15.		#	-71		-27		
16.		#	-48		-19		
17.		#	-31		-26		
18.		#	-17		-27		
19.		#	-18		-19		
20.		#	-44		-11		
Eyrie Bay							
1.	#		-48	0	-16	+9	-28
2.	#		-39	-18	-19	-33	+57
3.	#		-45	-36	-1	-19	+50
4.	#		-81	-36	-12	-14	+21
5.	#		-108	-32	-20	-41	+113
6.	#		-108	-41	-59	+7	-22
7.	#		-104	+30	-211		-8
8.	#		-100	+49	-200	-95	+157
9.	#		-69	+73	-234	-59	+28
10.	#		-5	+44	-234	-23	-2
11.	#		-26	+50	-198	-91	+10
12.	#		-30	+49	-226	-126	+29
13.	#		-16	+38	-219	-148	+6
14.	#		+7	+19	-182	-179	+56

Table 8*B*. Source materials for coastal-change measurements in the Duse Bay and Eyrie Bay area, Trinity Peninsula.

[Reliability ranking is explained in the Coastline Accuracies section of this pamphlet, p. 4. Abbreviations used: ETM+, Enhanced Thematic Mapper Plus; FID, Great Britain Colonial Office, Falkland Islands (and) Dependencies; FIDASE, Falkland Islands and Dependencies Aerial Survey Expedition; MSS, Multispectral Scanner; TM, Thematic Mapper]

Date	Type	Reliability	Identification
1946	Published map	3	FID, 1:150,000 scale.
1947	Unpublished map	3	FID, 1:100,000 scale.
12 Jan 1956	Aerial photography	1	FIDASE.
31 Jan 1977	Satellite image	2	Landsat 2 MSS (2740–11454; Path 229, Row 105).
29 Feb 1988	Satellite image	1	Landsat 4 TM (42054–12162; Path 215, Row 105).
10 Jan 1997	Satellite image	2	RADARSAT.
29 Jan 2000	Satellite image	1	Landsat 7 ETM+, LE7215104000002950 (Duse Bay).
21 Feb 2000	Satellite image	1	Landsat 7 ETM+, LE7216105000005250 (Eyrie Bay).

Outlet-Glacier, Ice-Stream, and Ice-Shelf Velocities

Only a few velocity measurements have been made in the map area, but those measurements are very useful in evaluating glaciological changes in the northern Antarctic Peninsula. The earliest measurements were made by Bindschadler and others (1994) on the northern Larsen Ice Shelf (Larsen A) using the cross-correlation technique of Scambos and others (1992) to track ice features over time. They used three satellite images from three different satellites and dates—a 1975 Kosmos Kate-200 photograph, a 1986 Landsat MSS image, and a 1989 Landsat TM image—to derive velocity fields from 1975 to 1986 and from 1986 to 1989. The ice-surface velocities during the earlier (1975 to 1986) time period ranged from 120 m a^{-1} to a maximum of 235 m a^{-1} in the Drygalski Glacier area. During the later time period (1986 to 1989), the velocities ranged from 156 m a^{-1} to 257 m a^{-1}. All areas of the northern Larsen Ice Shelf showed an increase in average velocity in the later time period, with the greatest increase (15 percent) in the southern part of the area. This did not correlate with the ice-front retreat that was more pronounced in the northern part. Rack and others (1999) did a similar study using cross-correlation techniques with a Landsat MSS image from 1986, Landsat TM images from 1988, 1989, and 1990, and ERS-1 SAR images from 1992 and 1993. Their results from 1986 to 1989 showed the same values as Bindschadler and others (1994). However, their ice-surface velocities derived from 1992 and 1993 ERS-1 SAR images were about 10 percent higher. Rott and others (2002) used a variety of satellite data to look at changes in the velocities of outlet glaciers after the collapse of the Prince Gustav and Larsen A Ice Shelves in 1995. ERS interferograms from 1995 and 1999 showed that Sjögren and Boydell Glaciers, which flowed into the Prince Gustav Ice Shelf, had strongly accelerated by 1999, and by as much as a factor of two in the central flow line of Sjögren Glacier. Looking at the velocities of Dinsmoor-Bombardier-Edgeworth and Drygalski Glaciers, which flowed into Larsen A Ice Shelf, the velocities of the central area of Dinsmoor-Bombardier-Edgeworth Glaciers had increased from 1.5 m per day (d^{-1}) (~550 m a^{-1}) in 1995 to 6.0 m d^{-1} (~2,200 m a^{-1}) in 1999. For Drygalski Glacier, the increase was very noticeable, but not as large. The 1995 interferogram gave a maximum velocity at the ice front of 3.3 m d^{-1} (~1,200 m a^{-1}). The 1999 interferogram showed that upstream velocities had increased by a factor of as much as 2.9, and that the velocity increase was even greater downstream. This would imply that the velocity of the Drygalski Glacier ice front had increased by at least a factor of three, to 10 m d^{-1} (~3,600 m a^{-1}). Later fieldwork and image analysis by De Angelis and Skvarca (2003) gave evidence of a surge of Drygalski, Bombardier, Edgeworth, Boydell, and Sjögren Glaciers after the collapse of the ice shelves.

In addition to the previous measurements, Ximenis and others (1999) made stake measurements of the ice velocity of Johnsons Glacier on Livingston Island from the austral summer of 1994–95 to the austral summer of 1997–98, and estimated values of 1 m a^{-1} near the head of the glacier and 40 m a^{-1} near the terminus. Pedro Skvarca, Instituto Antártico Argentino (IAA), made static differential Global Positioning System (GPS) measurements in 1998, 1999, and 2000 on a small outlet glacier located on the northern part of Vega Island. The velocities of the 14.3-km^2 glacier range from 1 to 14 m a^{-1} and are available from the U.S. National Snow and Ice Data Center (NSIDC), Boulder, Colo. Coren and others (2003) used interferometry to derive the ice-velocity field of the King George Island icecap.

Map Revisions and Comparisons

As discussed in the Sources section and the Analytical and Other Methodologies section, the Trinity Peninsula area and South Shetland Islands map was compiled from analysis of geographic and glaciologic features on Landsat 1–5 and 7 images, aerial photographs, other satellite imagery, and historical maps and manuscripts. The area previously had been extensively mapped by the United Kingdom and, in more localized areas, by other nations. As each new map was created, we made comparisons between the early maps (which were generated from aerial photographs and ground surveys) and the modern, satellite-derived sources. Significant retreat of the glaciers in the Duse Bay area, for example, was first recognized when a new, 1:250,000-scale map of the Trinity Peninsula, based on the IfAG satellite image mosaic (Bundesamt für Kartographie und Geodäsie and British Antarctic Survey, 1996), was compared with an earlier map prepared mostly from FIDASE aerial photographs from 1956 [Directorate of Overseas Surveys, 1974, Sheet SP 21-22/13; see table 2 (p. 23–26)]. Furthermore, the correct shape of James Ross Island was revealed only after satellite images became available; the BAS map of the island (British Antarctic Survey, 1995) was based on images acquired in the mid-1980s, and the retreat of glaciers since then is clearly visible on this coastal-change map.

Summary

The analysis of Landsat 1, 2, and 3 MSS images (1973–1979), Landsat 4 and 5 MSS and TM images (1986–1990), Landsat 7 ETM+ images (2000–2001), other satellite images, aerial photography, and historical data of the Trinity Peninsula area made it possible to identify and describe glaciological features, document coastal change, and look for trends in the changing coastline.

The Trinity Peninsula area and South Shetland Islands map covers the northernmost part of the Antarctic Peninsula and adjacent islands from lat 60° to 65° S. and from long 52° to 67° W., and includes the Danco, Davis, and Nordenskjöld Coasts. The most significant glaciological features in the map area prior to 1980 were the Prince Gustav and northernmost Larsen Ice Shelves. During the 1980s and 1990s major retreat occurred, and in 1995, most of the remaining parts of the ice shelves disintegrated. The rest of the coastline in the map area is composed mainly of semistable grounded ice walls and the floating ice fronts of a few small ice shelves and numerous outlet glaciers. There are 161 glaciological features whose names are currently recognized by the United States: 73 on the mainland, 4 on Anvers Island, 9 on Brabant Island, 1 on Clarence Island, 4 on Elephant Island, 5 on Greenwich Island, 8 on James Ross Island, 29 on King George Island, 25 on Livingston Island, and 3 on Wiencke Island. There are 126 unnamed glaciers and ice fronts where substantial coastal change has occurred. Although the Antarctic Peninsula is a challenging area in which to carry out a complete glacier inventory, excellent work has been done on James Ross Island, on King George Island, and locally on the peninsula.

Only a limited number of ice-velocity measurements have been made in the map area. The most interesting show an increase in velocities of outlet glaciers since 1995 that, prior to that time, were constrained by the Prince Gustav and Larsen A Ice Shelves.

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Appendix—Tables 1*A*, 1*B*, 2, 3, 4*A*, 4*B*, and 9

Table 1*A*. Aerial photographs used in analysis of ice-front change for the coastal-change and glaciological map of the Trinity Peninsula area and South Shetland Islands.

[Scales range from 1:10,000 to 1:50,000 but are not listed in the table because the scale is not directly related to the reliability of the ice-front-change analysis. See section on reliability in the Coastline Accuracies section of this pamphlet, p. 4. Abbreviations used: BAS, British Antarctic Survey; FIDASE, Falkland Islands and Dependencies Aerial Survey Expedition; IfAG, Institut für Angewandte Geodäsie; USA TMA, United States of America, Trimetrogon Antarctica]

Date	Source
1956–57	FIDASE vertical.
1964–69	USA TMA vertical and oblique.
1972–79, 1986, 1989, 1991, 1999	British Royal Navy vertical.
1979, 1980, 1986, 1989, 1990–97, 1999, 2001	BAS vertical.
1989	IfAG vertical.
2001	BAS hand-held camera from Twin Otter aircraft.

Table 1*B*. Landsat images used in analysis of ice-front change for the coastal-change and glaciological map of the Trinity Peninsula area and South Shetland Islands.

[Abbreviations used: ETM+, Enhanced Thematic Mapper Plus; MSS, Multispectral Scanner; TM, Thematic Mapper]

Path/Row	Eros Data Center (EDC) Entity Number	Date	Path/Row	Eros Data Center (EDC) Entity Number	Date
Landsat 1, 2, and 3 MSS images			Landsat 4, 5, and 7 MSS, TM, and ETM+ images		
229/105	2229105007703190	31 Jan 1977	214/103	7214103000005450	23 Feb 2000
229/106	2229106007703190	31 Jan 1977	215/104	7215104000002950	29 Jan 2000
230/105	2230105007703290	1 Feb 1977	215/104	4215104009004910	18 Feb 1990
230/106	2230106007703290	1 Feb 1977	215/105	4215105008806010	29 Feb 1988
232/104	3232104007905190	20 Feb 1979	216/103	4216103008930910	5 Nov 1989
232/105	3232105007905190	20 Feb 1979	216/105	4216105008930910	5 Nov 1989
232/106	3232106007830890	4 Nov 1978	216/105	7216105000005250	21 Feb 2000
233/104	1233104007304790	16 Feb 1973	217/103	4217103008902810	28 Jan 1989
233/105	1233105007400690	6 Jan 1974	217/104	4217104008902810	28 Jan 1989
233/105	1233105007304790	16 Feb 1973	217/104	5217104008636490	30 Dec 1986
233/106	1233106007304790	16 Feb 1973	217/105	5217105008606010	1 Mar 1986
234/104	1234104007304890	17 Feb 1973	217/106	5217106008606010	1 Mar 1986
234/105	1234105007304890	17 Feb 1973	219/104	4219104009004510	14 Feb 1990
			219/105	4219105008933010	26 Nov 1989

Table 2. Maps used as source materials for the coastal-change and glaciological map of the Trinity Peninsula area and South Shetland Islands.

[Abbreviations of areas covered: Adelaide, Adelaide Island; Clarence, Clarence Island; Danco, Danco Coast; Detroit, Detroit Plateau; Elephant, Elephant Island; Graham, Graham Land; Jnville, Joinville Island; JRI, James Ross Island; Ntrin, northern Trinity Peninsula; S_Shets, South Shetland Islands; Strin, southern Trinity Peninsula. Other abbreviations: BAS, British Antarctic Survey; BAT, British Antarctic Territory; BGLE, British Graham Land Expedition 1934–37; DCS, Great Britain, Directorate of Colonial Surveys; DMS, Great Britain, Directorate of Military Survey; DOS, Great Britain, Directorate of Overseas Surveys; FID, Great Britain Colonial Office, Falkland Islands (and) Dependencies; FIDASE, Falkland Islands and Dependencies Aerial Survey Expedition 1955–57; FIDS, Falkland Islands Dependencies Survey; MSS, Multispectral Scanner; RARE, Ronne Antarctic Research Expedition 1947–48; TMA, Trimetrogon Antarctica (USA); Provis., provisional; pub., published; unpub., unpublished]

Areas covered	Pub./ unpub.	Publisher	Map date	Map series	Edition	Scale	BAS reference number	Map name and sheet	Comments
Ntrin	Unpub.		Nov. 1946			1:150,000	ES2/EW1000A/FIDS E6/47	Trinity Peninsula North	Surveyor – Francis, S.J.; result of 1st and 3d sledge journeys.
Ntrin	Unpub.		May 1947?			1:100,000	ES2/EW1000A/ FIDS114/48	Trinity Peninsula SE Coast	Surveyor – Francis, S.J. (survey and compilation date May 1947).
Detroit, Danco, S_Shets	Pub.	DCS	1948	DCS 9	1st (Provis.)	1:500,000	PM/GB/02/C/01/A	FID – South Shetlands and Graham Land; Sheet A	Compiled from unpub. BGLE maps (1934–37); unpub. FIDS maps (1944); Admiralty Chart no. 3205 (1937).
JRI, Ntrin, Strin, Jnville, S_Shets	Pub.	DCS	1948	DCS 9	1st (Provis.)	1:500,000	PM/GB/02/C/01/B	FID – South Shetlands and Graham Land; Sheet B	Compiled from unpub. FIDS maps (1945–47) and Admiralty Chart no. 3205 (1937).
Graham, Adelaide	Pub.	DCS	1948	DCS 9	1st (Provis.)	1:500,000	PM/GB/02/C/01/C	FID – South Shetlands and Graham Land; Sheet C	Compiled from unpub. BGLE maps (1934–37); unpub. FIDS maps (1946–47); Admiralty Chart no. 3175 (1940).
Detroit	Pub.	DCS	1949	DCS 701	1st (Provis.)	1:500,000	PM/GB/02/C/01/E	FID – South Shetlands and Graham Land; Sheet E	Compiled from Admiralty Chart no. 3175 (1940) and unpub. 1:200,000 surveys by FIDS (1947).
JRI, Ntrin	Pub.	DCS	May 1948			1:100,000	PM/GB/02/D/11/ 6356SW	FID – South Shetlands and Graham Land; Sheet 63.56 SW	
JRI, Ntrin, Strin	Pub.	DCS	May 1948			1:100,000	PM/GB/02/D/11/ 6358SE	FID – South Shetlands and Graham Land; Sheet 63.58 SE	
JRI	Unpub.		May 1948			1:100,000	ES2/EW1000A/13A	Vega Island	Surveyor – Russell, V.I. (Feb. 1945–Jan. 1947).
JRI	Unpub.		May 1948			1:100,000	ES2/EW1000A/10	FID – Sheet 64.58 NE	Surveyor – Russell, V.I. (Feb. 1945–Jan. 1947).

Table 2. Maps used as source materials for the coastal-change and glaciological map of the Trinity Peninsula area and South Shetland Islands.—Continued

[Abbreviations of areas covered: Adelaide, Adelaide Island; Clarence, Clarence Island; Danco, Danco Coast; Detroit, Detroit Plateau; Elephant, Elephant Island; Graham, Graham Land; Jnville, Joinville Island; JRI, James Ross Island; Ntrin, northern Trinity Peninsula; S_Shets, South Shetland Islands; Strin, southern Trinity Peninsula. Other abbreviations: BAS, British Antarctic Survey; BAT, British Antarctic Territory; BGLE, British Graham Land Expedition 1934–37; DCS, Great Britain, Directorate of Colonial Surveys; DMS, Great Britain, Directorate of Military Survey; DOS, Great Britain, Directorate of Overseas Surveys; FID, Great Britain Colonial Office, Falkland Islands (and) Dependencies; FIDASE, Falkland Islands and Dependencies Aerial Survey Expedition 1955–57; FIDS, Falkland Islands Dependencies Survey; MSS, Multispectral Scanner; RARE, Ronne Antarctic Research Expedition 1947–48; TMA, Trimetrogon Antarctica (USA); Provis., provisional; pub., published; unpub., unpublished]

Areas covered	Pub./ unpub.	Publisher	Map date	Map series	Edition	Scale	BAS reference number	Map name and sheet	Comments
JRI	Unpub.		May 1948			1:100,000	ES2/EW1000A/11	FID – Sheet 64.56 NW	Surveyor – Russell, V.I. (Feb. 1945–Jan. 1947).
Ntrin	Unpub.		May 1948			1:100,000	ES2/EW1000A/14	FID – Sheet 63.56 NW	Surveyor – Russell, V.I. (Feb. 1945–Jan. 1947).
Strin	Unpub.		1948			1:200,000	ES2/EW1000A/8	FID – Sheet 64.58	Surveyor – Francis, S.J. (1947).
Danco	Unpub.		1947–1948			1:100,000	ES2/EW1000A/4	FID – Sheet 64.62 SW	Compiled by Russell, V.I.; surveys by Taylor, A. (1944) and Ryder, R.N. (1935).
S_Shets	Pub.		1947			1:100,000	PM/CL/04/D/XX/502	Admiralty Bay, King George Is. – Hydrography	Armada de Chile.
Jnville	Unpub.		May 1948			1:100,000	ES2/EW1000A/16	FID – Sheet 63.56 NE	Surveyor – Russell, V.I. (Feb. 1945–Jan. 1947).
S_Shets	Pub.		Last edition 1947			1:670,000	ES3/GY6/4.12/7	South Shetlands and Peninsula – working map	First published in 1901 (at the Admiralty), but many later editions up to 1947.
Danco	Unpub.		1948			1:10,000	ES3/GY1/4.22/1	Port Lockroy	Compiled by Pawson, K.; surveying by Taylor, A., in Aug. 1944.
Strin	Unpub.		1949			1:100,000	ES2/EW1000A/17	FID – Sheet 63.58 SW	Compiled at DCS by McNeile, S.; surveying between Mar. 1948 and Feb. 1949.
S_Shets	Unpub.		1950			1:200,000	ES2/EW1000A/3	King George Island	Compiled by Jefford, G.; surveying carried out 1949–50.
JRI	Unpub.		1954			1:100,000	ES2/EW1000A/ 6456NW	FID – Sheet 64.56 NW	Compiled at DCS by Blaiklock, K.V., and Stratton, D.G.; surveying between Aug. 1952 and Feb. 1954.
JRI	Unpub.		1954			1:100,000	ES2/EW1000A/ 6458NE	FID – Sheet 64.58 NE	Compiled at DCS by Blaiklock, K.V., and Stratton, D.G.; surveying between Aug. 1952 and Feb. 1954.

Table 2. Maps used as source materials for the coastal-change and glaciological map of the Trinity Peninsula area and South Shetland Islands.—Continued

[Abbreviations of areas covered: Adelaide, Adelaide Island; Clarence, Clarence Island; Danco, Danco Coast; Detroit, Detroit Plateau; Elephant, Elephant Island; Graham, Graham Land; Jnville, Joinville Island; JRI, James Ross Island; Ntrin, northern Trinity Peninsula; S_Shets, South Shetland Islands; Strin, southern Trinity Peninsula. Other abbreviations: BAS, British Antarctic Survey; BAT, British Antarctic Territory; BGLE, British Graham Land Expedition 1934–37; DCS, Great Britain, Directorate of Colonial Surveys; DMS, Great Britain, Directorate of Military Survey; DOS, Great Britain, Directorate of Overseas Surveys; FID, Great Britain Colonial Office, Falkland Islands (and) Dependencies; FIDASE, Falkland Islands and Dependencies Aerial Survey Expedition 1955–57; FIDS, Falkland Islands Dependencies Survey; MSS, Multispectral Scanner; RARE, Ronne Antarctic Research Expedition 1947–48; TMA, Trimetrogon Antarctica (USA); Provis., provisional; pub., published; unpub., unpublished]

Areas covered	Pub./ unpub.	Publisher	Map date	Map series	Edition	Scale	BAS reference number	Map name and sheet	Comments
Jnville	Unpub.		1954			1:100,000	ES2/EW1000A/ 6354NW/54	FID – Sheet 63.54 NW	Compiled at DCS by Blaiklock, K.V.; surveying between Aug. 1952 and Feb. 1954.
Jnville	Unpub.		1954			1:100,000	ES2/EW1000A/ 6356NE/54	FID – Sheet 63.56 NE	Compiled at DCS by Blaiklock, K.V.; surveying between Aug. 1952 and Feb. 1954.
Strin, Ntrin	Pub.	DCS	Sept. 1955			1:200,000	PM/GB/02/D/12/6358	FID – Sheet 63 58	Corrections in Nov. 1956.
Danco	Unpub.		1955			1:200,000	ES2/EW1000A/ 64.62/55	FID – Sheet 64 62	Compiled at DCS by Blaiklock, K.V. (1955); surveying carried out in Mar. and Apr. 1955.
Danco, S_Shets	Unpub.		1956			1:100,000	ES2/EW1000A/ 64.62SW/56	FID – Sheet 64.62 SW	Compiled at DCS by Rennie, A.J., and Hindson, W.J. (1956); surveying during 1955–56.
JRI	Unpub.		1957			1:100,000	ES2/EW1000A/ 63.58SE/56	FID – Sheet 63 58 SE	Compiled by Leppard, N.A.G.; surveys by Blaiklock, K.V. (Aug. 1952 and June–Oct. 1955).
Detroit	Unpub.		1957			1:200,000	ES2/EW1000A/ 65.58/57	FID – Sheet 65 58	Compiled at DCS by Leppard, N.A.G.; surveys by Leppard (Oct. 1955) and from 1947 and 1953.
Ntrin	Pub.	DOS	1960	DOS 310	1st	1:25,000	PM/GB/02/E/02/6356	FID – Graham Land; Hope Bay	
JRI	Pub.	DOS	1961	DOS 650 Series D501	1st	1:200,000	PM/GB/02/D/01/6456	FID – Sheet W 64 56; Graham Land	
Detroit	Pub.	DOS	1961	DOS 610 Series D501	1st	1:200,000	PM/GB/02/D/01/6558	FID – Sheet W 65 58; Graham Land	Compiled from surveys by Leppard, N.A.G. (1954–56) and Blaiklock, K.V. (1952–54); Argentine Chart 110 (1957).
Strin, JRI, Detroit	Pub.	U.S. Naval Oceanographic Office	Oct. 1966		1st	1:200,000	PM/US/04/XX/01/6940 (1)	Antarctic Peninsula – East Coast; Corry Island to Robertson Island	

Table 2. Maps used as source materials for the coastal-change and glaciological map of the Trinity Peninsula area and South Shetland Islands.—Continued

[Abbreviations of areas covered: Adelaide, Adelaide Island; Clarence, Clarence Island; Danco, Danco Coast; Detroit, Detroit Plateau; Elephant, Elephant Island; Graham, Graham Land; Jnville, Joinville Island; JRI, James Ross Island; Ntrin, northern Trinity Peninsula; S_Shets, South Shetland Islands; Strin, southern Trinity Peninsula. Other abbreviations: BAS, British Antarctic Survey; BAT, British Antarctic Territory; BGLE, British Graham Land Expedition 1934–37; DCS, Great Britain, Directorate of Colonial Surveys; DMS, Great Britain, Directorate of Military Survey; DOS, Great Britain, Directorate of Overseas Surveys; FID, Great Britain Colonial Office, Falkland Islands (and) Dependencies; FIDASE, Falkland Islands and Dependencies Aerial Survey Expedition 1955–57; FIDS, Falkland Islands Dependencies Survey; MSS, Multispectral Scanner; RARE, Ronne Antarctic Research Expedition 1947–48; TMA, Trimetrogon Antarctica (USA); Provis., provisional; pub., published; unpub., unpublished]

Areas covered	Pub./ unpub.	Publisher	Map date	Map series	Edition	Scale	BAS reference number	Map name and sheet	Comments
S_Shets	Pub.	DOS	1968	DOS 610 Series D501	1st	1:200,000	PM/GB/02/D/01/6258	BAT – Sheet W 62 58; South Shetland Islands	Compiled from FIDASE aerial photography (1956–57).
S_Shets	Pub.	DOS	1968	DOS 610 Series D501	1st	1:200,000	PM/GB/02/D/01/6260	BAT – Sheet W 62 60; South Shetland Islands	Compiled from FIDASE aerial photography (1956–57).
S_Shets	Pub.	DOS	1968	DOS 610 Series D501	1st	1:200,000	PM/GB/02/D/01/6256	BAT– Sheet W 62 56; South Shetland Islands	Compiled from FIDASE aerial photography (1956–57).
Elephant, Clarence	Pub.	DMS	1972	D501 (Part of DOS 610 series)	1st	1:200,000	PM/GB/02/D/01/6154	BAT – Sheet W 61 54 (extended); South Shetland Islands	Compiled using FIDASE aerial photography (1956–57).
Jnville	Pub.	DOS	1973	BAS 250	1st	1:250,000	PM/GB/02/D/06/SP21-22/14	BAT – Sheet SP21-22/14 (extended); Joinville Island	Compiled using FIDASE aerial photography (1956–57).
JRI, Ntrin, Strin	Pub.	DOS	1974	BAS 250	1st	1:250,000	PM/GB/02/D/06/SP21-22/13	BAT – Sheet SP21-22/13; Trinity Peninsula	Compiled using FIDASE aerial photography (1956) and TMA (1966).
JRI, Detroit	Pub.	DOS	1974	BAS 250	1st	1:250,000	PM/GB/02/D/06/SQ21-22/1	BAT – Sheet SQ21-22/1; James Ross Island	Compiled using FIDASE aerial photography (1956) and TMA (1966).
Detroit, Danco	Pub.	DOS	1974	BAS 250	1st	1:250,000	PM/GB/02/D/06/SQ19-20/4	BAT –Sheet SQ19-20/4	Compiled using FIDASE aerial photography (1956) and TMA (1968–69).
Detroit	Unpub.		1979			1:250,000	ES2/EW1000A/217	Robertson Island	Compiled by Harris, J.S.; coastline date is 1977.
Danco	Pub.	DOS	1979	BAS 250 P	1st	1:250,000	PM/GB/03/D/07/SQ19-20/3	Sheet SQ19-20/3; Anvers Island	Based on U.S. Landsat MSS imagery, Band 7.

Table 3. Manuscripts in the British Antarctic Survey (BAS) Archives used as source materials for the coastal-change and glaciological map of the Trinity Peninsula area and South Shetland Islands.

Aitkenhead, N., 1963, Nordenskjöld Coast; trace showing iceshelf edge, November 1961, between Cape Longing and Robertson Island: Cambridge, United Kingdom, British Antarctic Survey, unpublished notes, BAS Archives no. ES2/EW1000A/123.

Bibby, J.S., 1958, Sea ice and shelf ice conditions, James Ross Island area, August 1958: Cambridge, United Kingdom, British Antarctic Survey, manuscript map, BAS Archives no. ES4/4/2.

Bibby, J.S., 1959, Sea ice and shelf ice conditions, James Ross Island area, August 1959: Cambridge, United Kingdom, British Antarctic Survey, manuscript map, BAS Archives no. ES4/4/3.

Herbert, W.W., 1957, Map of sea ice and shelf ice conditions, James Ross Island area, August 1957: Cambridge, United Kingdom, British Antarctic Survey, manuscript map, BAS Archives no. ES4/4/1.

Nelson, P.H.H., 1964, Sheet 64.58NE with manuscript additions: Cambridge, United Kingdom, British Antarctic Survey, manuscript map, BAS Archives no. ES2/EW1000A/Sheet 64.58NE(A).

Taylor, A., 1945, First sledge journey: Cambridge, United Kingdom, British Antarctic Survey, unpublished manuscript, BAS Archives no. AD6/1D/1945/K1.

Table 4*A*. Inventory of named glaciers and glaciological features on the coastal-change and glaciological map of the Trinity Peninsula area and South Shetland Islands.

[Bold italic type indicates that glacier or glaciological feature has fluctuated an average of more than 75 m a^{-1} during some time period since the 1940s. Names in parentheses are as described in the Excel table on the SCAR ADD Web site (http://www.add.scar.org)]

Location and geographic place-name[1]	Glaciological term[2]
SOUTH SHETLAND ISLANDS	
King George Island	
Ajax Icefall	outlet glacier
Anna Glacier	outlet glacier
Arctowski Dome	icecap
Baranowski Glacier	outlet glacier
Dobrowolski Glacier (S. Precious Peaks)	outlet glacier
Doctors Icefall (Goulden Cove)	outlet glacier
Domeyko Glacier (west part, Mackellar glacier; east part, W. Keller Peninsula)	outlet glacier
Dragon Glacier	outlet glacier
Ecology Glacier	outlet glacier
Eldred Glacier	outlet glacier
Emerald Icefalls	icefall
Flagstaff Glacier	mountain glacier
Fourcade Glacier (Potter Cove)	outlet glacier
Goetel Glacier (E. Ullmann Spur)	outlet glacier
Hektor Icefall	outlet glacier
Krak Glacier (Lussich Cove)	outlet glacier
Kraków Dome	icefield
Lange Glacier	outlet glacier
Moby Dick Icefall	outlet glacier
Moczyłowski Glacier (Marian Cove)	outlet glacier
Noble Glacier	mountain glacier
Poetry Glacier	outlet glacier
SOUTH SHETLAND ISLANDS—Continued	
King George Island—Continued	
Polar Club Glacier (Telefon Point)	outlet glacier
Polonia Piedmont Glacier (King George Bay)	outlet glacier
Stenhouse Glacier	outlet glacier
Stwosz Icefall	outlet glacier
Usher Glacier	outlet glacier
Viéville Glacier	outlet glacier
Warszawa Dome	icefield
Greenwich Island	
Bravo Glacier	outlet glacier
Fuerza Aérea Glacier	outlet glacier
Quito Glacier	outlet glacier
Solis Glacier (Yankee Harbour)	outlet glacier
Traub Glacier	outlet glacier
Livingston Island	
Argentina Glacier	outlet glacier
Balkan Snowfield	outlet glacier
Boyana Glacier	valley glacier
Charity Glacier	valley glacier
Contell Glacier	outlet glacier
Española Glacier	outlet glacier
Huntress Glacier	outlet glacier
Hurd Dome	icecap

Table 4*A*. Inventory of named glaciers and glaciological features on the coastal-change and glaciological map of the Trinity Peninsula area and South Shetland Islands.—Continued

[Bold italic type indicates that glacier or glaciological feature has fluctuated an average of more than 75 m a^{-1} during some time period since the 1940s. Names in parentheses are as described in the Excel table on the SCAR ADD Web site (http://www.add.scar.org)]

Location and geographic place-name[1]	Glaciological term[2]
SOUTH SHETLAND ISLANDS—Continued	
Livingston Island—Continued	
Huron Glacier	outlet glacier
Iskŭr Glacier	valley glacier
Johnsons Glacier	outlet glacier
Kaliakra Glacier	outlet glacier
Las Palmas Glacier	outlet glacier
Macy Glacier	valley glacier
Magura Glacier	valley glacier
Perunika Glacier	outlet glacier
Peshtera Glacier	outlet glacier
Pimpirev Ice Wall	outlet glacier
Prespa Glacier	valley glacier
Ruen Icefall	outlet glacier
Sally Glacier	outlet glacier
Sea Lion Glacier	outlet glacier
Sopot Ice Piedmont	ice piedmont
Srebŭrna Glacier	valley glacier
Tarnovo Ice Piedmont	ice piedmont
Elephant Island	
Endurance Glacier	outlet glacier
Furness Glacier	outlet glacier
Sultan Glacier	outlet glacier
The Stadium	outlet glacier
Clarence Island	
Highton Glacier	outlet glacier
PALMER ARCHIPELAGO	
Anvers Island	
Hooper Glacier	outlet glacier
Iliad Glacier	valley glacier
Marr Ice Piedmont	ice piedmont
William Glacier	valley glacier
Wiencke Island	
Channel Glacier	mountain glacier
Harbour Glacier	mountain glacier
Thunder Glacier	mountain glacier
Brabant Island	
Hippocrates Glacier	outlet glacier
Jenner Glacier	outlet glacier
Koch Glacier	outlet glacier
Laënnec Glacier	outlet glacier
Lister Glacier	outlet glacier
Mackenzie Glacier	outlet glacier

Location and geographic place-name[1]	Glaciological term[2]
PALMER ARCHIPELAGO—Continued	
Brabant Island—Continued	
Malpighi Glacier	outlet glacier
Paré Glacier	outlet glacier
Rush Glacier	outlet glacier
JAMES ROSS ISLAND	
Ball Glacier	outlet glacier
Coley Glacier	outlet glacier
Gourdon Glacier	outlet glacier
Hobbs Glacier	outlet glacier
Howarth Glacier	outlet glacier
Ineson Glacier	outlet glacier
Swift Glacier	outlet glacier
Tait Glacier	outlet glacier
ANTARCTIC PENINSULA	
Danco Coast	
Almirante Ice Fringe	outlet glacier
Arago Glacier	valley glacier
Astudillo Glacier	outlet glacier
Avalanche Glacier	outlet glacier
Bagshawe Glacier	outlet glacier
Bayly Glacier	outlet glacier
Blanchard Glacier	outlet glacier
Blériot Glacier	outlet glacier
Blue Icefalls	outlet glacier
Bruguet Glacier	outlet glacier
Cayley Glacier	outlet glacier
Deville Glacier	mountain glacier
Gregory Glacier	valley glacier
Grubb Glacier	outlet glacier
Henryk Glacier	valley glacier
Ice Gate Glacier	outlet glacier
Krebs Glacier	outlet glacier
Leonardo Glacier	outlet glacier
Lilienthal Glacier	outlet glacier
Miethe Glacier	outlet glacier
Montgolfier Glacier	outlet glacier
Moser Glacier	outlet glacier
Mouillard Glacier	outlet glacier
Nobile Glacier	outlet glacier
Orel Ice Fringe	mountain glacier
Renard Glacier	outlet glacier
Rozier Glacier	outlet glacier

Table 4*A*. Inventory of named glaciers and glaciological features on the coastal-change and glaciological map of the Trinity Peninsula area and South Shetland Islands.—Continued

[Bold italic type indicates that glacier or glaciological feature has fluctuated an average of more than 75 $m\ a^{-1}$ during some time period since the 1940s. Names in parentheses are as described in the Excel table on the SCAR ADD Web site (http://www.add.scar.org)]

Location and geographic place-name[1]	Glaciological term[2]
ANTARCTIC PENINSULA—Continued	
Danco Coast—Continued	
Rudolph Glacier	outlet glacier
Sikorsky Glacier	outlet glacier
Suarez Glacier	outlet glacier
Vidaurrazaga Glacier	outlet glacier
Vivallos Glacier	outlet glacier
Vogel Glacier	outlet glacier
Wellman Glacier	outlet glacier
Wheatstone Glacier	mountain glacier
Woodbury Glacier	outlet glacier
Davis Coast	
Andrew Glacier	outlet glacier
Henson Glacier	outlet glacier
McNeile Glacier	outlet glacier
Sabine Glacier	outlet glacier
Stringfellow Glacier	outlet glacier
Temple Glacier	outlet glacier
Whitecloud Glacier	outlet glacier
Wright Ice Piedmont	ice piedmont
Nordenskjöld and Oscar II Coasts[3]	
Albone Glacier	outlet glacier
Arrol Icefall	outlet glacier
Bombardier Glacier	outlet glacier
Dinsmoor Glacier	outlet glacier
Drygalski Glacier	outlet glacier
Edgeworth Glacier	outlet glacier
Eliason Glacier	outlet glacier

Location and geographic place-name[1]	Glaciological term[2]
ANTARCTIC PENINSULA—Continued	
Nordenskjöld and Oscar II Coasts[3]—Continued	
Green Glacier	outlet glacier
Hektoria Glacier	outlet glacier
Larsen Ice Shelf (northern ice front [Larsen Inlet]; southern ice front [Larsen A])	ice shelf
Polaris Glacier	outlet glacier
Pyke Glacier	outlet glacier
Wallend Glacier	outlet glacier
Trinity Peninsula	
Aitkenhead Glacier	outlet glacier
Arena Glacier	outlet glacier
Boydell Glacier	outlet glacier
Cugnot Ice Piedmont	ice piedmont
Depot Glacier	outlet glacier
Diplock Glacier	outlet glacier
Gavin Ice Piedmont	ice piedmont
Kenney Glacier	outlet glacier
Mondor Glacier	outlet glacier
Mott Snowfield	icefield
Pettus Glacier	outlet glacier
Prince Gustav Ice Shelf (northern, southern, and eastern ice fronts)	ice shelf
Russell East Glacier	outlet glacier
Russell West Glacier	outlet glacier
Sjögren Glacier	outlet glacier
Victory Glacier	outlet glacier

[1]The comprehensive listing of 161 named glaciers and other named glaciological features was derived from published maps and gazetteers of the area encompassed by the Trinity Peninsula area and South Shetland Islands map. The geographic place-names are included in Alberts (1981, 1985), in National Science Foundation (1989), and on the USGS Geographic Names Information System (GNIS) Web site.

[2]The descriptive terms used to characterize the glaciological or geographic features were derived from analysis of Landsat images. For definition of glaciological terms, see Armstrong and others (1973, 1977) [primary references] and Jackson (1997) [secondary reference].

[3]The part of the Oscar II Coast on the map is too small to be identified; however, Green and Hektoria Glaciers flow southeastward into the Weddell Sea and are part of the Oscar II Coast.

Table 4*B*. Inventory of unnamed glaciers and ice fronts for which measurements of advance and retreat were made on the coastal-change and glaciological map of the Trinity Peninsula area and South Shetland Islands.

[Bold italic type indicates that glacier or ice front has fluctuated an average of more than 75 m a^{-1} during some time period since the 1940s. Geographic descriptions are as given in the Excel table on the SCAR ADD Web site (http://www.add.scar.org)]

Location and geographic location code[1]	Geographic description[2]
SOUTH SHETLAND ISLANDS	
King George Island	
1. AN76210S5849W	Collins Harbour
2. AN76210S5836W	Cardozo Cove ice front
Nelson Island	
1. AN76216S5858W	Edgell Bay ice front
Livingston Island	
1. AN76238S6041W	***Walker Bay ice front***
2. AN76232S6019W	E. Gleaner Heights ice front
Deception Island	
1. AN76256S6036W	Pendulum Cove rock coast
2. AN76255S6040W	Telefon Bay rock coast
Smith Island	
1. AN76255S6221W	Smith Island ice front a.
2. AN76256S6222W	Smith Island ice front b.
3. AN76257S6223W	Smith Island ice front c.
4. AN76258S6225W	Smith Island ice front d.
5. AN76259S6227W	Smith Island ice front e.
6. AN76300S6229W	Smith Island ice front f.
7. AN76301S6230W	***Smith Island ice front g.***
8. AN76302S6231W	Smith Island ice front h.
9. AN76302S6232W	Smith Island ice front i.
10. AN76302S6233W	Smith Island ice front j.
11. AN76303S6235W	Smith Island ice front k.
Low Island	
1. AN76317S6214W	***Jameson Point ice front***
PALMER ARCHIPELAGO	
Trinity Island	
1. AN76343S6036W	Trinity Island ice front a.
2. AN76344S6037W	Trinity Island ice front b.
3. AN76345S6040W	Trinity Island ice front c.
4. AN76347S6040W	Trinity Island ice front d.
5. AN76350S6041W	Trinity Island ice front e.
Liège Island	
1. AN76403S6156W	Liège Island ice front a.
2. AN76404S6157W	Liège Island ice front b.
3. AN76405S6200W	***Liège Island ice front c.***
4. AN76403S6202W	Liège Island ice front d.
5. AN76401S6158W	Liège Island ice front e.
PALMER ARCHIPELAGO—Continued	
Brabant Island	
1. AN76406S6214W	Virchow Hill ice front
2. AN76416S6208W	S. Einthoven Hill glacier
3. AN76420S6212W	N. Pinel Point ice front
4. AN76416S6232W	Minot Point glacier
5. AN76413S6230W	Lanusse Bay glacier a.
6. AN76413S6228W	Lanusse Bay glacier b.
7. AN76406S6232W	Guyou Bay ice front
Anvers Island	
1. AN76417S6316W	W. Cape Bayle ice front
2. AN76419S6311W	***S. Cape Bayle ice front***
3. AN76428S6314W	***Patagonia Bay glacier***
4. AN76431S6312W	Fournier Bay ice front a.
5. AN76434S6317W	Fournier Bay ice front b.
6. AN76435S6315W	Fournier Bay ice front c.
7. AN76435S6309W	Fournier Bay ice front d.
8. AN76433S6304W	Fournier Bay ice front e.
9. AN76432S6300W	Parker Peninsula ice front a.
10. AN76432S6252W	Parker Peninsula ice front b.
11. AN76435S6254W	Parker Peninsula ice front c.
12. AN76436S6257W	Parker Peninsula ice front d.
13. AN76438S6304W	Parker Peninsula ice front e.
Wiencke Island	
1. AN76453S6325W	E. Fief Mountains (Sierra Du-Fief) ice front
JAMES ROSS ISLAND	
1. AN76404S5722W	W. Skep Point glacier
2. AN76404S5716W	E. Skep Point glacier
3. AN76405S5709W	W. Ula Point glacier
4. AN76407S5710W	N. Coley Glacier ice front
5. AN76423S5728W	E. Tortoise Hill ice front
6. AN76422S5733W	E. Lomas Ridge ice front
7. AN76423S5737W	***W. Lomas Ridge ice front***
8. AN76425S5751W	Sungold Hill ice front a.
9. AN76426S5754W	***Sungold Hill ice front b.***
10. AN76426S5757W	E. Cape Foster ice front
11. AN76426S5800W	W. Cape Foster ice front
12. AN76423S5810W	***W. [E.] Nygren Point ice front***

Table 4*B*. Inventory of unnamed glaciers and ice fronts for which measurements of advance and retreat were made on the coastal-change and glaciological map of the Trinity Peninsula area and South Shetland Islands.—Continued

[Bold italic type indicates that glacier or ice front has fluctuated an average of more than 75 m a^{-1} during some time period since the 1940s. Geographic descriptions are as given in the Excel table on the SCAR ADD Web site (http://www.add.scar.org)]

	Location and geographic location code[1]	Geographic description[2]
	JAMES ROSS ISLAND—Continued	
13.	***AN76359S5813W***	***Holluschickie glacier***
14.	AN76354S5807W	Whisky Bay glacier
15.	AN76404S5750W	S. Blyth Spur ice front
16.	AN76405S5749W	N. Flett Buttress ice front
17.	AN76404S5744W	S. Stark Point ice front
18.	AN76400S5741W	N. Stark Point ice front
	ANTARCTIC PENINSULA	
	Snow Hill Island	
1.	***AN76425S5717W***	***N. ice shelf***
2.	***AN76429S5728W***	***S. ice shelf***
	Joinville Island	
1.	AN76317S5547W	Haddon Bay glacier
2.	AN76319S5553W	Gibson Bay glacier
3.	AN76320S5601W	E. Nodule Nunatak glacier
4.	AN76325S5616W	d'Urville Monument ice front
5.	***AN76324S5628W***	***E/W Cape Kinnes ice front***
6.	AN76319S5626W	Suspiros Bay (Kinnes Cove) ice front
	Dundee Island	
1.	***AN76333S5604W***	***W. Cape Purvis ice front***
	Vega Island	
1.	AN76349S5707W	NW Cape Gordon ice front
2.	AN76352S5707W	SW Cape Gordon ice front
3.	AN76352S5716W	E. Pastorizo Bay ice front
4.	AN76353S5719W	W. Pastorizo Bay ice front
5.	AN76353S5731W	S. Vega Island ice front a.
6.	AN76353S5727W	S. Vega Island ice front b.
7.	AN76353S5725W	S. Vega Island ice front c.
8.	AN76351S5739W	W. Sandwich Bluff ice front
9.	AN76348S5737W	W. Vertigo Cliffs ice front
10.	AN76349S5720W	S. Cape Well-met ice front
11.	AN76349S5717W	S. Devil Island ice front
	Eagle Island	
1.	AN76340S5732W	Eagle Island ice front
	Trinity Peninsula	
1.	AN76328S5700W	S. Trepassey Bay ice front
2.	AN76333S5708W	S. Buttress Hill ice front
	ANTARCTIC PENINSULA—Continued	
	Trinity Peninsula—Continued	
3.	***AN76331S5722W***	***Duse Bay glacier***
4.	***AN76335S5740W***	***Eyrie Bay glacier***
5.	AN76338S5741W	E. McCalman Peak ice front
6.	AN76339S5747W	W. Crystal Hill ice front a.
7.	AN76339S5749W	W. Crystal Hill ice front b.
8.	AN76340S5751W	N. Camp Hill ice front
9.	AN76341S5759W	W. Chapel Hill ice front
10.	AN76340S5805W	N. Levassor Nunatak glacier
11.	AN76356S5834W	Detroit Plateau glacier a.
12.	AN76358S5839W	Detroit Plateau glacier b.
13.	***AN76422S5849W***	***Longing Gap N. ice front***
14.	***AN76429S5904W***	***Longing Gap S. ice front***
15.	AN76453S6230W	E. Forbes Point glacier
16.	AN76452S6227W	Andvord Bay glacier
17.	AN76438S6231W	Orne Harbour glacier a.
18.	AN76438S6229W	Orne Harbour glacier b.
19.	AN76443S6223W	Beaupré Cove glacier
20.	AN76424S6122W	Salvesen Cove glacier a.
21.	AN76426S6120W	Salvesen Cove glacier b.
22.	AN76425S6118W	Salvesen Cove glacier c.
23.	AN76410S6052W	Cierva Cove glacier/Breguet Glacier
24.	AN76357S6027W	Wright Ice Piedmont glacier
25.	AN76356S5957W	S. Chanute Peak glacier
26.	AN76353S5924W	Lindblad Cove glacier a.
27.	AN76353S5925W	Lindblad Cove glacier b.
28.	AN76349S5922W	N. Auster Point ice front a.
29.	AN76349S5925W	N. Auster Point ice front b.
30.	AN76343S5906W	S. Bone Bay glacier
31.	AN76331S5847W	N. Bone Bay glacier
32.	AN76328S5825W	N. Marescot Ridge glacier
33.	AN76328S5809W	Lafond Bay glacier
34.	AN76325S5802W	Misty Pass glacier
35.	AN76322S5756W	Unwin Cove glacier
36.	AN76316S5732W	N. Coupvent Point ice front
37.	***AN76432S5857W***	***W. Cape Longing ice front***

Table 4*B*. Inventory of unnamed glaciers and ice fronts for which measurements of advance and retreat were made on the coastal-change and glaciological map of the Trinity Peninsula area and South Shetland Islands.—Continued

[Bold italic type indicates that glacier or ice front has fluctuated an average of more than 75 m a^{-1} during some time period since the 1940s. Geographic descriptions are as given in the Excel table on the SCAR ADD Web site (http://www.add.scar.org)]

[1]The 126 unnamed glaciers and ice fronts that have been identified on Landsat images were each given a geographic location code. For example, the code AN77427S11344W represents Antarctica (AN7), location at lat 74° 27' S. (7427S), long 113° 44' W. (11344W). AN7 is the continent code assigned by the World Glacier Monitoring Service for Antarctica. A latitude and longitude designator (degrees and minutes) is used in place of a drainage basin/glacier number code because the latter has not been defined for Antarctica.

[2]The descriptive terms used to characterize the glaciological or geographic features were derived from analysis of Landsat images. For definitions of glaciological terms, see Armstrong and others (1973, 1977) [primary references] and Jackson (1997) [secondary reference].

Table 9. Coastal-change and glaciological maps of Antarctica at 1:1,000,000 scale, published to date.

[Information on ordering published maps can be obtained by calling the U.S. Geological Survey at 1–888–ASK–USGS or by visiting the USGS online at http://www.usgs.gov/pubprod]

As shown on index map	Map number	Map name	Reference (see References Cited)
A	I–2600–A	Trinity Peninsula and So. Shetland Islands	This report
D	I–2600–D	Ronne Ice Shelf	Ferrigno and others (2005)
E	I–2600–E	Eights Coast	Swithinbank and others (2004)
F	I–2600–F (2d ed.)	Bakutis Coast	Swithinbank and others (2003b)
G	I–2600–G	Saunders Coast	Swithinbank and others (2003a)